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Health Risk Assessment of Natural Radionuclides Ingestion from Selected Edible Crops in Farmlands Around Limestone Excavation Area in Ewekoro, Ogun State

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Abstract: *Natural radionuclides are found in the air, water and soil. They are introduced to the plants through the leaves and absorption of nutrients and water from the soil by the roots. The presence of radionuclides in plants can affect directly humans through the consumption of the plant or indirectly through the food chain. The concentrations of natural radionuclides in some crops from farms around Ewekoro limestone excavation area in Ewekoro town, Ogun State in Nigeria, were determined and the annual committed effective dose to the consumers was also determined. In addition, soil samples from the farms where each crop was planted were collected to determine the transfer factor and the radiological safety of people on the farms. The gamma spectrometry method was used for the analysis. The highest concentrations of* ^{40}K, ^{238}U *and* ^{232}Th *in crops were 856.13 ± 32.25Bqkg*$^{-1}$, *35.27 ± 5.91Bqkg*$^{-1}$ *and 13.39 ± 2.75Bqkg*$^{-1}$ *respectively. The average annual committed effective dose of the natural radionuclides to the consumers was calculated to be 0.9214mSvyr*$^{-1}$, *which was below the limit of 1.0mSvyr*$^{-1}$ *recommended globally. The average excess lifetime cancer risk of the radionuclides consumption to the consumers was determined to be 3.225 x* 10^{-6}, *which was below the recommended limit of 1.45 x* 10^{-3} *and therefore indicated that the ingestion of these radionuclides through the consumption of these crops has no significant radiological health hazard to the consumers. However, the average annual effective dose equivalent of the radionuclides from soils within the investigated farms showed an average value of 0.0458 mSvyr*$^{-1}$, *which was below the limit of 1 mSvyr*$^{-1}$. *Average excess lifetime cancer risk was determined to be 0.1547 x* 10^{-3} *which was below the recommended limit, indicating that the farmers and the people in the environs were not exposed to radiological health hazards.*

Keywords*: Crops, radionuclides, gamma spectrometry, concentration, dose, health hazard.*

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1.0 Introduction

All organisms on Earth are continuously exposed to ionizing radiation originating from outer space. Natural exposures arising mainly from the primordial radionuclides

are distributed widely and are present in almost all geological materials in the earth's environment. These radionuclides are known as naturally occurring radioactive material (NORM) (Santawamaitre *et al.*, 2010). According to Sowole and Egunjobi (2019), the primordial radionuclides are capable of releasing ionizing radiations and a significant amount of energy under disintegration. The disintegration of radionuclides can be destructive if monitoring, check and balance mechanisms are not properly considered. They exist in water, air, soils and rocks, and serve as a threat to human health because the intake may lead to radiological health hazards such as cancer in organs of the body. They find their way into plants through the roots from the soil and are stored in their parts, the edible parts of the plants are fed on by animals including humans, and get contaminated with them. According to Tawalbeh *et al.* (2012), ingested radionuclides could be concentrated in certain parts of the body. Chemical uranium toxicity primarily affects the kidney, causing damage to the proximal tubule, while this metal has also been identified as a potential reproductive toxicant (Linares *et al.*, 2006). ^{232}Th causes effects in the lungs, liver and skeleton tissues, and ^{40}K causes effects in muscles. Depositions of large quantities of these radionuclides in particular organs will affect the health condition of the human such as weakening the immune system, inducing various types of diseases, and finally increasing in mortality rate (Tawalbeh *et al*., 2012).

