Journal of Food Protection 86 (2023) 100160

Contents lists available at ScienceDirect

Journal of Food Protection

journal homepage: www.elsevier.com/locate/jfp

Research Note

Assessment of Radium Equivalent Activity and Total Annual Effective Dose in Cassava cultivated around Ewekoro Cement Factory

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ARTICLE INFO

Keywords:
Cassava
Total Annual Effective Dose
Hyper Pure Germanium Spectrometry
Activity concentrations
Radionuclides

ABSTRACT

In this study, cassava tubers cultivated in the Ewekoro cement area were investigated with the aid of Hyper Pure Germanium (HPGe) detector in order to assess the radionuclide content. Twenty-seven (27) samples of both arable soil and cassava tubers were studied at different sites to the epicenter of the mining activity. The results revealed the highest activity concentrations of K-40, Ra-226, and Th-232 to be 194.10, 63.92, and 76.90 Bq/kg, respectively, in soil to be at site 1, which was 50 m away from the cement mining site. Similarly, cassava reported the highest activity concentrations of 228.15 and 81.50 Bq/kg for K-40 and Ra-226, respectively, at sites 2, which was 150 m away from the mining site. However, the highest value of Th-232 in cassava was noted in site 1. Also, the highest values of Raeq for arable soil and cassava tubers were estimated to be 188.84 Bq/kg and 199.89 Bq/kg at site 1 and site 2, respectively. All the above results were higher than the recommended safe limits by a factor of 2. Moreover, the Total Annual Effective Dose of exposure by oral ingestion of cassava tubers for different age groups revealed children to have the highest level of exposure with the highest mean value of 7.98 mSv. This is followed by adults and infants, which reported 5.66 and 5.38 mSv, respectively, all at site 2. This result is far greater than the recommended safe limits of 1 mSv. Therefore, the results of the total averages of annual effective doses due to consumption of the three natural radionuclides in cassava tubers and other products from it by adults, children, and infants were found to be above the average annual ingestion radiation dose due to natural sources. Further statistical analysis of the results showed significant differences between sites 1 and 2 and between sites 1 and 3, where there was no statistically significant difference between sites 2 and 3.

Variations in the concentration of radionuclides in soil can be attributed to both natural and anthropogenic sources (Ababneh et al., 2018). Prominent among the anthropogenic activities contributing to the high presence of radioactive materials in soil and the environment include industrialization, large-scale farming involving the use of fertilizers and mining (Fall et al., 2023). Mining has been recognized as one of the major means of income generation that contributes positively to the growth and development of the economy (Abojassim et al., 2015: Al-Hamarneh & Awadallah, 2009). However, mining industries have their own share of disadvantages in that they explore great depth to exhume radioactive materials to the surface, which in turn alters the natural sequence of radionuclides in the environment (Salbu et al., 2013). Highly radioactive materials are known to be associated with mining activities either from excavated geological formations, the depth of mining or both (Fall et al., 2023: IAEA, 2015). The abundant presence of naturally occurring radioactive materials (NORMs) is very hazardous to humans' health (IAEA, 2015). The most abundant and well-studied radioactive materials are the ^{238}U, ^{232}Th, and ^{40}K (UNSCEAR, 2000a, 2000b). This is largely due to their very harmful effect, long half-life, and natural origin (Khan & Gibbons, 2014). These radionuclides attract attention because of their high instability, which calls for their long decay series in order to achieve stability (Kumar et al., 2017). Soil has been known to be a natural source of radioactive materials because man depends on it for raw materials and food (Li et al., 2006; Lu et al., 2006; Monira et al., 2005).

Food items are also known to be embedded with different proportions of radioactive content depending on where they are cultivated (Merz et al., 2013: Hosseini, Fathivand, Abbasisiar, et al., 2006; Hosseini, Fathivand, Barati, et al., 2006). Moreover, residents of communities where mining activities are heightened also depend on the

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https://doi.org/10.1016/j.jfp.2023.100160
Received 16 February 2023; Accepted 6 September 2023
Available online 10 September 2023
0362-028X/

farm produce cultivated in their area for sustenance. Doses of exposure to radiation by ingestion are due mainly to the presence of K-40, U-238, and Th-232 radionuclide series that are found in food and drinking water (Chen et al. 2016; Forte et al., 2007). However, feeding on food items that have a high content of radioactive contamination can result in adverse health consequences such as respiratory issues or cancer (Hamada and Ogino, 2012; Hassona et al., 2008). Studies have shown that undue exposure to radiation over a prolonged period can damage the organs of the body when it is beyond the recommended safe limit (Jibiri and Okusanya, 2008; Hosseini, Fathivand, Abbasisiar, et al., 2006).

Hassan et al. (2021) assessed the level of radioactivity in staple foodstuffs as a result of contamination of soil from technological and nuclear advancement. However, the results revealed that the radionuclides in the foodstuffs were below the recommended safe limits for consumption. Cassava is a very popular food consumed by all in major part of Africa. It is often used to make different types of food such as gari flour, cassava flour and so on that are commonly eaten by people of all ages. Therefore, this study was targeted at determining the level of radium equivalent activity and total annual effective dose due to radioactive exposure from cassava products consumed by the people of Ewekoro area in Ogun state, Nigeria, where cement mining activity is carried out regularly.

