Radiological Analysis of Cassava Samples From a Coal Mining Area in Enugu State Nigeria

Authors: Amakom, Chijioke M, Orji, Chikwendu E, Okeoma, Kelechukwu B, and Echendu, Obi K

Source: Environmental Health Insights, 17(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/11786302231199836

Radiological Analysis of Cassava Samples From a Coal Mining Area in Enugu State Nigeria

Chijioke M Amakom, Chikwendu E Orji, Kelechukwu B Okeoma and Obi K Echendu

Department of Physics, Federal University of Technology, Owerri, Imo, Nigeria.

Environmental Health Insights
Volume 17: 1–8
© The Author(s) 2023
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/11786302231199836
Sage

ABSTRACT: Cassava holds a vital position as a staple food in Nigeria, forming a significant portion of the daily diet for the population. Unfortunately, food intake can serve as a pathway for radiological contamination in humans and animals. In this study conducted in an old coal mining area in Enugu State, Nigeria, cassava samples from the area were analyzed using gamma ray spectroscopy. The results revealed significant mean activity concentrations of the radionuclides 40K, ^{226}Ra, and ^{232}Th in camp 1, camp 2, and Pottery areas. The activity concentration ranged from 193.68 to 300.92 Bq/kg for 40 K, 23.03 to 37.24 Bq/kg for ^{226}Ra, and 135.33 to 158.43 Bq/kg for ^{232}Th, respectively. Of concern is the total mean annual effective dose resulting from exposure to these 3 observed radionuclides that was calculated to be 2.03 mSv/yr. This value exceeds the recommended limit of 1 mSv/yr, indicating potential health risks associated with the radiological contamination from cassava consumption in this region. In summary, the study shows that cassava samples from the investigated area exhibited elevated levels of radiotoxicity, raising concerns about the safety of consuming cassava from this region as a food source.

KEYWORDS: Activity concentration, annual effective dose, cassava, coal mining area, Enugu, radionuclides

RECEIVED: July 23, 2023. **ACCEPTED:** August 22, 2023.

TYPE: Original Research

FUNDING: The author(s) received no financial support for the research, authorship, and/or publication of this article.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Chijioke M Amakom, Department of Physics, Federal University of Technology, Ihiagwa, P. M. B. 1526, Owerri, Imo 460114, Nigeria. Email: camakom@gmail.com

Introduction

Human activities associated with mineral exploitation, such as coal mining and petroleum drilling, can introduce natural radionuclides into the environment.[1] While these activities may contribute to employment and economic benefits for communities and operators, they also pose significant risks to natural reserves through landscape alterations and pollution. The consequences often include the destruction of the ecosystems, environmental contamination, changes in landscape, and reduced agricultural crop yields due to the introduction of novel substances. In particular, the seepage waters from tailings, along with the deposition of re-suspended radioactive materials from tailing piles, can result in elevated levels of radionuclides in nearby soils. These radionuclides have the potential to be absorbed, retained, and taken up by plants.[2] This ability of plants to uptake various cations in their root zone has been observed regardless of their biological necessity.[3]

The behavior of radioactive elements in soils is intricate, involving a dual process: some of these elements are transported into the soil solution, while others become tightly bound to soil particles.[4] Consequently, the root system of plants serves as a significant conduit for the migration of natural radionuclides from soil to humans through the food chain.[5] In certain instances, natural radionuclides like ^{238}U, ^{232}Th, and 40K exploit their chemical similarity with other elements essential for the plant's growth.[6] As a result, when these plants are consumed, they directly contribute to internal radiation doses for both humans and non-human biota.[7] This highlights the significance of contaminated food ingestion as a crucial exposure pathway for radionuclides in dose assessment models.

In the context of the radioactive decay chain, certain radionuclides such as $^{226}Ra(^{238}U)$ and $^{228}Ra(^{232}Th)$ exhibit particularly high radiotoxicity, with radium itself being identified as a carcinogen.[8] Research has indicated that the gradual accumulation of small amounts of environmental radium in bone tissues can lead to damage in the bone marrow and subsequent carcinogenesis in bone cells.[9] When considering radiation exposure, it has been found that a significant portion of the average radiation doses present in various organs in the body comes from radionuclides ingested through food intake. Notably, approximately one-eighth of the mean annual effective dose attributed to natural radionuclides can be traced back to food consumption.[10] Consequently, radiation doses from ingested food represent a pathway that necessitates long-term health considerations.[11] According to reports by Priharti and Samat[12], the general public receives approximately 3.01 mSv of radiation dose per year, of which 79.73% (2.4 $mSv.y^{-1}$) arises from natural radiation sources, with the remainder originating from anthropogenic sources. This clearly illustrates the significant contribution of natural radiation sources to the total annual dose received by members of the public.

