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Assessment of Radionuclides Contents in Soil and Food Samples Due to Civil War in Enugu State, South-Eastern, Nigeria and Its Radiological Hazards

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ABSTRACT
Human activities may influence the distribution of naturally occurring radioactive materials in the environment. This therefore, cause for concern radiological, as human are exposed to these radioactive materials without their consent. This study hereby evaluate the radionuclide contents from natural and artificially occurring radionuclides in soil samples and farm produce in Enugu. Gamma-ray spectroscopy was used to determine the radioactivity concentration level of the environmental radionuclides such as ^{238}U, ^{232}Th, and ^{40}K and manmade radionuclides in soil, cassava, and bitter leaf samples within studied locations in Enugu State, Nigeria. The mean activity concentration of the radionuclides detected in the samples were 1136.74±27.07, 1118.53±4.85, 196.104±0.02 Bqkg^{-1} for ^{40}K, 41.66±0.04, 22.99±0.38, Bqkg^{-1} for ^{238}U and 36.44±0.04, 15.89±0.07, 7.69±0.02 Bqkg^{-1}for ^{232}Th. ^{137}Cs ranged from 3.07 ± 0.01 – 7.81 ± 0.03 Bqkg^{-1}. The radioactivity levels and estimated radiological indices were higher than the recommended limits. The values confirmed the reports of different fora on the radiological hazards due to exposure to high radiation in the region assayed.

Keywords:
Civil war,
Enugu State,
Food,
Nigeria,
Radionuclides,
Soil.

INTRODUCTION

Radiation has always been an integral part of the human environment, and radiation exposure is a continuing and inescapable phenomenon on Earth. The environment occupied by living things is normally radioactive, and individuals are frequently exposed to radiation from the inestimable beams, characteristic radionuclides in water, air, soil, and man-made radioactivity from aftermaths of post-war activities, clinical applications e.t.c (Ademola *et al.*, 2014). Radionuclides and their decay products from ^{238}U and ^{232}Th series together with ^{40}K are terrestrial primordial radionuclides that originated from the earth's crust and are the sources of natural radioactivity in the environment (Kessaratikoon and Awaekechi, 2008).

According to Kabore et al. (2017), Naturally Occurring Radioactive Materials (NORMs) are ubiquitously distributed in all living and non-living components of the biosphere. Tettey-Larbi *et al.* (2013) stated that NORMs are found in every constituent of the environment such as air, water, soil, food, and in humans. However, a variety of human activities like civil war, mining, and milling of natural resources may result in Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) in the products and by-products of those activities (UNSCEAR, 2000). Artificial radiation results from radioactive materials concentrated by human activities such as medical practices, nuclear reactors, post-war activities, and so on. However, both natural and artificial radiations constitute damage to biological matter.

The presence of radioactive materials and radiation generators is harmful to humans and the environment. However, exposure to radioactive material is very detrimental to the biological system, and as such the interaction alters the genetic makeup of the biological system. Radionuclides detected in plants are originally contained in soil from where they get translocated via the root system to different plants' parts or transported either by direct fallout of radionuclides and re-suspension of contaminated soils followed by deposition on plant leaves or soils within the vicinity of the plants (Noordijik *et al.*, 1992). The study therefore aimed to determine the activity concentration level in soil and food samples collected across Enugu State, South Eastern Nigeria. This study was necessitated because of several media reports on the incidences of cancer and other health challenges in some parts of the study area to which radiation may be one of the factors causing the health issues. This study will go a long way in providing baseline radiometric information which could help in future epidemiological investigation.

MATERIALS AND METHODS

Study Area

Enugu State is one of the states in the Southeastern part of Nigeria where the civil war was waged half a century ago. As a result, these areas may have elevated levels of radioactivity, and associated health risks. The knowledge of radionuclides and radiation levels in the environment is therefore important for assessing the effects of radiation exposure due to terrestrial and extra-terrestrial sources.