Materials and Methods

Geology and Geographical Location of the Study Area. The study was conducted in Ota, Ogun state, which falls within the eastern part of the Dahomey (Benin) Basin in south-western Nigeria (Olabode, 2006). The basin stretches along the continental margin of the Gulf of Guinea. Rocks in the Dahomey basin are Late Cretaceous to Early Tertiary in age (Omatsola & Adegoke, 1981). The general sequence of the rock unit from the top are the Coastal plain sands, Ilaro formation, Oshosun formation, Akinbo formation, Ewekoro formation, and Abeokuta Group lying on the Southwestern Basement Complex of Nigeria (Adegoke, 1975). The Cretaceous Abeokuta Group consists of Ise, Afowo, and Araromi Formations consisting of poorly sorted ferruginized grit, siltstone, and mudstone with shale-clay layers (Fig. 1).

The Dahomey is one of the sedimentary basins on the continental margin of the Gulf of Guinea, extending from southeastern Ghana in the west to the western flank of the Niger Delta (Jones & Hockey, 1964). The basin is bounded in the west by faults and other tectonic structures associated with the landward extension of the fracture zone. Its eastern limit is similarly marked by the Hinge line, a major fault structure marking the western limit of Niger Delta (Olabode, 2006). It is also bounded in the north by the Precambrian basement rock and the Bright of Benin in the south. Stratigraphic studies of Dahomey basin were conducted by various researchers among who are (Omatsola & Adegoke, 1981). The population of the study area is about 896,700 people according to the national population projection of 2022.

Sample Collections and Preparations. Fifteen (15) samples of Soil and Twelve (12) samples of cassava tubers were investigated in this study. A total of five samples of soil and four samples of cassava tubers were collected at 50 m distance from the mining site as shown in Figure 2, and another five samples of soil and four samples of cassava tubers were collected at a distance that is 150 m from the mining site (Taskin et al., 2009). The last five samples of soil and four samples of cassava tubers, which were intended to be the control were collected at another site 15 km away from the mining site. At each site where the cassava tubers were collected, the soil at the root of the plants were also collected in order to ascertain if there is any transfer from the soil to the cassava tubers (Chukwuma, 1995). The samples were kept separately in different polyethylene bags. The polyethylene bags were labeled with permanent marker and strips of paper tape. The collected samples of cassava tubers were peeled, washed, sliced, and dried in the sun for 7 days. This was done in order to remove any contamination in the cassava that could be caused by the outer layer or cassava skin and soil deposit. Similarly, the collected soil samples were dried in the sun for 3 (three) days to remove any form of moisture.

Both samples of cassava tubers and soils were oven dried at 60°C and 105°C, respectively, for 6 h to eliminate any form of moisture in the samples (Falandysz et al., 2018). The dried samples of cassava tubers were pulverized and sieved using a 250 μm sieve for particle size homogeneity, at the mechanical engineering department of Covenant University. Similarly, the soil samples were crushed with a mortar and pestle in order to achieve fine soil that could be sieved using 250 μm sieve. After each use, the pulverizer, pestle, mortar, and the sieves were thoroughly cleaned in order to prevent cross-contamination of the samples (Lu & Xiolan, 2006).

Analysis of Samples. The samples were transported to the center for energy research and training at Ahmadu Bello University in Zaria for analysis using Hyper Pure Germanium (HPGe) detector with model no GLP-36385/10 manufactured by ORTEC. The HPGe detector used for analysis was an n-type coaxial ORTEC with a crystal diameter of 55.1 mm and a thickness of 52.2 mm. The detector was connected to a computer-based multichannel analyzer card system, which determined the area under characteristic's peak energy by the use of Gamma Vision Software. In order to estimate the energy resolution of the HPGe detector, a standard calibrated radioactive ^{60}Co was used. Data were collected for the two cascade gamma-ray energies of 1173.23 keV and 1332.51 keV. The energy resolution of the detector was 1.90 keV full width at half maximum at the 1332.50 keV peak of ^{60}Co. The used detector and measuring arrangement were calibrated for energy and efficiency in order to determine the type of radionuclides and the quantities present in the measured samples. The calibrations were done using a cylindrical shape multinuclide standard source (Khandaker et al., 2012; Kumar et al, 2017). Measured quantity of 500 g samples of sieved cassava tubers and soils were poured into 500 μL of Marinelli beakers that were properly labeled (Merz et al., 2015). The beakers were sealed to avoid air from getting into the containing samples. The samples were left for 28 days in order to achieve secular equilibrium between U-238 and its daughter radionuclides (Nasim et al., 2012).