Cassava (*Manihot esculenta*) is a root crop extensively consumed on a daily basis in Nigeria, serving as a major source of carbohydrates.[13] It plays a crucial role in the preparation of popular foods like Gari, fufu and tapioca. The significance of cassava cannot be overstated, as it contributes approximately 50% of all calories consumed in sub-Saharan Africa and stands as the third most important calorie source in tropical regions.[14] Furthermore, cassava holds great importance in the production of industrial starch, ethanol, and animal feed.[15]

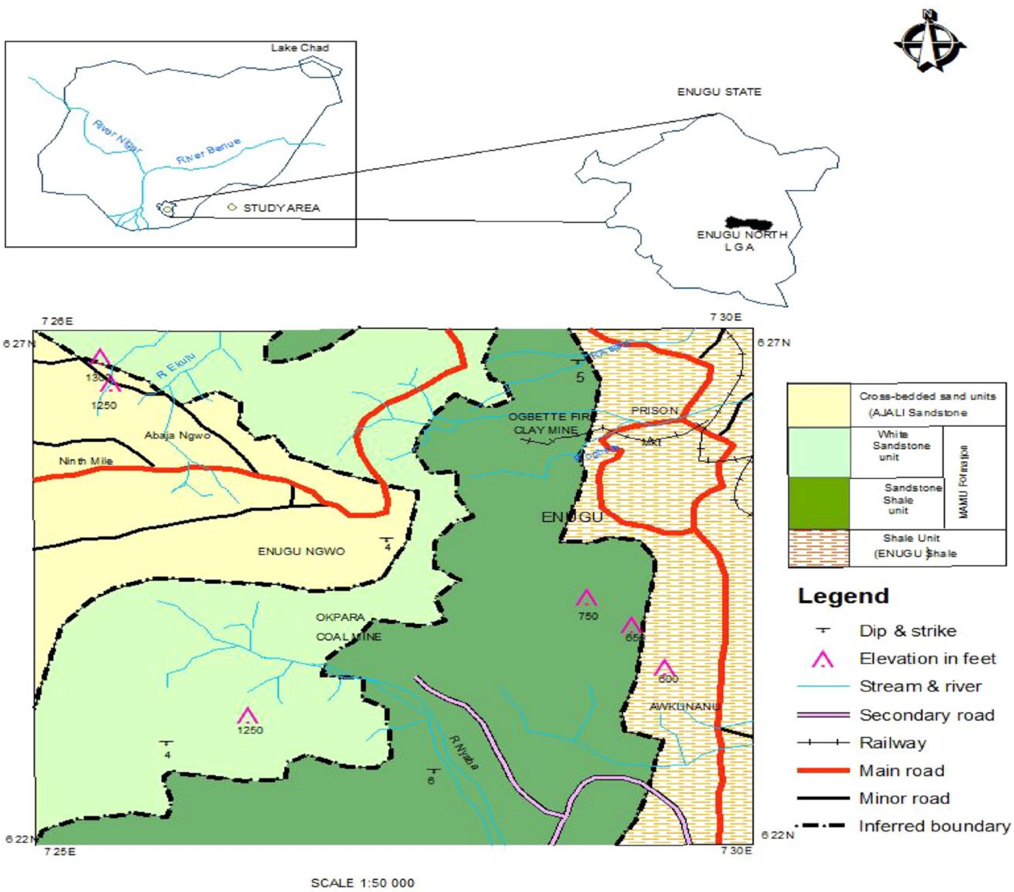

Figure 1. Physiographic and geologic map of the study area (After Ezeigbo and Ezeanyim, 1993).

Studies have shown that cassava exhibits a higher tendency to absorb radionuclides through its roots rather than trapping them on its external surfaces.[16] Given the widespread use and consumption of cassava products in the study area, combined with the occurrence of coal mining activities in that region, the primary objective of this study is to assess the radiotoxicity associated with cassava products cultivated in the study area

Materials and Methods

Study area

Iva Valley, situated in Enugu state, Nigeria, is home to the Okpara Coal Mine (See Figure 1), one of the 5 distinct and now defunct mines in the Enugu area. This mine, opened in 1952 by the Nigerian Coal Corporation (NCC), was part of the group that included Onyeama, Obwetti, Okpara, and Ribadu.[17,18] Over the years, production in the Okpara Coal Mine experienced a decline, going from a peak of 3040 tons in 1984 to 1016 tons in 1990,[19] eventually leading to its closure. Thereafter, the mine was briefly reopened in 1999 but was abandoned again during 2004/2005 due to economic considerations.[20] The coal mine spoils left untreated and scattered throughout the area, consist of a mixture of diverse fragments, including carbonaceous shale, sandstones, clay, and coal.[21] Additionally, the presence of pyrite and marcasite has been identified in association with these minerals.

The study area is situated within specific geographical coordinates, namely between latitudes 06° 22′N and 06° 27′N and longitudes 007° 25′E and 007° 30′E. It is approximately 5 km to the west of Enugu town and about 15 km from the AkanuIbiam International Airport in Enugu North Local Government Area, southeastern Nigeria.[22] The study area is also in close proximity to the neighboring town of Enugu Ngwo, at a distance of around 4.7 km. In addition, it is located near the Iva Valley, on the periphery of the city and adjacent to the Hill tops of Enugu in the Ogbete and Enugu Coal Camp layouts. Moreover, the study area shares borders with certain sections of the Obwetti fire clay mine and coal processing plant.

Sample collection and preparation

In the Iva Valley area, a total of 32 cassava samples were gathered using a hand trowel and black polyethylene bags. The area was divided into 3 sections, namely pottery, camp 1, and camp 2. Each sample, weighing approximately 0.5 kg, was collected for gamma spectroscopy. To ensure cleanliness, the cassava samples were washed with fresh water to remove dust and mud. Subsequently, all the samples underwent a 5-day drying process under direct sunlight and humid conditions. They were then individually dried in an electric oven set at 110°C to achieve a constant dry weight. The samples were then crushed

Table 1. Spectral Energy Windows used in the analysis (CERT Manual, 1999).

RADIONUCLIDE	GAMMA ENERGY (KEV)	ENERGY WINDOW
^{226}Ra	1764.0	1620-1820
^{232}Th	2614.5	2480-2820
40K	1460.0	1380-1550

to fine powder and sieved to a grain size of less than 0.63 mm by using a mesh sieve and then sealed in plastic containers.