Assessment of activity concentrations of ^{40}K, ^{238}U and ^{232}Th in surface soil samples from different locations at Igbokoda, where crude oil exploration is taking place, at Ondo State in Nigeria, was done by gamma spectrometry method. NaI (TI) detector coupled with a pre-amplifier base connected to a multiple channel analyzer (MCA) was used to determine the radiological indicators (Sowole & Egunjobi, 2019). Ten (10) samples were collected from the study area taking into consideration the densely populated parts where crude oil exploration and drilling of its wells were taking place. The mean activity concentrations of ^{40}K, ^{238}U and ^{232}Th obtained from the soil samples were 494.64 ± 10.46, 19.76 ± 3.09 and 31.98 ± 5.10 Bq kg^{-1}, respectively. The mean external hazard index (H_{ex}) and mean internal hazard index (H_{in}) for all the soil samples were 0.2836 and 0.3370, respectively, while the mean radium equivalent activity was 104.92 Bq kg^{-1}. The mean absorbed dose rate value was 49.68 nGy hr^{-1} with a mean annual effective dose equivalent of 0.0610 mSv yr^{-1}. The mean excess lifetime cancer risk for outdoor exposure was 0.2132 x 10^{-3}. The values of the radiological parameters: mean external and internal hazard indices, mean radium equivalent activity, mean absorbed dose rate, mean annual effective dose equivalent and mean excess lifetime cancer risk were within the recommended limits of 1.0 Bq kg^{-1}, 370 Bq kg^{-1}, 55.00 nGy hr^{-1}, 1.0 mSv yr^{-1} and 1.45 x 10^{-3}, respectively. Najam & Younis (2015) studied the natural radionuclides in the soil samples of selected regions in Nineveh province in Iraq, and the health implications to individuals in the study area. The average absorbed dose rate, average radium equivalent value, and average internal and external hazard indices were obtained to be 48.91 nGy hr^{-1}, 89.41 Bq kg^{-1}, 0.329 Bq kg^{-1} and 0.238 Bq kg^{-1}, respectively, and all the values were within the recommended limits globally. Also, Sowole (2014) studied the activity concentrations of radionuclides in surface soil samples of major markets in Sagamu and obtained the highest radioactivity

concentrations of ^{40}K, and ^{238}U from Falawo market surface soil samples with values of 1274.26 ± 4.26Bqkg^{-1} and 40.72 ± 3.12Bqkg^{-1} respectively while that of ^{232Th} was obtained from Sabo market surface soil sample with value 115.62 ± 16.39Bqkg^{-1}. The mean external hazard index (H_{ex}) and mean internal hazard index (H_{in}) for all the soil samples from Falawo market were determined to be 0.616 Bqkg^{-1} and 0.691Bqkg^{-1} respectively, and that of Awolowo market were 0.566 Bqkg^{-1} and 0.634 Bqkg^{-1} respectively. Also, for Sabo market the mean values were calculated to be 0.594 Bqkg^{-1} and 0.658 Bqkg^{-1} respectively. All the values obtained were less than 1.0 Bqkg^{-1} as recommended by the International Commission on Radiological Protection (ICRP, 2007) and therefore have no negative radiological health implications for the people within the markets and their environs. Furthermore, a preliminary investigation of naturally occurring radionuclides in some traditional medicinal plants used in Nigeria for the treatment of some diseases by Njinga *et al.* (2015) revealed that the average annual committed effective doses due to the ingestion of ^{226}Ra, ^{232}Th and ^{40}K from the plants by the consumers ranged from 0.00426mSvyr^{-1} to 0.00686mSvyr^{-1} with an average value of 0.00538mSvyr^{-1} which was below the worldwide average value of 0.3mSvyr^{-1} for an individual provided in UNSCEAR 2000 report indicating that the consumers are radiologically safe. The research work done by Giri *et al.* (2013) concerning foodstuffs and water ingestion by human beings in India from the uranium mining area of the study area revealed that the ingestion dose was below the dose limit of 1mSvyr^{-1} for public exposure in planned exposure situations as recommended by CRP (2007) indicating also that the people are radiologically safe. In order to collect data for the Nigerian, situation, especially, Ogun State, this research work aims to determine the activity concentrations, and annual committed effective doses of ^{40}K, ^{238}U and ^{232}Th, along with the average annual committed effective dose from some crops purchased from farmlands around Ewekoro limestone excavation areas in Ogun State, Southwest of Nigeria to consumers. In addition, to collect soil samples from these farms and determine the radiological parameters to ascertain the radiological safety of the people in the farmlands and their environs.