Sample measurements. The background-level measurement is significant and used to determine the minimum detectable activity (Mersz et al., 2015; Mersz et al., 2013). In order to determine the background distribution in the environment around the detector, an empty sealed beaker was counted in the same manner and in the same geometry as the samples (Hosseini, Fathivand, Barati, et al., 2006). To qualitatively identify the contents of radionuclides in paint samples and to quantitatively determine their activities, all prepared samples were measured by means of a gamma-ray spectrometry system using a high-purity Germanium (HPGe) detector for 10,000 s. The background count per second (cps) was subtracted from each sample count to obtain the net cps (Alrefae et al., 2012; Aoun et al., 2015; Forte et al., 2007).

The equal counting time for background and sample measurement was chosen to minimize the uncertainty in the net counts (Akeozcan, 2013). The spectrum of each sample was analyzed, and the identification of unknown radionuclides was carried out by considering their peak centroid energies. The centroid energies of the peaks from the spectrum were compared with the reference gamma-ray energies (Al-Masri et al., 2004).

Activity Calculation. The activity of each sample of cassava tubers was determined by using the calibrated HPGe detector (Khandaker et al., 2012). The activity concentration of each radionuclide in the cassava tubers sample was measured by using the net count rates (cps) for the same counting time under the selected photo peaks, the weight of the sample, photo peak efficiency, and the gamma intensity

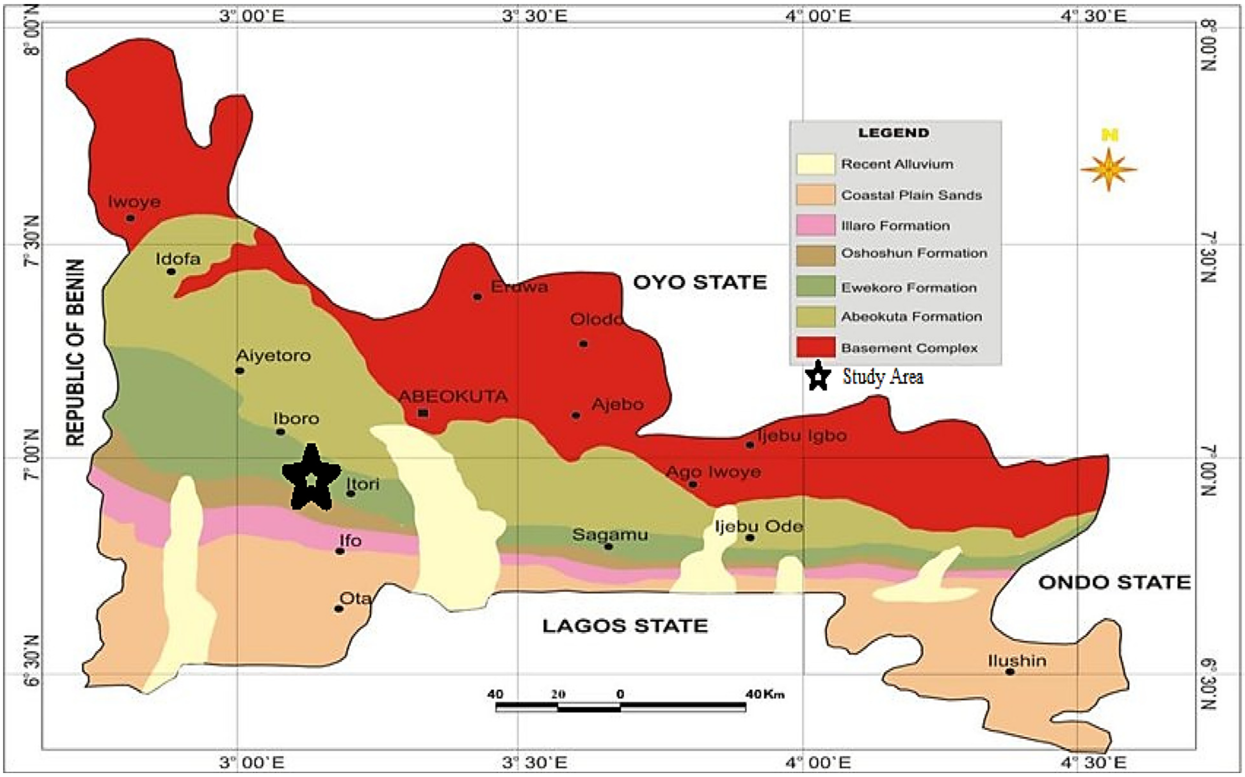

Figure 1. Geological map of the area of study.