To ensure accurate measurements, the samples were stored for a minimum of 30 days before conducting the analysis. This period allowed for the establishment of secular equilibrium between thorium and radium, as well as their decay products.

Gamma ray spectroscopy

The gamma-ray spectrometry setup consists of a NaI (Tl) detector with dimensions of 7.62 cm by 7.62 cm. The detector is housed in a 6 cm thick lead shield, which effectively reduces background radiation and is lined with cadmium and copper sheets.[23] During the analysis, the samples were placed on the surface of the detector and counted for approximately 29 000 seconds, ensuring consistent and reproducible sample detector geometry. The configuration and geometry were maintained based on well-established laboratory protocols at the Centre for Energy Research and Training (CERT) in Zaria Nigeria.

For data acquisition and gamma spectra analysis, a computer-based Multichannel Analyzer (MCA) program called MAESTRO from ORTEC was utilized. In assessing the activity concentration of radionuclides in the samples, specific gamma lines were employed. The 1764 keV gamma line of 214Bi was used for ^{238}U, while the 2614.5 keV gamma line of ^{208}Tl was used for ^{232}Th. The 1460 keV gamma line of 40 K was utilized to evaluate its content in the samples in line with the work by Rilwan et al[24]. The Spectral Energy Windows used in the sample analysis are provided in Table 1.[25]

After correcting for decay, the activity concentration (C) of radionuclides in the samples was calculated using equation (1)[26]:

$$C_s(Bq/kg) = \frac{C_a}{\varepsilon_\gamma \times M_s \times t_c \times P_\gamma} \tag{1}$$

Where C_s = Sample concentration in Bq/kg, C_a = net peak area of a peak at energy of interest, ε_γ = Efficiency of the detector for a γ-energy of interest, M_s = Sample mass, t_c = total counting time, and P_γ = the abundance of the γ-line in a radionuclide.

Detection limit. The limit of detection (LOD) for a measurement system characterizes its performance in the absence of sample effects. The LOD, expressed in units of Bq/kg, is utilized to calculate the smallest detectable activity within a sample. This value was determined following the methodology outlined by Jibiri and Emelue[27].

$$DL\left(Bqkg^{-1}\right) = 4.65\frac{(C_b)^{1/2}}{t_b}k \tag{2}$$

Where C_b is the net background count in the corresponding peak, t_b is the background counting time in second, $k = \dfrac{1}{\varepsilon P_\gamma M_s}$, ε is the detector efficiency at the specific gamma-ray energy, P_γ is the absolute transition probability of the specific gamma ray and M_s is the mass of the sample (kg). With the measurement system used in this study, the detection limits obtained for the samples were 16.96, 3.65 and 4.43 Bqkg^{-1} for 40 K, ^{226}Ra and ^{232}Th, respectively. Any activity concentration values below these numbers was taken as below detection limit (BDL) of the detector.

Daily intake of radionuclides

The daily intake of radionuclides is influenced by the radionuclide content present in the cassava samples and how they accumulate in the human body through consumption by an average adult. This estimation is based on equation (3).[28] Cassava products such as fufu, cassava flour, and garri are commonly consumed, and the mean annual cassava consumption of (116.6 kg/y) was obtained from the study conducted by Jibiri and Abiodun[29] in Abeokuta region of Nigeria.

The daily intake of radionuclides by adult individuals is given by

$$D_{int} = \frac{A_C \times A_{ig}}{Y_d} \tag{3}$$

Where, D_{int} represents the daily intake of radionuclides (in Bq) by adult individuals, A_c denotes the activity concentration of radionuclides (in Bq kg^{-1}), A_{ig} stands for the per capita per year consumption of cassava (in kg/y) and Y_d is the number of days in a year.

Annual effective dose

To assess the radiological risk associated with consuming cassava products, the annual effective dose resulting from the intake of radionuclides was calculated. The purpose of determining the effective dose is to provide information regarding the annual effective dose for the population in the specific area due to their consumption of cassava products. Equation (4) was utilized to calculate the annual effective dose arising from the ingestion of ^{226}Ra, ^{232}Th, and 40K radionuclides. This calculation takes into account the consumption rates of cassava products, the concentrations of the radionuclides, and the relevant dose conversion factor.[8]

Table 2. Activity concentration of radionuclides in cassava samples of camp 1 (Bq/kg).

SAMPLE CODE	40K	^{226}RA	^{232}TH
A1	109.64 ± 9.33	39.39 ± 3.82	118.47 ± 4.10
A2	185.56 ± 6.75	42.70 ± 3.56	114.45 ± 3.80
A3	39.34 ± 5.59	89.22 ± 5.09	70.46 ± 1.59
A4	179.47 ± 2.02	18.42 ± 5.44	169.89 ± 2.50
A5	193.07 ± 3.20	34.12 ± 5.87	119.10 ± 2.46
A6	262.02 ± 4.20	57.91 ± 6.03	182.23 ± 3.82
A7	442.45 ± 6.99	20.97 ± 1.85	118.92 ± 6.84
A8	319.87 ± 5.98	36.62 ± 8.27	140.29 ± 3.10
A9	234.28 ± 5.32	24.28 ± 5.73	116.38 ± 5.38
A10	162.83 ± 1.86	49.13 ± 2.54	173.77 ± 2.50
A11	186.38 ± 4.29	22.43 ± 3.29	131.48 ± 3.43
A12	274.65 ± 9.02	11.70 ± 1.50	168.52 ± 1.40
Mean	215.79 ± 5.37	37.24 ± 4.41	135.33 ± 3.41