2.0 Materials and Methods

The method of gamma spectrometry was adopted for the analysis of the samples collected to obtain concentrations of ^{40}K, ^{238}U and ^{232}Th in the crops and soil samples. Twenty (20) samples of edible crops: cassava, wateryam, cocoyam, maize and potato were purchased from farmlands in the study area, and twenty soil samples (20) were also collected from the farms. The crop samples were rinsed with distilled water to avoid contamination, and cut into pieces, after which they were oven-dried at 80^0C (Akinloye *et al.*, 1999), pulverized, weighed, packed 120.0g by mass in plastic containers and carefully sealed and kept for twenty-eight days (28) to establish secular radioactive equilibrium between the natural radionuclides and their respective progenies. Also, soil samples collected from the farms where the crops were harvested respectively were dried at room temperature, crushed, packed in plastic containers of uniform dimensions, and weighed 130.0g each. The spectrometer used was a Canberra lead-shielded 7.6cm x 7.6cm NaI (Tl) detector coupled to a multi-channel analyzer (MCA) through a preamplifier base. The resolution of the detector is about 10% at 0.662MeV of ^{137}Cs. For the analysis of ^{40}K, ^{238}U and ^{232}Th, the photo peak regions of ^{40}K (1.46 MeV), ^{214}Bi (1.76 MeV) and ^{208}TI (2.615

MeV) were respectively used. The cylindrical plastic containers holding the samples were put to sit on the high geometry 7.6cm x 7.6cm NaI (TI) detector. High-level shielding against the environmental background radiation was achieved by counting in a Canberra 10cm thick lead castle. The counting of each sample was done for 10hrs because of suspected low activities of the radionuclides in the samples. The areas under the photo-peaks of ^{40}K, ^{238}U and ^{232}Th were computed using the Multichannel Analyzer system.

The activity concentrations of the radionuclides were calculated based on the measured efficiency of the detector and the net count rate under each photopeak over a period of 10 hours using equation 1. (IAEA, 1989)

$$A = \frac{N(E_\gamma)}{\varepsilon(E_\gamma) I_\gamma M t_c} \quad (1)$$

where $N(E_\gamma)$ = Net peak area of the radionuclide of interest, $\varepsilon(E_\gamma)$ = Efficiency of the detector for the γ- energy of interest, I_γ = Intensity per decay for the γ- energy of interest, M = Mass of the sample, t_c = Total counting time in seconds (36000s).

2.1 Annual committed effective dose (ACED) for ingestion

In addition, the annual committed effective dose (ACED) for ingestion of NORMs in crops was determined using the expression (Tettey-Larbi *et al.*, 2013):

$$ACED = C\ x\ DCF\ x\ CR \quad (2)$$

C = Concentration of each radionuclide, DCF = Dose conversion factor for ingestion obtained from UNSCEAR (2000) and CR = Consumption rate of intake of NORMs from the crops.

2.2 Excess lifetime cancer risk

Excess lifetime cancer risk (ELCR) to the consumer was determined based on the values of the annual committed effective dose as shown in table 2.0 using equation 3.0 (ICRP, 2007)

$$ELCR = ACED\ x\ LE\ x\ RF \quad (3)$$

Where LE is life expectancy taken to be 70 years and RF is the fatal risk factor per sievert which was 0.05 (ICRP, 2007).