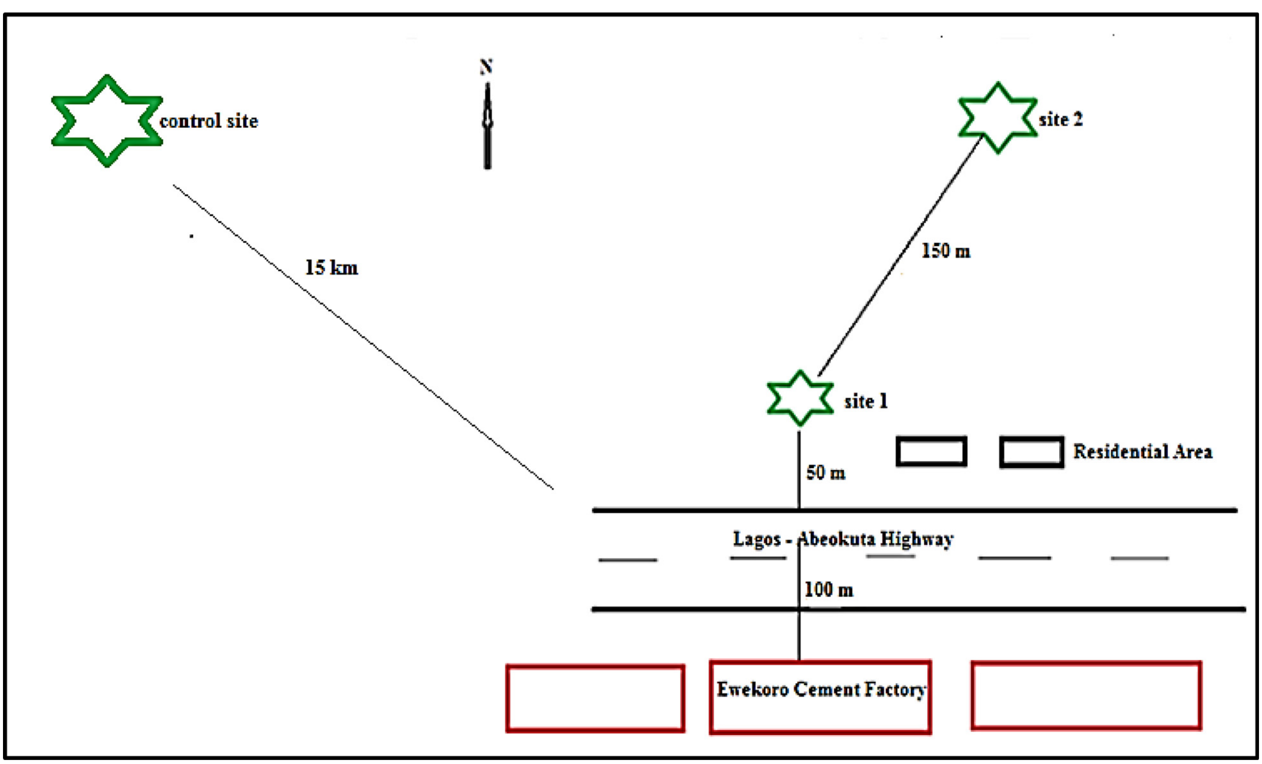

Figure 2. Base map of the study area.

at specific energy as given by the following equation (1) (Kumar et al., 2017; Beck & De Planque, 1968):

$$A = \frac{N \times 1000}{\varepsilon \times P_{\gamma} \times w} \quad (1)$$

Where, A is the activity of the sample in Bq/kg, N is the net counts per second (cps) is the difference between Sample cps and background cps, ε is the efficiency in percent (%), Pγ is the transition probability of gamma-ray, and w is the weight of the sample in gram.

Radium Equivalent Activity. This is estimated in order to compare the specific activities of materials containing different quantities of Ra-226, Th-232, and K-40. The equation (2) was used for this estimation (Attallah et al., 2020: ICRP, 1972).

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \tag{2}$$

Where, A_{Ra}, A_{Th}, and A_K are the specific activity concentrations (Bq/kg) of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

The annual effective dose, due to the consumption of cassava cultivated in the area of study or other products from it was determined using equation (3) (Abojassim et al., 2015; Hassona et al., 2008).

$$D\left(\frac{Sv}{yr}\right) = A \times E \times I \tag{3}$$

Where, A (Bq/kg) stands for the activity concentration of the radionuclide, while I stands for the annual consumption of cassava and its products (kg/yr) (Abojassim et al., 2015). The values of I were taken as 140, 90, and 45 (kg/yr) for adults, children, and Infants, respectively. Similarly, the factor for dose conversion E (Sv/Bq) (UNSCEAR, 2000a, 2000b) is presented in Table 1.

Results and discussion

The results of the activity concentrations for all the studied radionuclides in the three (3) sites are presented in Table 2. The range of values for K-40 for the sites 1, 2, and 3 varied from 131.60 to 217.07, 146.18 to 216.32, and 161.73 to 201.47 Bq/kg, respectively. Furthermore, the mean results showed the value of K-40 to be 194.10 Bq/kg at site 1, 50 m to the mining site. Similarly, the average value of K-40 at site 2, which is 150 m away from the cement mining area, was noted to be 173 Bq/kg. Furthermore, the average result of K-40 at the control site, which was estimated to be about 15 km away from the mining site, was observed to be 180.54 Bq/kg. From the result, site 1 presented the highest value of K-40, which could be largely because of the deposit of lime in the area of study. However, site 2 offered the lowest value. However, site 3 presented a higher value of K-40 than site 2, which could be as a result of the application of potassium-rich fertilizer in the farmland studied. In a similar vein, the results of Ra-226 ranged from 46.26 to 86.00, 42.47 to 72.67, and 54.89 to 66.12 Bq/kg for sites 1, 2, and 3, respectively. Moreover, the average value of Ra-226 was found to be 63.92 Bq/kg in site, which was located 50 m from the mining site while the result of Ra-226 at site 2 is 59.69 while at site 3, the value was found to be 60.97 Bq/kg. The average result of Ra-226 at site 1 was noted to be higher than the value of 59.69 Bq/kg at site 2. This could be as a result of the proximity of station 3 to the mining area. However, the mean result of Ra-226 at site 3, 60.97 Bq/kg was observed to be higher than the result at site 2. This could be as a result of the intrusion of foreign materials to the near-surface soil of the area studied.