The formula for computing the annual effective dose (E_{eff}) is as follows:

$$E_{eff} = A_c \times A_{ig} \times D_{cf} \qquad (4)$$

Where E_{eff} represents the annual effective dose (measured in Sievert per year), A_c denotes the average activity concentration of radionuclides (in Bq kg^{-1}), A_{ig} stands for the annual intake of cassava (measured in kg per year), and D_{cf} represents the ingestion dose conversion factor for the specific radionuclides (2.8×10^{-7} SvBq^{-1} for ^{226}Ra, 7.2×10^{-8} SvBq^{-1} for ^{232}Th and 6.2×10^{-9} SvBq^{-1} for 40 K).

Results and discussions

The cassava samples collected from the Enugu old coal mining area, also known as Iva valley, underwent gamma spectroscopic analysis. The results obtained from the 3 designated areas, namely Camp 1, Camp 2, and Pottery, are detailed below.

Activity concentrations in camp 1

Table 2 provides the results for the activity concentrations of radionuclides in the cassava samples collected from the Iva-valley area, specifically classified as camp 1. The activity concentrations vary across the samples, with values ranging from 39.34 Bq/kg to 442.45 Bq/kg for 40 K, 11.7 Bq/kg to 89.22 Bq/kg for ^{226}Ra, and 70.46 Bq/kg to 182.23 Bq/kg for ^{232}Th.

The cassava samples exhibited varying levels of radionuclide activity concentrations, spanning a considerable range for 40 K, ^{226}Ra, and ^{232}Th. These results underscore the importance of assessing the potential radiological impact of consuming cassava products from this region.

Table 3. Activity concentration of radionuclides in cassava samples of camp 2 (Bq/kg).

SAMPLE CODE	40K	^{226}RA	^{232}TH
A13	246.03 ± 5.13	19.11 ± 7.18	173.77 ± 2.39
A14	242.44 ± 7.34	31.28 ± 7.23	187.28 ± 4.23
A15	253.96 ± 1.39	38.81 ± 3.70	164.08 ± 1.36
A16	184.99 ± 6.12	43.83 ± 5.21	212.77 ± 3.29
A17	178.32 ± 3.94	25.32 ± 4.39	132.47 ± 2.39
A18	113.99 ± 7.30	16.10 ± 1.15	157.58 ± 3.19
A19	137.23 ± 4.30	54.32 ± 3.23	85.29 ± 1.20
A20	192.53 ± 5.92	46.29 ± 7.32	154.23 ± 2.43
Mean	193.68 ± 5.18	34.38 ± 4.92	158.43 ± 2.56

Activity concentrations in camp 2

Table 3 presents the activity concentration of radionuclides in the cassava samples gathered from the vicinity of the camp 2 site. The obtained values for 40 K range from 113.99 Bq/kg to 253.96 Bq/kg, while for ^{226}Ra, the concentrations span from 16.10 Bq/kg to 54.32 Bq/kg. Additionally, the samples exhibit activity concentrations of 85.29 Bq/kg to 212.77 Bq/kg for ^{232}Th.

Activity concentration in the pottery

Table 4 displays the outcomes of gamma spectroscopic analysis performed on cassava samples collected from the vicinity of the pottery area. The activity concentrations of radionuclides in these cassava samples exhibit varying values, with ranges of 180.87 Bq/kg to 423.42 Bq/kg for 40 K, 12.38 Bq/kg to 46.92 Bq/kg for ^{226}Ra, and 59.40 Bq/kg to 203.48 Bq/kg for ^{232}Th.

The concentration values of radionuclides observed in the cassava samples from the Iva-valley area were found to be higher than those reported by Jwanbot et al[30] and Jibiri and Abiodun[29], Avwiri et al[31] for cassava and other root tuber crops such as yam and cocoyam at Jos-Plateau, Abeokuta, and Niger Delta region respectively; the Abeokuta region is known for its quarrying activities, the Jos plateau region is predominantly tin ore mining area while the Niger Delta region is known for oil and gas exploration. The observed high radionuclide concentrations in the cassava samples could be attributed to the coal mining operations and local geology of the area. Furthermore, when comparing the results with the findings of Tchokossa et al[32], the activity concentrations in the Iva-valley area were also higher. In contrast, a similar study conducted by Addo et al[33] on activity concentration around a cement factory in Ghana revealed lower values compared to those obtained in this current study. In this study, except for Camp1, the mean activity concentration was determined to be lower than the world average of 35.0 Bq/kg for (^{226}Ra) and 400 Bq/kg for (40 K), but higher for ^{232}Th (30.0 Bq/kg), as reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in their comprehensive report from the year 2000.[34]

Table 4. Activity concentration of radionuclides in cassava samples of Pottery (Bq/kg).