2.3 Radium equivalent activity (Ra_{eq})

This was calculated by the equation described by Beretka and Mathew (1985) and Yang *et al.* (2005) as indicated by equation 4.

$$Ra_{eq} = \frac{10}{130} C_k + \frac{10}{7} C_{Th} + C_{Ra} \quad (4)$$

Where: C_{Ra}, C_{Th} and C_k were the activity concentrations in Bq kg^{-1} of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.4 External hazard index (H_{ex})

Commonly used to evaluate radiation dose rate due to external exposure to gamma radiation from natural radionuclides in soil samples as reported by Hamzah *et al*. (2008) was presented in equation 5.

$$H_{ex} = \frac{C_k}{4810} + \frac{C_{Th}}{259} + \frac{C_{Ra}}{370} \quad (5)$$

2.5 Internal hazard index (H_{in})

H_{in} is a parameter for estimating the negative effect of radioactive materials on the lungs and other respiratory organs. The risk of internal exposure due to the natural radionuclides: ^{40}K, ^{226}Ra and ^{232}Th can be assessed from the value of H_{in} using equation 6. (Hamzah *et al*., 2008)

$$H_{in} = \frac{C_k}{4810} + \frac{C_{Th}}{259} + \frac{C_{Ra}}{185} \quad (6)$$

2.6 Absorbed dose rate (D)

The absorbed dose rate in air for external gamma radiation at about 1.0 m above the ground from the natural radionuclides D (nGy hr^{-1}) was given by UNSCEAR (2000) and EU (1999):

$$D\ (\text{nGy hr}^{-1}) = 0.041C_k + 0.604C_{Th} + 0.462C_{Ra} \quad (7)$$

The absorbed dose rate in air was used to estimate the annual outdoor effective dose equivalent for individuals. The effective dose conversion factor was taken to be 0.7 Sv. Gy yr^{-1} and an outdoor occupancy factor of 0.2 with an annual occupancy time of approximately 8760 hr yr^{-1}.

2.7 Annual effective dose equivalent (AEDE)

This was estimated using equation 8. as expressed in UNSCEAR (2000).

AEDE (mSv yr^{-1}) = D (nGy hr^{-1}) x 8760 (hr yr^{-1}) x 0.2 x 0.7 (Sv Gy^{-1}) x 10^{-6} (8)

2.8 Excess lifetime cancer risk (ELCR)

This was calculated based on the values of the annual outdoor effective dose equivalent as in Table 42 using equation 9. (UNSCEAR, 2000):

ELCR = AEDE x LE x RF (9)

Where LE is life expectancy taken to be 70 years and RF is the fatal risk factor per sievert which is 0.05 (ICRP, 2007). According to UNSCEAR (2000), activity concentrations of radionuclides and their effects on bone marrow and the bone surface cells are considered organs of interest.

2.9 Annual Gonadal Equivalent Dose (AGED)

The radiological estimation parameter for the people using the soil of the study area as a building material was calculated using equation 10. (Xinwei, 2006):

AGED (mSv yr^{-1}) = 3.09 C_{Ra} + 4.18 C_{Th} + 0.314 C_k (10)

Where C_{Ra}, C_{Th} and C_k were the activity concentrations in Bq kg^{-1} of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.10 Representative Gamma Index (Iyr)

Representative Gamma Index was used to estimate the γ-radiation hazard associated with the natural radionuclides in specific investigated samples. OECD (1979) expressed representative gamma index as:

$$I_{yr} = \frac{C_k}{1500} + \frac{C_{Th}}{100} + \frac{C_{Ra}}{150} \quad (11)$$

This gamma index was also used to correlate the annual dose rate due to the excess external gamma radiation caused by superficial materials. It was a screening tool for identifying materials that might become of health concern when used for construction (Tufail *et al*. 2007). Values of I yr ≤ 1 correspond to annual effective doses of less than or equal to 1 mSv, while values of I yr ≤ 0.5 correspond to annual effective doses less or equal to 0.3 mSv (Turhan and Gündüz, 2008).\

3.0 Results and Discussion

The obtained concentrations of natural radionuclides in the crops from the farms were shown in Table 1, the highest for ^{40}K, ^{238}U and ^{232}Th were 856.13 ± 32.25Bqkg^{-1} from maize (EMaizS2), 35.27 ± 5.91Bqkg^{-1} from maize (EMaizS2) and 13.39 ± 2.75Bqkg$^{-1.}$ from potato (EPotaS1) respectively.