The values of Th-232 were found to range from 63.08 to 91.60, 57.89 to 66.71, and 49.81–71.55 Bq/kg from sites 1, 2, and 3, respectively. The average activity concentrations for Th-232 were estimated to be 76.90 Bq/kg at station 1, 61.10 Bq/kg at station 2, and 60.31 at station 3. Station 1 had the highest average activity concentration of Th-232, which could be due largely to the influence of the mining activities in the area of study. Similarly, the average value reported for Th-232 was noted to be higher than the mean result at station 3. This could be as a result of the dominance of Thorium-232 in the general geology of the area considered as sites 1 and 2, which is the basement complex portion of the local government. However, the slightly low result observed in station 3 could be as a result of the fact that the study area is located in a slightly different geology of coastal plain sand. The results of activity concentrations obtained in the present study were compared with Fall et al (2023), which reported Ra-226 to be 4082 Bq/kg, Th-232 to be 1060 Bq/kg, and K-40 to be 568 Bq/kg. The results of activity concentrations obtained in the present study were by far lower. This could be due to the influence of oil and gas residue in the site studied by Fall et al. (2023). The results of the present study were compared with the world-recommended safe limits, and it was noted that Ra-226 and Th-232 were higher by factors of 1.7 and 2.0, respectively. However, the result of K-40 was lower than the recommended safe limit. This could mean that the cassava tubers cultivated in this soil may be unduly exposed to the high activity concentrations of K-40, Ra-226, and Th-232 present in the soil.

The results of the radium activity equivalent obtained for soil on which the cassava is cultivated were presented in Table 2. The radium activity equivalent ranged from 162.19 to 210.66, 141.59 to 177.34, and 147.31 to 176.21 Bq/kg, respectively. Site 1 recorded the highest average value of radium equivalent activity, which is 188.84 Bq/kg. This could be largely due to the mining activities being carried out in the area of study. Similarly, site 3, which is the control for this study, reported the second-highest average value of 160.40 Bq/kg, which could be as a result of the intrusion of foreign soil materials in the area of study. However, the results of Radium equivalent activity observed in this study were far lower than Fall et al. (2023), whose average value was 5642 Bq/kg. This could be as a result of the influence of the residues of oil and gas present in the area of study. In contrast, the results of radium equivalent activity for soil in the present study are far lower than the world-recommended average safe limit by a factor of 2. This implies that the soil in this farm may not pose any danger to the farmers or the people that are occasionally exposed to it. Therefore, periodic monitoring of the farm products, such as cassava, in the study area must be carried out in order to protect the people from imminent danger.

The results of the specific activity concentrations in the harvested cassava tubers, cultivated in the area of study, are presented in Table 3. It was noted that the range of K-40, Ra-226, and Th-232 varied from 188.76 to 249.04, 65.92 to 71.23, and 68.41 to 86.86 Bq/kg, respectively, at site 1. Furthermore, at site 2, the observed values of activity concentrations of radionuclides in cassava tubers ranged from 209.73 to 250.05, 72.35 to 90.12, and 64.17 to 77.18 Bq/kg for K-40, Ra-226, and Th-232, respectively. Also, the range of values measured at site 3 for K-40, Ra-226, and Th-232 were from 221.20 to 237.08, 65.60 to 78.10, and 66.84–83.55 Bq/kg, respectively. Consequently, the average value measured at station 1 for K-40 was 217.04 Bq/kg, which is lower than 228.15 Bq/kg obtained from cassava tubers at 150 m distance from the mining site. The variation in the values could be due to the rate of absorption of K-40 from the soil on which it was cultivated. However, the result of K-40 in the cassava tubers harvested in the site 3 was estimated to be 182.24 Bq/kg, which is the lowest of the three sites. This could be as a result of low absorption of K-40 from the soil in the study area. Similarly, the mean value of Ra-226 at site 2 was

Table 1
Factor for dose conversion

Age Group	Age Range(years)	K-40 (nSv/Bq)	Ra-226 (nSv/Bq)	Th-232 (nSv/Bq)
Infants	0 – 1	42	960	450
Children	≤ 18	13	800	290
Adults	≥ 18	6.2	280	230

Table 2
The Radium equivalent activities and Activity Concentrations of K-40, Ra-226 and Th-232 in arable soil