SAMPLE CODE	40K	^{226}RA	^{232}TH
PT1	246.03 ± 1.08	19.11 ± 7.18	173.54 ± 3.42
PT2	411.50 ± 4.66	33.25 ± 4.63	59.40 ± 4.90
PT3	327.32 ± 3.29	19.39 ± 3.20	93.20 ± 1.29
PT4	298.09 ± 5.20	16.39 ± 3.20	189.32 ± 0.93
PT5	180.87 ± 1.55	14.02 ± 5.21	144.81 ± 1.48
PT6	221.38 ± 6.26	19.28 ± 5.29	154.38 ± 3.11
PT7	231.10 ± 3.11	46.92 ± 5.79	68.87 ± 2.62
PT8	302.95 ± 8.08	30.47 ± 4.86	154.88 ± 2.16
PT9	423.42 ± 4.29	22.38 ± 4.20	203.48 ± 1.56
PT10	276.83 ± 7.29	24.43 ± 6.29	166.29 ± 1.89
PT11	276.31 ± 5.32	12.38 ± 4.01	154.28 ± 1.39
PT12	415.32 ± 6.20	18.43 ± 5.39	192.42 ± 3.10
Mean	300.92 ± 4.69	23.03 ± 4.93	146.23 ± 2.32

These results demonstrate notable variations in radionuclide activity concentrations within the cassava samples in the area. Such disparities could arise from differences in soil compositions, geological factors, and historical mining activities in the area, this was also observed by Adesiji and Ademola[35], where mine tailings contributed significantly in the increment of radionuclide concentrations in plants.

To gain a comprehensive understanding of the potential radiological impact, it is essential to consider both the concentration levels and the long-term effects of consuming these cassava products. Furthermore, the observed variations in radionuclide activity concentrations highlight the need for continuous monitoring and thorough assessments of radionuclide levels in the environment, particularly in regions associated with past mining activities. Such studies will contribute to a better understanding of radiological risks and aid in formulating appropriate measures to safeguard public health and the environment.

Table 5 provides a comprehensive comparison of the results obtained from this study and other similar pieces of research conducted in different locations. The higher radionuclide activity concentrations observed in the Iva-valley area highlight the significance of understanding and addressing potential radiological risks associated with agricultural produce in regions with historical mining activities. It emphasizes the need for continuous monitoring and assessment of radionuclide levels in food crops to ensure food safety and public health.

Statistical analysis

To address the wide variations in radionuclide concentrations within the study areas, a comprehensive statistical analysis was conducted on the activity concentration values of the cassava samples. The statistical tool utilized to determine if there are significant differences in the activity concentrations obtained from various areas was a single factor "Analysis of Variance"

Table 5. Comparison between radionuclides concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in Cassava.

SAMPLE CATEGORY	40K (BQ/KG)	226RA (BQ/KG)	232TH (BQ/KG)	SOURCE	LOCATION
Cassava tuber	223.79 ± 33.85	13.07 ± 2.88	19.11 ± 2.09	Rilwan[36]	Jos, Nigeria
Cassava tuber	479.87 ± 42.42	2.97 ± 1.02	0.67 ± 0.08	Jibiri and Abiodun[29]	Ogun State, Nigeria
Cassava tuber	17.97 ± 1.24	2.25 ± 0.40	2.62 ± 0.16	Jwanbot et al[30]	Jos, Nigeria
Cassava tuber	67.27 ± 4.55	77.51 ± 4.99	28.86 ± 5.79	Avwiri et al[31]	Niger-Delta, Nigeria
Cassava tuber	746.08 ± 0.48	24.83 ± 10.87	859.41 ± 2.47	Ononugbo et al[16]	Delta state, Nigeria
Cassava tuber	27.2 ± 3.61	0.64 ± 0.21	0.57 ± 0.18	Doyi et al[37]	Ghana
cassava flour	91.78 ± 5.02		1.09 ± 0.17	Lopes et al[38]	Brazil
Cassava tuber	242.19 ± 5.07	31.20 ± 4.73	145.19 ± 2.78	This study	Enugu, Nigeria

Table 6. ANOVA Results for the area under study.

GROUPS	F-VALUE	F-CRITICAL	DECISION
40K	4.81	3.32	REJECT H_0
^{226}Ra	2.61	3.32	ACCEPT H_0
^{232}Th	0.79	3.32	ACCEPT H_0

(ANOVA). In employing ANOVA, 2 hypotheses were formulated: the null hypothesis (H_0) and the alternative hypothesis (H_1).

(i) The null hypothesis (H_0) suggests that there is no significant difference in the mean values of the activity concentrations within the area. (ii) The alternative hypothesis (H_1) posits that there is a significant difference in the mean values of the activity concentrations within the area.

The statistical analysis was conducted using the Microsoft EXCEL statistical package at a 95% confidence level.

As shown in Table 6, the ANOVA results for 40 K in the cassava samples indicate that the calculated F-value surpassed the F-critical value for the 3 locations (the F-value and F-critical value are crucial statistics used to determine whether there are statistically significant differences between the means of 2 or more groups), leading to the rejection of H_0 and acceptance of H_1. This implies that there is a statistically significant difference in the mean activity concentrations of 40 K in the cassava samples within the 3 investigated areas. On the other hand, for ^{226}Ra and ^{232}Th, no significant difference in activity concentrations was observed, leading to the acceptance of H_0. The lack of significant differences in the mean activity concentrations of ^{226}Ra and ^{232}Th may indicate a relatively consistent distribution of these radionuclides across the study areas.

One possible reason for the variation in the mean activity concentration of 40 K could be the diverse application of fertilizers by different farmers. This was also observed by Avwiri et al[31] Fertilizer usage can introduce varying amounts of potassium, which is the source of 40 K, into the soil, consequently impacting the uptake of 40 K by the cassava crops.[39] The ANOVA results highlight the importance of considering agricultural practices and environmental factors when interpreting variations in radionuclide concentrations in food crops.