Table 1. Radioactivity concentrations of natural radionuclides in crop samples

Crop name	Sample code	Activity concentrations of radionuclides (Bqkg^{-1})		
		^{40}K	^{238}U	^{232}Th
Cassava	ECasS1	259.74 ± 12.35	8.53 ± 0.53	6.38 ± 0.91
Cassava	ECasS2	286.25 ± 11.28	13.67 ±1.04	7.84 ± 0.54
Cassava	ECasS3	174.46 ± 6.81	9.68 ± 1.32	12.16 ± 2.31
Cassava	ECasS4	253.08 ± 14.37	20.24 ± 2.62	6.84 ± 0.72

Wateryam	EWatyS1	705.93 ± 26.87	14.94 ± 3.25	5.28 ± 0.62
Wateryam	EWatyS2	384.57 ± 10.42	10.69 ± 1.37	4.83 ± 0.38
Wateryam	EWatyS3	657.18 ± 25.03	17.48 ± 3.62	8.45 ± 0.45
Wateryam	EWatyS4	554.09 ± 18.32	11.67 ± 2.04	6.91 ± 0.27
Cocoyam	ECocoyS1	698.72 ± 23.15	29.86 ± 4.03	7.97 ±0.95
Cocoyam	ECocoyS2	412.64 ± 16.39	19.37 ± 2.58	6.06 ± 0.21
Cocoyam	ECocoyS3	685.23 ± 21.06	23.14 ± 1.92	7.58 ± 0.75
Cocoyam	ECocoyS4	457.31 ± 12.25	13.47 ± 3.02	5.11 ± 0.63
Maize	EMaizS1	621.73 ± 18.47	32.39 ± 4.03	8.52 ± 1.17
Maize	EMaizS2	856.13 ± 32.25	35.27 ± 5.91	10.38 ± 0.84
Maize	EMaizS3	771.86 ± 34.79	25.86 ± 4.32	8.47 ± 1.25
Maize	EMaizS4	437.92 ± 8.64	19.26 ± 4.83	6.02 ± 0.67
Potato	EPotaS1	523.75 ± 13.17	15.75 ± 4.47	13.39 ± 2.75
Potato	EPotaS2	198.46 ± 6.24	10.89 ±3.08	4.94 ± 0.32
Potato	EPotaS3	373.67 ± 4.46	17.91 ± 5.29	9.41 ± 0.87
Potato	EPotaS4	410.89 ± 12.51	15.48 ± 3.63	12.05 ± 3.03