Sample ID	Site 1				Site 2				Site 3 (Control)			
	Ra(eq) (Bq/kg)	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	Ra(eq) (Bq/kg)	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	Ra(eq) (Bq/kg)	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)
S1	162.19	131.60	46.26	73.99	177.34	151.59	70.27	66.71	152.43	201.47	65.68	49.81
S2	210.66	211.50	86.00	75.78	167.79	146.18	72.67	58.64	163.46	161.73	61.20	62.80
S3	196.98	207.58	66.51	80.06	141.59	177.82	43.46	59.04	147.31	168.97	54.89	55.53
S4	197.38	202.76	50.78	91.60	165.71	173.32	69.59	57.89	173.34	182.54	56.97	71.55
S5	176.99	217.07	70.07	63.08	149.55	216.32	42.47	63.24	176.21	188.01	66.12	61.84
Min.	162.19	131.60	46.26	63.08	141.59	146.18	42.47	57.89	147.31	161.73	54.89	49.81
Max.	210.66	217.07	86.00	91.60	177.34	216.32	72.67	66.71	176.21	201.47	66.12	71.55
Average	**188.84**	**194.10**	**63.92**	**76.90**	**160.40**	**173.05**	**59.69**	**61.10**	**162.55**	**180.54**	**60.97**	**60.31**
World												

Average3704003530S: soil sample

Table 3
The Radium equivalent activities and Activity concentrations of K-40, Ra-226 and Th-232 in Cassava tubers

Sample ID	Site 1				Site 2				Site 3 (Control)			
	Ra(eq) (Bq/kg)	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	Ra(eq) (Bq/kg)	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	Ra(eq) (Bq/kg)	K-40 (Bq/kg)	Ra-226 (Bq/kg)	Th-232 (Bq/kg)
C6	198.67	249.04	65.92	79.42	195.04	215.90	76.70	71.13	184.09	229.62	65.60	70.50
C7	202.09	227.53	66.83	82.33	180.26	209.73	72.35	64.17	181.41	223.30	68.63	66.84
C8	184.68	202.81	71.23	68.41	216.43	250.05	86.81	77.18	203.77	237.08	66.04	83.55
C9	209.45	188.76	70.71	86.86	207.83	236.92	90.12	69.56	195.22	221.20	78.10	69.99
Min.	184.68	188.76	65.92	68.41	180.26	209.73	72.35	64.17	181.41	221.20	65.60	66.84
Max.	209.45	249.04	71.23	86.86	216.43	250.05	90.12	77.18	203.77	237.08	78.10	83.55
Average	**198.72**	**217.04**	**68.67**	**79.26**	**199.89**	**228.15**	**81.50**	**70.51**	**191.12**	**182.24**	**69.59**	**72.72**
World												

Average4003530C: cassava sample.

estimated to be 81.50 Bq/kg while at site 1, the mean value was 68.67 Bq/kg.

The mean activity concentration of Ra-226 at site 2 was higher than at site 1, this could be as a result of the rate of absorption of the radionuclides by the cassava tubers from the soil and the level of maturity of the cassava tubers before they were harvested. The average activity concentration of Ra-226 at site 3 was noted to be 69.59 Bq/kg, which is far lower than the reading obtained at stations 1 and 2. This could be as a result of the variations in the maturity of the cassava tubers before harvest and the rate of absorption of Ra-226 by the plants from the soil. Finally, average values of Th-232 at sites 1, 2, and 3 are 79.26, 70.51, and 72.72 Bq/kg, respectively. The result at site 1 was higher than sites 2 and 3; this could be attributed to the variations in the level of absorption of Th-232 by the cassava plant from the surrounding soil. The results of activity concentrations obtained in this study were lower than the results of Ononugbo et al. (2019), which reported Ra-226, Th-232, and K-40 to be 54.43, 561.67, and 413.64 Bq/kg, respectively. The great difference in the results observed in the two studies could be attributed to the differences in the geology of the areas of study. The average values of K-40 reported in all the studied sites were far lower than the world-recommended safe limit of 400 Bq/kg. However, the mean values of Ra-226 and Th-232 were higher than the world-recommended safe limits of 35 and 30 Bq/kg, respectively, by a factor of 2. Consequently, consuming cassava tubers or its produce with this level of activity concentrations could pose much danger to the public (IAEA, 2003).

The results of the radium equivalent activity of cassava tubers at the three (3) sites were also presented in Table 3. The results ranged from 184.68 to 209.45, 180.26 to 216.43, and 181.41 to 203.77 Bq/kg, at sites 1, 2, and 3, respectively. Furthermore, the average values of the radium equivalent activity were estimated to be 198.72, 199.89, and 191.12 Bq/kg. The mean results of Ra(eq) obtained in this study are far lower than the range of results from 68.41 to 492.27 Bq/kg reported in Mgbokwere et al. (2021). The differences in the results could be as a result of the variation in the contributions of the geological factors, characterized by the presence of solid minerals in their area of study. However, the results of the present study were half the values of the world average recommended safe limits when compared. This result showed that the exposure due to oral ingestion of cassava tuber and its product may not pose immediate danger but may have hazardous effects on the public/consumers after a long time.