Daily intake of radionuclide

Table 7 presents the estimated daily intake of radionuclides resulting from the consumption of the investigated cassava samples. The mean daily intake of the radionuclides 40 K, ^{226}Ra, and ^{232}Th in the 3 study areas displayed variations, ranging from 61.87 Bq to 96.12 Bq for 40 K, 7.35 Bq to 11.89 Bq for ^{226}Ra, and 43.23 Bq to 50.61 Bq for ^{232}Th.

Table 7. Daily intake of radionuclides and Annual effective Dose (AED) from the three areas under study.

SAMPLE CODE	D_{INT}40K (BQ)	$D_{INT}{}^{226}$RA (BQ)	$D_{INT}{}^{232}$TH (BQ)	TOTAL AED (MSV/YR)
CAMP1				
A1	35.02	12.58	37.85	0.92
A2	59.28	13.64	36.56	1.56
A3	12.57	28.50	22.51	0.33
A4	57.33	5.88	54.27	1.51
A5	61.68	10.90	38.05	1.62
A6	83.70	18.50	58.21	2.20
A7	141.34	6.70	37.99	3.72
A8	102.18	11.70	44.82	2.69
A9	74.84	7.76	37.18	1.97
A10	52.02	15.69	55.51	1.37
A11	59.54	7.17	42.00	1.57
A12	87.74	3.74	53.83	2.31
CAMP 2				
A13	78.59	6.10	55.51	2.07
A14	77.45	9.99	59.83	2.04
A15	81.13	12.40	52.42	2.13
A16	59.10	14.00	67.97	1.55
A17	56.96	8.09	42.32	1.50
A18	36.41	5.14	50.34	0.96
A19	43.84	17.35	27.25	1.15
A20	61.50	14.79	49.27	1.62
POTTERY				
PT1	78.59	6.10	55.44	2.07
PT2	131.45	10.62	18.98	3.46
PT3	104.56	6.19	29.77	2.75
PT4	95.23	5.24	60.48	2.50
PT5	57.78	4.48	46.26	1.52
PT6	70.72	6.16	49.32	1.86
PT7	73.83	14.99	22.00	1.94
PT8	96.78	9.73	49.48	2.54
PT9	135.26	7.15	65.00	3.56
PT10	88.43	7.80	53.12	2.33
PT11	88.27	3.95	49.29	2.32
PT12	132.67	5.89	61.47	3.49
Mean	77.37	9.97	46.38	2.03

Among the natural radionuclides, 40 K accounted for the highest daily intake, followed by ^{232}Th. Potassium-40 is typically of limited concern since, being an isotope of an essential element, it is homeostatically regulated in human cells.[29] Therefore, the potential radiological impact of 40 K in the studied cassava samples might not be a major concern due to its physiological regulation.

Conversely, the daily intake of ^{232}Th in the cassava samples was found to be higher than that of ^{226}Ra. However, since ^{232}Th is an alpha emitter, when it is ingested, the alpha particles can cause damage to the cells in the lungs, digestive tract, and other organs, potentially leading to an increased risk of cancer.[40] This finding highlights the importance of evaluating the radiological implications of consuming cassava products, as elevated levels of ^{232}Th in the diet could contribute to internal radiation exposure in individuals.

Understanding the daily intake of radionuclides from food consumption is crucial for assessing potential radiological risks to human health. Monitoring the intake of radionuclides from various food sources, including cassava, can aid in formulating appropriate safety guidelines and ensuring the overall well-being of the population.

Annual effective dose

Table 7 also presents the total annual effective dose resulting from the 3 radionuclides (40 K, ^{226}Ra, and ^{232}Th) in the area under investigation. The values ranged from 0.33 to 3.72 mSv/yr, with a mean value of 2.03 mSv/yr. It is crucial to assess the annual effective dose as it provides essential information regarding the potential radiation exposure for the population consuming cassava from this region.

Comparing the results with previous studies, the annual effective dose in this study was found to be higher than the values reported by Jibiri and Abiodun[29] and Hassan et al[41] in their respective studies. On the other hand, the values were lower than what Jayasinghe et al[42] obtained for food crops from a high background area of Sri Lanka. Such variations in dose levels can be attributed to differences in radionuclide content in the environment, agricultural practices, and geological characteristics of the study areas, and such disparities could arise from differences in soil compositions, geological factors, and historical mining activities which is evident from the mine wastes which were dumped in landfills and surface dumps[43] within the study area. Furthermore, the annual effective dose values obtained in this study were generally higher than the world average values reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2000. UNSCEAR reported world average values of 120 μSv/yr for uranium and thorium series radionuclides and 170 μSv/yr for non-series 40 K. The higher values obtained in the current study indicate a potential higher radiation exposure in the study area compared to the global average.

It is crucial to note that an average radiation dose from cassava samples in the study area exceeds the 1 mSv/yr recommended by United Nations Scientific Committee on the Effects of Atomic Radiation, & Annex, B[44] as the annual dose limit for the general public due to ingestion of radionuclides from food and water. As a result, individuals consuming cassava from this study area face a potential risk of receiving double the recommended value of internal radiation ingestion from their food intake.

These findings underscore the significance of continuous monitoring and regulation of radionuclide levels in food crops, particularly in regions with historical mining activities. Proper risk assessment and awareness programs are essential to protect public health and minimize potential radiological risks associated with food consumption.

Conclusion

In this study, we conducted gamma ray spectroscopy to measure the activity concentrations of naturally occurring ^{226}Ra, ^{232}Th, and 40K radionuclides in cassava samples from the Iva Valley coal mining area. A total of 32 cassava samples were collected from the 3 areas surrounding the coal mine. The results revealed the presence of only the radionuclides ^{226}Ra, ^{232}Th, and 40K, with no trace of artificial radionuclides detected in the cassava samples.