Table 2. The determined annual committed effective dose to consumers of crops

Crop name	Sample code	^{40}K ACED (mSvyr^{-1})	^{238}U ACED (mSvyr^{-1})	^{232}Th ACED (mSvyr^{-1})	^{40}K ELCR x 10^{-6}	^{238}U ELCR x 10^{-6}	^{232}Th ELCR x 10^{-6}
Cassava	ECasS1	0.4971	1.8273	0.4454	1.7398	6.3956	1.5590
Cassava	ECasS2	0.5396	2.4292	0.7027	1.8884	8.5023	2.4593
Cassava	ECasS3	0.4790	1.4940	0.5474	1.6765	5.2291	1.9160
Cassava	ECasS4	0.3537	2.0630	0.9403	1.2379	7.2205	3.2909
Wateryam	EWatyS1	0.5733	0.9517	0.2259	2.0067	3.3308	0.7906
Wateryam	EWatyS2	0.6386	0.8212	0.1882	2.2351	2.8740	0.6586
Wateryam	EWatyS3	0.5216	0.5310	0.1926	1.8254	1.8584	0.6742
Wateryam	EWatyS4	0.4430	0.3688	0.0995	1.5507	1.2906	0.3482
Cocoyam	ECocoyS1	0.8759	2.2074	0.2585	3.0658	7.7261	0.9048
Cocoyam	ECocoyS2	0.8311	2.0588	0.3498	2.9089	7.2057	1.2241
Cocoyam	ECocoyS3	0.9157	2.7532	0.4330	3.2048	9.6362	1.5154
Cocoyam	ECocoyS4	0.6836	3.1697	0.2399	2.3926	11.0939	0.8397
Maize	EMaizS1	0.6703	2.6561	0.4659	2.3460	9.2962	1.6307
Maize	EMaizS2	0.8156	1.5849	0.3312	2.8545	5.5470	1.1591
Maize	EMaizS3	0.8586	1.2748	0.2501	3.0049	4.4618	0.8752
Maize	EMaizS4	0.9940	1.9574	0.5128	3.4788	6.8509	1.7948
Potato	EPotaS1	0.4844	1.7297	0.2829	1.6955	6.0541	0.9868
Potato	EPotaS2	0.2377	1.5777	0.4145	0.8318	5.5218	1.4507
Potato	EPotaS3	0.6515	2.3074	0.2255	2.2802	8.0758	0.7891
Potato	EPotaS4	0.3514	1.4172	0.5813	1.2298	4.9600	2.0347
	MEAN	**0.6208**	**1.7590**	**0.3844**	**2.1727**	**6.1565**	**1.3451**

No artificial radionuclide was detected in all the samples. The highest ACED to the consumers for ^{40}K was obtained to be 0.9940mSvyr^{-1} with a mean value of 0.6208mSvyr^{-1} as shown in table 2. Also, the highest ACED to the consumers for ^{238}U was obtained to be 3.1697mSvyr^{-1} with a mean value of 1.7590 mSvyr^{-1} and the highest for ^{232}Th was 0.9403 mSvyr^{-1} with a mean value of 0.3844 mSvyr^{-1}. The

average for all the radionuclides was calculated to be 0.9214 mSvyr^{-1}. All the values obtained were below the world average recommended limit of 1.0 mSvyr^{-1} (ICRP, 2007) except for ^{238}U, which may be due to the high deposit of uranium in the soil of the study area, according to Adewole and Ewumi (2011) report.

The activity concentrations of ^{40}K from the soil samples ranged from 206.07 ± 4.92 Bqkg^{-1} to 974.28 ± 41.26 Bqkg^{-1}, ^{238}U ranged from 9.17 ± 1.64 Bqkg^{-1} to 39.85 ± 7.24 Bqkg^{-1} and ^{232}Th ranged from 5.08 ± 2.01 Bqkg^{-1} to 14.29 ± 3.85 Bqkg^{-1} as shown in table 3. ^{40}K had the highest activity concentration while ^{232}Th recorded the lowest value. The activity concentrations were within the range of values for a normal background area (Akinloye and Olomo, 1995). Radium equivalent activity (Ra_{eq}) as shown in Table 4, ranged from 36.86 Bqkg^{-1} to 132.2 Bqkg^{-1} with a mean value of 74.76 Bqkg^{-1}, which was lower than the mean value of 89.41 Bqkg^{-1}obtained by Najam and Younis (2015) for Iraq, both were below the world limit of 370 Bqkg^{-1} (OECD, 1979; Beretka and Mathew, 1985). Furthermore, the study made by Akinloye *et al*. (2012) on the surface soil of Ore metropolis, Ondo State, Nigeria gave a similar result for radium equivalent activity ranging from 33.39 Bqkg^{-1} to 85.07 Bqkg^{-1}; though lower than the results obtained in this work. Moreover, the external hazard index (H_{ex}) ranged from 0.0996 Bqkg^{-1} to 0.3573 Bqkg^{-1} with a mean of 0.2021 Bqkg^{-1} as shown in Table 4. The values were within the limit of the safety value of 1.0 Bqkg^{-1} recommended by the European Commission (1999), ICRP (2007) and UNSCEAR (2000).