The total annual effective dose from cassava tuber consumption by people of all ages is presented in Table 4. The results of 7.27 and 7.98 mSv at sites 1 and 2 for children, respectively, revealed that children are more exposed than both infants and adults. These high results could be attributed to the rate of consumption of cassava products by children and the factors for dose conversion presented in Table 1. Similarly, the adults reported 5.43 and 5.66 mSv at sites 1 and 2, while the infants reported 4.99 and 5.38 mSv at the same sites, respectively. The results of total annual effective dose observed at site 3 for adults, children, and infants are 5.27, 7.18, and 4.91 mSv, respectively, which is lower than the results obtained at sites 1 and 2. The result of total annual effective dose reported in the present study was much higher than the results obtained in Ononugbo et al. (2019) and Van (2020). However, the results obtained at all the sites far exceeded the recommended safe limit of 1 mSv according to the International Commission on Radiological Protection (ICRP, 1996; UNSCEAR, 1993). This result implies that the total averages of annual effective doses due to consumption of the three natural radionuclides in cassava tubers and products by adults, children, and infants were found to be above the average annual ingestion radiation dose due to natural sources (Tables 5a–7d).

Statistical analysis of results

One-Sample T Test for K-40. The mean of the sample dose rates for K-40 (201.13 Bq/kg) for all the samples and sites was compared with the world average value (400 Bq/kg) using a one-sample T test in SPSS

Table 4
Total Annual Effective Dose (mSv)

Sample ID	Site 1			Site 2			Site 3		
	Adults	Children	Infants	Adults	Children	Infants	Adults	Children	Infants
C6	5.36	7.11	4.93	5.48	7.63	5.16	5.04	6.83	4.70
C7	5.47	7.23	4.99	5.08	7.13	4.82	5.04	6.95	4.74
C8	5.17	7.15	4.85	6.11	8.56	5.79	5.49	7.21	4.99
C9	5.73	7.58	5.17	5.98	8.58	5.75	5.51	7.71	5.21
Average	**5.43**	**7.27**	**4.99**	**5.66**	**7.98**	**5.38**	**5.27**	**7.18**	**4.91**

Table 5a
One-Sample Statistics Test for K-40

a)One-Sample Statistics				
	N	Mean	Std. Dev.	Std. Error Mean
K-40	27	201.1259	31.30417	6.02449

Table 5b
One-Sample Test for K-40

b)One-Sample Test						
	Test Value = 400					
	t	df	Sig. (2 tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
K-40	−33.011	26	.000	−198.87407	−211.2576	−186.4906

Table 5c
Tests of Between-Subjects Effects for K-40

Dependent Variable: K-40						
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	13086.789[a]	5	2617.358	4.436	.006	.514
Intercept	1103742.473	1	1103742.473	1870.456	.000	.989
Location	116.828	2	58.414	.099	.906	.009
Materials	11628.397	1	11628.397	19.706	.000	.484
Location * Materials	1250.498	2	625.249	1.060	.364	.092
Error	12391.945	21	590.093			
Total	1117672.962	27				
Corrected Total	25478.734	26				

[a] R Squared = .514 (Adjusted R Squared = .398)

Table 6a
One-sample Statistics Test for Ra-226

a)One-Sample Statistics				
	N	Mean	Std. Dev.	Std. Error Mean
Ra-226	27	66.7400	12.02909	2.31500

Table 6b
One-Sample Test for Ra-226

b)One-Sample Test						
	Test Value = 35					
	t	df	Sig. (2 tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Ra-226	13.711	26	.000	31.74000	26.9815	36.4985

Table 6c
Tests of Between-Subjects Effects

Dependent Variable: Ra-226

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1372.695[a]	5	274.539	2.413	.071	.365
Intercept	121109.115	1	121109.115	1064.372	.000	.981
Location	141.306	2	70.653	.621	.547	.056
Materials	916.348	1	916.348	8.053	.010	.277
Location * Materials	355.279	2	177.640	1.561	.233	.129
Error	2389.477	21	113.785			
Total	124026.317	27				
Corrected Total	3762.172	26				

a. R Squared = .365 (Adjusted R Squared = .214)

Table 7a
One-Sample Statistics for Th-232

a)One-Sample Statistics

	N	Mean	Std. Dev.	Std. Error Mean
Th-232	27	69.6852	10.11643	1.94691

Table 7b
One-Sample Test for Th-232

b)One-Sample Test

	Test Value = 30					
	t	df	Sig. (2 tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Th-232	20.384	26	.000	39.68519	35.6833	43.6871

Table 7c
Tests of Between-Subjects Effects for Th-232

Dependent Variable: Th-232

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1474.328[a]	5	294.866	5.219	.003	.554
Intercept	131163.048	1	131163.048	2321.338	.000	.991
Location	843.997	2	421.998	7.469	.004	.416
Materials	432.840	1	432.840	7.660	.012	.267
Location * Materials	118.531	2	59.265	1.049	.368	.091
Error	1186.567	21	56.503			
Total	133773.572	27				
Corrected Total	2660.896	26				