The Pottery area exhibited the highest mean activity concentration for 40 K, while also displaying the lowest mean activity concentration for ^{226}Ra. Notably, the activity concentrations of ^{226}Ra and ^{232}Th observed in this study were found to be higher compared to values reported in other parts of the country. The total annual effective dose resulting from the 3 radionuclides, our study revealed values that exceeded the recommended limit of 1 mSv/yr.[44] These findings indicate potential variations in radionuclide distribution within different regions of the country, possibly influenced by geological and environmental factors. It also raises significant radiological concerns, as it indicates a potential higher radiation risk associated with consuming cassava crops cultivated in the area under study. The study therefore, provides valuable insights into the radionuclide content in cassava samples from the study area and emphasizes the need for ongoing vigilance to ensure the safety of food supplies and the well-being of the population. It therefore underlines the importance of continuous monitoring and assessment of radionuclide levels in food crops, particularly in regions with historical mining activities.

Limitations

This study did not consider the radionuclides ^{210}Pb and ^{210}Po, these radionuclides will be considered in future monitoring and assessment of the health impacts of radionuclides within the study area.

Author's Contribution

Amakom, Chijioke M. designed the research and participated in analysis of the results and writing of manuscript. Orji, Chikwendu E. designed the research methods and participated in results analysis and writing of manuscript. Okeoma, Kelechukwu B. and Echendu, Obi K. participated in results analysis and writing of manuscript.