Table 3. Radioactivity concentrations of natural radionuclides in soil samples

Sample code	Activity concentrations of radionuclides (Bqkg^{-1})		
	^{40}K	^{238}U	^{232}Th
ECasSS1	344.65 ± 10.25	9.17 ± 1.64	8.59 ± 2.26
ECasSS2	295.14 ± 7.06	14.82 ± 3.05	9.31 ± 2.14
ECasSS3	206.07 ± 4.92	11.55 ± 2.64	13.45 ± 4.36
ECasSS4	274.38 ± 12.17	24.15 ± 7.36	8.09 ± 2.34
EWatySS1	738.42 ± 30.87	15.47 ± 4.09	6.35 ± 1.72
EWatySS2	425.39 ± 11.57	10.94 ± 1.85	5.08 ± 2.01
EWatySS3	697.81 ± 27.09	18.27 ± 4.92	9.25 ± 2.66
EWatySS4	588.24 ± 17.48	13.05 ± 3.16	8.36 ± 1.57
ECocoySS1	713.22 ± 25.41	31.27 ± 6.94	8.64 ± 1.65
ECocoySS2	482.19 ± 18.07	20.86 ± 4.15	7.35 ± 2.04
ECocoySS3	722.36 ± 24.39	24.03 ± 3.27	9.14 ± 2.86
ECocoySS4	503.54 ± 14.87	15.72 ± 5.04	6.52 ± 1.37
EMaizSS1	682.64 ± 19.09	38.49 ± 6.17	9.35 ± 3.47
EMaizSS2	974.28 ± 41.26	39.85 ± 7.24	12.18 ± 2.39
EMaizSS3	827.65 ± 34.47	27.19 ± 6.37	9.67 ± 3.85
EMaizSS4	475.12 ± 9.13	21.58 ± 5.08	8.24 ± 1.57
EPotaSS1	587.36 ± 12.36	17.25 ± 5.09	14.29 ± 3.85
EPotaSS2	212.78 ± 5.03	12.38 ± 3.46	5.68 ± 1.47
EPotaSS3	516.39 ± 7.95	19.67 ± 8.33	12.34 ± 3.09
EPotaSS4	487.25 ± 11.65	18.02 ± 5.79	13.06 ± 4.17

Table 4. Determined radiological parameters to individuals in farmlands around limestone excavation areas in Ewekoro

SAMPLE	Ra_{eq}	H_{ex}	D	I_{yr}	AGED	$AEDE_{OUT}$	ELCR x 10^{-3}
CODE	(Bq kg^{-1})	(Bq kg^{-1})	(nGy hr^{-1})	(mSv)	(mSv yr^{-1})	(mSv yr^{-1})	(Outdoor)
$ECasSS_1$	47.95	0.1296	23.8	0.3768	172.46	0.0292	0.1022
$ECasSS_2$	50.82	0.1374	24.78	0.3887	177.39	0.0304	0.1064
$ECasSS_3$	46.62	0.1260	22.05	0.3489	156.62	0.0271	0.0947
$ECasSS_4$	56.81	0.1536	27.49	0.4248	194.60	0.0337	0.1180
$EWatySS_1$	81.34	0.2199	41.78	0.6589	306.21	0.0512	0.1793
$EWatySS_2$	50.92	0.1376	25.86	0.4073	188.61	0.0317	0.1110
$EWatySS_3$	85.16	0.2302	43.13	0.6795	314.23	0.0529	0.1851
$EWatySS_4$	70.24	0.1898	35.61	0.5628	259.98	0.0437	0.1528
$ECocoySS_1$	98.48	0.2662	49.41	0.7704	356.69	0.0606	0.2121
$ECocoySS_2$	68.45	0.185	34.18	0.5340	246.59	0.0419	0.1467
$ECocoySS_3$	92.65	0.2504	46.75	0.7332	339.28	0.0573	0.2007
$ECocoySS_4$	63.77	0.1724	32.2	0.5057	233.94	0.0395	0.1382
$EMaizSS_1$	104.36	0.2820	51.9	0.8052	372.37	0.0637	0.2228
$EMaizSS_2$	132.20	0.3573	66.4	1.0370	479.97	0.0814	0.2850
$EMaizSS_3$	104.67	0.2829	52.92	0.8297	384.32	0.0649	0.2271
$EMaizSS_4$	69.90	0.1889	34.76	0.5430	250.31	0.0426	0.1492
$EPotaSS_1$	82.85	0.2239	41.09	0.6495	297.47	0.0504	0.1764
$EPotaSS_2$	36.86	0.0996	18.02	0.2812	128.81	0.0221	0.0774
$EPotaSS_3$	77.02	0.2082	38.07	0.5988	274.51	0.0467	0.1634
$EPotaSS_4$	74.16	0.2004	36.53	0.5756	263.27	0.0448	0.1568
MEAN	**74.76**	**0.2021**	**37.34**	**0.5681**	**269.88**	**0.0458**	**0.1547**