[a] R Squared = .554 (Adjusted R Squared = .448)

Table 7d
Pairwise Comparisons for Th-232

Dependent Variable: Th-232

(I) Location	(J) Location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
Site 1	Site 2	12.272	3.566	.002	4.857	19.686
	Site 3	11.566	3.566	.004	4.151	18.980
Site 2	Site 1	−12.272	3.566	.002	−19.686	−4.857
	Site 3	−0.706	3.566	.845	−8.121	6.709
Site 3	Site 1	−11.566	3.566	.004	−18.980	−4.151
	Site 2	0.706	3.566	.845	−6.709	8.121

with a significant level of 0.05. The variation between the two means was observed to be statistically significant (P value less than 0.05) as presented in Tables 5a and 5b. From the compared means, the average K-40 concentration for all sites is significantly lower than the world average.

Two-way Analysis of Variance (ANOVA) for K-40. A two-way analysis of variance with a significant value of 0.05 was carried out to compare the means of the dose rate of the two sample groups (soil and tubers) among those of the different sites (Sites 1–3). The test showed a statistically significant difference in the means of the dose rate of sample groups within all the locations but no statistically significant difference in the dose rate of samples among the locations see Table 5c.

One-Sample T Test for Ra-226. Comparison of the mean of all samples across all sites using the one-sample T test revealed a statistically significant (p value less than 0.05) variation between the sample mean and the world average for Ra-226 as shown in Tables 6a and 6b. It can be inferred that the sample mean of 66.74 Bq/kg is significantly larger than the world average value of 35 Bq/kg.

Two-way ANOVA for Ra-226. The two-way ANOVA analysis of 0.05 alpha level shows a statistically significant variation between the means of the specimen groups for all sites (p value = 0.01). However, the analysis revealed no statistically significant variation between the means of the locations (p value of 0.547) as presented in Table 6c.

One-Sample T Test for Th-232. The mean dose rate of the samples for Th-232 (69.69 Bq/kg) for all locations is significantly higher compared to the world average of 30 Bq/kg from the one-sample T test carried out as seen in Tables 7a and 7b.

Two-way ANOVA for Th-232. The mean of the dose rate between the two groups of materials within locations is shown to be statistically significant with a p value of 0.012 as presented in Table 7c. Similarly, the means of the dose rates between the locations are also statistically significant. A statistical pairwise comparison was carried out to know which of the locations were significantly different from each other. The comparison revealed significant differences between Site 1 and Site 2 and between Site 1 and Site 3. However, no statistically significant difference was observed between Site 2 and Site 3 as shown in Table 7d.

Conclusion

This study assessed the activity concentrations of K-40, Ra-226, and Th-232 with the aid of Hyper Pure Germanium (HPGe) detector on soil and cassava products cultivated at Ewekoro cement-producing area of Ogun State, Nigeria. The results revealed the highest activity concentrations of K-40, Ra-226, and Th-232 to be194.10, 63.92, and 76.90 Bq/kg, respectively, in soil to be at site 1, which was 50 m away from the cement mining site. Similarly, Cassava reported the highest activity concentrations of 228.15 and 81.50 Bq/kg for K-40 and Ra-226, respectively, at site 2, which was 150 m away from the mining site. However, the highest value of Th-232 in Cassava was noted in site 1. Also, the highest values of Raeq for arable soil and Cassava tubers were estimated to be 188.84 Bq/kg and 199.89 Bq/kg at site 1 and site 2, respectively. All the above results were higher than the recommended safe limits by a factor of 2. Moreover, the Total Annual Effective Dose of exposure by oral ingestion of Cassava tubers for different age groups revealed children to be most prone with the highest mean value of 7.98 mSv at site 2. This is followed by adults and infants, which reported 5.66 and 5.38 mSv, respectively all at site 2. This result is far greater than the recommended safe limits of 1 mSv. Therefore, the results of the total averages of annual effective doses due to consumption of the three natural radionuclides in cassava tubers and other products from it by adults, children, and infants were found to be above the average annual ingestion radiation dose due to natural sources. Moreover, a two-way analysis of variance (ANOVA) with a significant value of 0.05 was carried out. The average K-40 concentration for all sites is significantly lower than the world average. Comparison of the mean of all samples across all sites using the one-sample T test revealed a statistically significant (p value less than 0.05) variation between the sample mean and the world average for Ra-226. The mean dose rate of the samples for Th-232 (69.69 Bq/kg) for all locations is significantly higher compared to the world average of 30 Bq/kg from the one-sample T test carried out. The pairwise comparison revealed significant differences between Sites 1 and 2 and between Sites 1 and 3. However, no statistically significant difference was observed between Sites 2 and 3.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors wish to acknowledge the Chief and the residents of Ewekoro for the support provided during the collection of samples for this investigation. Our appreciation also goes to the management of Covenant University for providing the funding for this research output with grant number CUCRID/RG/003.11.21/VC. Sincere thanks to Dr. Iyanu Ogunriola for his timely assistance with the statistical analysis.

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