Figure 1: The map of the study area

Sampling

Soil samples were collected across different communities, by clearing the surface vegetation at each location after which soil auger was used to collect the samples at depths of 10 cm. This was in a bid to determine the presence of ^{137}Cs that may be present in the soil (Akinloye *et al.,* 2012). Cassava (*Manihot esculenta*) samples were collected during the harvest period, directly from selected farmlands across the study area to ensure they were site-specific samples. The Bitter-leaf (*Vernonia amygdalina*) samples were handpicked across communities in the civil war zone. A total of seventy-five (75) samples were collected for analysis; soil (25), cassava (*Manihot esculenta*) (25), and bitter leaf (*Vernonia amygdalina*) (25), respectively. At the point of collection, samples were carefully placed in separate polythene bags, labeled, and transferred to the laboratory for further processing. The samples were air-dried, to constant weight, pulverized, and sieved to ensure uniform particle size after which they were sealed tight in containers weighing 200 g each and were kept for a minimum of 28 days for secular equilibrium to take place.

Radioactivity Measurements

After the secular equilibrium was attained, the samples were counted using a well-shielded and -calibrated sodium iodide-based gamma spectrometer detector at the Radiation and Health Physics laboratory, Ladoke Akintola University of Technology, Nigeria. Data acquisition and analysis of gamma-ray spectra were achieved using Theremino software. The activity concentration A ($Bqkg^{-1}$) of each identified radionuclide in the samples was calculated using Equation 1:

$$A\ (Bqkg^{-1}) = \frac{C_{net}}{P\gamma \times \varepsilon \times m \times t} \quad (1)$$

where C_{net} is the net peak area, P_γ is the absolute gamma-ray emission probability, ε is the obtained full energy peak efficiency for each identified radionuclide, m is sample mass and t is the counting time.

Calculation of radiological hazard indices in the samples

External absorbed dose rate (D_R)

The external Gamma Dose Rate (D) for the sediment samples was determined using Equation (2) from the Activity Concentrations at about 1.0 m above ground (Uosif et al., 2014)

$$D\ (nGyh^{-1}) = 0.462\ A_u + (0.621\ A_{Th}) + (0.0417\ A_k) \quad (2)$$

Where, A_U, A_{Th} and A_K are the activity concentration of ^{238}U, ^{232}Th and ^{40}K respectively.

Annual Effective Dose Equivalent (AEDE)

The effective dose in millisieverts per year was calculated using Equation (3)

$$AEDE\ (mSvyr^{-1}) = D\ (nGyh^{-1}) \times 8760 (hy^{-1}) \times 0.2 \times 0.7 (SvGy^{-1}) \times 10^{-6} \quad (3)$$

Where, 0.7 $SvGy^{-1}$ is the conversion coefficient which transforms the absorbed dose rate in the air to an effective dose, and 10^{-6} is the factor converting nano into milli.

Annual effective dose due to ingestion of food cultivated in the area

The Annual effective dose due to ingestion (D_{ing}) was determined with Equation 4 (UNSCEAR 2000);

$$D\ (Svyr\text{-}1) = A \times CR \times DF \quad (4)$$

Where, A ($Bqkg^{-1}$) is the activity concentration of radionuclide, CR is the consumption rate per year ($kgyr^{-1}$), and DF ($SvBq^{-1}$) is the standard dose conversion factor which is equal to 0.28 μSv Bq^{-1} for ^{238}U, 0.23 μSvBq-^{1} for ^{232}Th and 0.0062 μSvBq^{-1} for ^{40}K for the persons who live over 17 years. The food consumption rates for maize, vegetables, fruits, and yams obtained from Food Balance Sheet Nigeria, 2014 were 31.10, 46.70, 59.50, and 100.40 $kgyr^{-1}$ respectively.

Excess lifetime cancer risk (ELCR)

The excess lifetime cancer risk (ELCR) was calculated using Equation 5:

$$ELCR = AEDE \times DL \times R \quad (5)$$

Where, AEDE, is the annual effective dose due to ingestion, DL is the duration of life (70 years) (WHO, 2018) and risk factor R is 0.05 Sv^{-1} which is fatal cancer risk per sievert.