The absorbed dose rate in air; ranged from 18.02 $nGyhr^{-1}$ to 66.4 $nGyhr^{-1}$ with a mean value of 37.34 $nGyhr^{-1}$, which was less than the limit of 55.00 $nGyhr^{-1}$ worldwide mean value as reported by UNSCEAR (2000). In addition, the representative Gamma Index (I_{yr}) ranged from 0.2812 to 1.0370 with a mean value of 0.5681 in which the values were within the recommended world limit of unity (ICRP, 2007; Orgun *et al*., 2007). The Annual Gonnadal Equivalent Dose **(**AGED) ranged from 128.81 $Bqkg^{-1}$ to 479.97 $Bqkg^{-1}$ with a mean value of 269.88 $Bqkg^{-1}$. Furthermore, the annual outdoor effective dose equivalent ranged from 0.0221 $mSvyr^{-1}$ to 0.0814 $mSvyr^{-1}$ with a mean value of 0.0458 $mSvyr^{-1}$, which was below the limit of 1.0 $mSvyr^{-1}$ (UNSCEAR, 2000). The excess lifetime cancer risk for outdoor exposure ranged from 0.0774 x 10^{-3} to 0.2850 x 10^{-3} with a mean value of 0.1547 x 10^{-3}, which was below the world's average of 1.45 x 10^{-3} (Qureshi *et al*., 2014). In a research done by Ramasamy *et al*. (2009) in evaluating ELCR in river sediments of Karnataka and Tamilnadu, India, the average ELCR was obtained to be 0.20 x10^{-3}, which was higher than the average value obtained in this research work.

4.0 Conclusion

The activity concentrations, annual committed effective doses of ^{40}K, ^{238}U and

^{232}Th, along with average annual committed effective dose from some cultivated crops purchased from farmlands around Ewekoro limestone mining area at Ogun State, Southwest of Nigeria to consumers had been determined from the research work. More so, radiological parameters for the safety of farmers, other people on the farms and their environs were determined. Thus, all the values obtained were below the world average recommended limits for ingestion of natural radionuclides from the crops and the safety of farmers on the farms. In conclusion, the results obtained indicate that the consumption of the crops by the people in the study area does not pose any significant radiological health risk to them and the farmers are radiologically safe.

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Declarations

The authors declare that they have no conflict of interest.

Data availability

All data used in this study will be readily available to the public.

Consent for publication

Not Applicable.

Availability of data and materials

The publisher has the right to make the data public.

Competing interests

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Authors' contribution

SO conceived the idea. SO and EKA collected the samples from the field and processed them. SO carried out the computational calculations and wrote the initial draft of the manuscript. All authors revised the manuscript and made appropriate input.