REFERENCES

1. Chałupnik S. 2010. Radium in discharge waters from coal mines in Poland
2. Galhardi JA, García-Tenorio R, Bonotto DM, Díaz Francés I, Motta JG. Natural radionuclides in plants, soils and sediments affected by U-rich coal mining activities in Brazil. *J Environ Radioact*. 2017;177:37-47.
3. Demidchik V, Maathuis FJM. Physiological roles of nonselective cation channels in plants: from salt stress to signalling and development. *New Phytol*. 2007;175:387-404.
4. Sparks DL, Singh B, Siebecker MG. *Environmental Soil Chemistry*. Elsevier; 2022.
5. Amakom C, Orji C, Eke B, Okoli U, Ndudi C. The influence of selected soil physicochemical properties on radionuclide transfer in cassava crops. *Int J Plant Soil Sci*. 2017;14:1-7.
6. Manigandan PK. 2009. Activity concentration of radionuclides in plants in the environment of Western Ghats.
7. Sabyasachi R, Yadav S, Pulhani V. Transfer of radionuclides from soil to selected tropical plants of Indian Subcontinent: A review. *J Environ Radioact*. 2021;235:106652.
8. Nahar A, Asaduzzaman K, Islam MM, Rahman MM, Begum M. Assessment of natural radioactivity in rice and their associated population dose estimation. *Radiat Eff Defects Solids*. 2018;173:1105-1114.
9. Janković MM, Todorović DJ, Todorović NA, Nikolov J. Natural radionuclides in drinking waters in Serbia. *Appl Radiat Isot*. 2012;70:2703-2710.
10. Salih NF. Measurement the natural radioactivity concentration levels of radionuclides in selected vegetables collected from Kirkuk, Iraq using HPGe detector. *Int J Environ Anal Chem*. 2023;103:1323-1342.
11. Aswood MS, Jaafar MS, Salih N. Estimation of annual effective dose due to natural radioactivity in ingestion of vegetables from Cameron Highlands, Malaysia. *Environ Technol Innov*. 2017;8:96-102.
12. Priharti W, Samat SB. Radiological risk assessment from the intake of vegetables and fruits in Malaysia. *Malays J Anal Sci*. 2016;20:1247-1253.
13. Chijioke MA, Chikwendu EO, Benedict CE, Chinedu I, Bridget AO. Gross alpha and beta activity concentrations in soil and some selected Nigerian food crops. *Int J Phys Sci*. 2018;13:183-186.
14. Agriculture Organization. *The State of Food and Agriculture 2008: Biofuels: Prospects, Risks and Opportunities*. Vol. 38. Food & Agriculture Org; 2008.
15. Adjei-Nsiah S, Sakyi-Dawson O. Promoting cassava as an industrial crop in Ghana: Effects on soil fertility and farming system sustainability. *Appl Environ Soil Sci*. 2012;2012:1-8.
16. Ononugbo CP, Azikiwe O, Avwiri GO. Uptake and distribution of natural radionuclides in cassava crops from Nigerian government farms. *J Sci Res Rep*. 2019;23:1-15.
17. Awoniyi JF. Nigerian mineral industry: its history, trend and prospects. *J Min Geol*. 1977;14:73-78.
18. Akande SO, Hoffknecht A, Erdtmann BD. Rank and petrographic composition of selected Upper Cretaceous and Tertiary coals of southern Nigeria. *Int J Coal Geol*. 1992;20(3-4):209-224.
19. Utom AU, Odoh BI, Egboka BCE. Assessment of hydrogeochemical characteristics of groundwater quality in the vicinity of Okpara coal and Obwetti fireclay mines, near Enugu town, Nigeria. *Appl Water Sci*. 2013;3:271-283.
20. Nganje TN, Adamu CI, Ntekim EE, Ugbaja AN, Neji P, Nfor EN. Influence of mine drainage on water quality along River Nyaba in Enugu South-Eastern Nigeria. *Afr J Environ Sci Technol*. 2010;4(3).
21. Obiadi II, Obiadi CM, Akudinobi BEB, Maduewesi UV, Ezim EO. Effects of coal mining on the water resources in the communities hosting the Iva Valley and Okpara coal Mines in Enugu State, Southeast Nigeria. *Sustain Water Resour Manag*. 2016;2:207-216.
22. Nganje TN, Adamu CI, Ugbaja AN, Ebieme E, Sikakwe GU. Environmental contamination of trace elements in the vicinity of Okpara coal mine, Enugu, Southeastern Nigeria. *Arab J Geosci*. 2011;4:199-205.
23. CERT Manual. *Operation of Sodium Iodide- Thallium Gamma Spectrometry System Manual, Centre for Energy Research and Training*. Ahmadu Bello University; 1999:24-29.
24. Rilwan U, Hudu A, Ubaidullah A, et al. Fertility cancer and hereditary risks in soil sample of Nasarawa, Nasarawa State, Nigeria. *World J Oncol Res*. 2021;3:22-27.
25. Manual CE. 1999 Operation of sodium iodidethallium gamma spectrometry system manual. Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria.
26. Chijioke AM, Chikwendu OE, Chinedu I, Benedict EC, Amarachi NU, Afam MD, Kosisochukwu UG, Tochukwu OJ. Radionuclide concentration: The coal ash effect. *Inter J Phys Sci*. 2018;13(15):230-234.
27. Jibiri NN, Emelue HU. Soil radionuclide concentrations and radiological assessment in and around a refining and petrochemical company in Warri, Niger delta, Nigeria. *J Radiol Prot*. 2008;28:361-368.
28. Nahar A, Asaduzzaman K, Islam MM, Rahman MM, Begum M. Assessment of natural radioactivity in rice and their associated population dose estimation. *Radiat Eff Defects Solids*. 2018;173(11-12):1105-1114.
29. Jibiri NN, Abiodun TH. Effects of Food Diet Preparation Techniques on Radionuclide Intake and Its Implications for Individual Ingestion Effective Dose in Abeokuta. *World J Nucl Sci Technol*. 2012;2:106-113.
30. Jwanbot DI, Izam MM, Nyam GG. Radioactivity in Some Food Crops From High Background Radiation Area on the Jos-Plateau. *J Nat Sci Res*. 2012;2:6:76-78.
31. Avwiri GO, Ononugbo CP, Olasoji JM. Radionuclide transfer factors of staple foods and its health risks in Niger delta region of Nigeria. *Int J Innov Environ Stud Res*. 2021;9:21-32.
32. Tchokossa P, Olomo JB, Balogun FA, Adesanmi CA. Assessment of radioactivity contents of food in the oil and gas producing areas in delta State, Nigeria. *Aceh Int J Sci Technol*. 2013;3:245-250.
33. Addo MA, Darko EO, Gordon C, Nyarko BJB. A preliminary study of natural radioactivity ingestion from cassava grown and consumed by inhabitants around a cement production facility in the Volta region, Ghana. *Int J Environ Sci*. 2013;3:2312-2323.
34. Murniasih S, Prabasiwi DS, Sukirno S. Assessment of radiological hazards in soil, water and plants around coal power plant. *Atom Indones*. 2022;48:137-145.
35. Adesiji NE, Ademola JA. Soil-to-cassava plant transfer factor of natural radionuclides on a mining impacted soil in a tropical ecosystem of Nigeria. *J Environ Radioact*. 2019;201:1-4.
36. Rilwan U, Jafar M, Musa M, Idris MM, Waida J. Transfer of Natural Radionuclides from Soil to Plants in Nasarawa, Nasarawa State, Nigeria. *J Radiat Nuc Appl, Internat J*. 2022;7:81-86.
37. Doyi INY, Essumang DK, Agyapong AK, Asumadu-Sarkodie S. Soil-to-cassava transfer of naturally occurring radionuclides from communities along Ghana's oil and gas rich Tano Basin. *J Environ Radioact*. 2018;182:138-141.
38. Lopes JM, Garcêz RWD, Filgueiras RA, Silva AX, Braz D. Committed effective dose due to the intake of 40K, 226Ra, 228Ra and 228Th contained in foods included in the diet of the Rio de Janeiro city population, Brazil. *Radiat Prot Dosimetry*. 2018;181:149-155.
39. Savci S. An agricultural pollutant: chemical fertilizer. *Int J Environ Sci Dev*. 2012;3:73-80.
40. Pambianchi E, Pecorelli A, Valacchi G. Gastrointestinal tissue as a "new" target of pollution exposure. *IUBMB Life*. 2022;74:62-73.
41. Hassan YM, Zaid HM, Guan BH, et al. Radioactivity in staple foodstuffs and concomitant dose to the population of Jigawa state, Nigeria. *Radiat Phys Chem*. 2021;178:108945.
42. Jayasinghe C, Pinnawala UC, Rathnayaka T, Waduge V. Annual committed effective dosage from natural radionuclides by ingestion of local food growing in mineral mining area, Sri Lanka. *Environ Geochem Health*. 2020;42:2205-2214.
43. Ugbede FO, Akpolile AF, Ibeh GF, Mokobia CE. In-situ assessment of background gamma radiation dose levels in outdoor environment of Enugu urban areas, Enugu state, Nigeria. *Environ Forensics*. 2022;23:334-345.
44. United Nations Scientific Committee on the Effects of Atomic Radiation, & Annex, B. Exposures from natural radiation sources. *cosm Rays*. 2000;9: 83-105.