Radium Equivalent Activity (Ra_{eq})

It is mathematically calculated by Equation (6) to address the levels of ^{238}U, ^{232}Th, and ^{40}K thus taking into account the radiological risks associated with them (Agbalagba and Onoja, 2011);

$$Raeq = Au + (1.43\ A_{TH}) + (0.077\ A_k) \quad (6)$$

Where, A_U, A_{Th}, and A_K are the activity concentration of ^{238}U, ^{232}Th, and ^{40}K respectively.

Radiation Hazard Indices

These indices are used to estimate the level of gamma radiation hazard associated with the natural radionuclide in samples. The external radiation hazard (H_{ext}) and the internal radiation hazard (H_{int}) was calculated using Equation 7a and b respectively:

$$H_{ext} = (A_U/370) + (A_{Th}/259) + (A_K/4810) \quad (7a)$$

$$H_{int} = (A_U/185) + (A_{Th}/259) + (A_K/4810) \quad (7b)$$

Where, A_U, A_{Th} and A_K are the radioactivity concentration in $Bqkg^{-1}$ of ^{238}U, ^{232}Th, and ^{40}K respectively. H_{in} should be less than unity for the radiation hazard to be negligible. Internal exposure to radon is very hazardous which can lead to respiratory diseases like asthma (Tufail *et al.*, 2007; Orosun *et al.*, 2018).

RESULTS AND DISCUSSION

The activity concentrations of the radionuclides in Tables 1, 2, and 3 showed that the values of soil samples for ^{40}K, fall in the range of 269.53 ± 2.07 to 2559.87 ± 19.7 $Bqkg^{-1}$, having a mean value of 1136.74±27.07 $Bqkg^{-1}$, The concentrations of ^{238}U ranged from 8.96 ± 0.44 to 85.02 ± 19.38 $Bqkg^{-1}$ while the mean value was recorded to be 41.66±0.04 $Bqkg^{-1}$. The activity concentrations of ^{232}Th ranged from 8.25 ± 0.04 to 82.26 ± 1.56 $Bqkg^{-1}$ having a mean value of 36.44±0.04 $Bqkg^{-1}$, with ^{137}Cs ranging from 3.21 ± 0.01 – 6.48 ± 0.03 $Bqkg^{-1}$. The activity concentrations of cassava samples for ^{40}K, were found to range from 239.58 ± 4.85 to 2275.44 ± 14.96 $Bqkg^{-1}$ having a mean value of 1118.53±4.85 $Bqkg^{-1}$. The concentrations of ^{238}U ranged from 5.26 ± 0.38 to 52.4 ± 4.69 $Bqkg^{-1}$ recording a mean value of 22.99±0.38 $Bqkg^{-1}$. The activity concentrations of ^{232}Th were observed to lie in the range of 4.79 ± 0.07 to 36.51 ± 1.44 $Bqkg^{-1}$ having a mean value of 15.89±0.07 $Bqkg^{-1}$ with ^{137}Cs ranging from 3.07 ± 0.01 to 7.66 ± 0.03 $Bqkg^{-1}$. The activity concentrations in bitter leaf samples values for ^{40}K in Enugu were between 44.33 ± 0.02 to 759.51 ± 6.89 $Bqkg^{-1}$ with a mean value of 196.10±0.02 $Bqkg^{-1}$. The activity concentrations of ^{238}U ranged from 10.17 ± 0.06 to 19.99 ± 1.18 $Bqkg^{-1}$ while the mean value was recorded to be 13.78±0.06 $Bqkg^{-1}$. The concentrations of ^{232}Th ranged from 5.01 ± 0.02 – 13.09 ± 0.07 $Bqkg^{-1}$ with a mean value of 7.69±0.02 $Bqkg^{-1}$ and ^{137}Cs ranged from 3.85 ± 0.01 – 7.81 ± 0.03 $Bqkg^{-1}$.^{40}K displayed the highest activity. This is expected because ^{40}K is a naturally occurring radionuclide that abounds in the earth's crust. The mean activity concentration of k-40 and U-238 obtained for the soil samples of the study area is higher than the recommended value (UNSCEAR, 2000) and in agreement with the global trend on the distribution of natural radionuclides in the soil as reported in literature. The detection of Cs-137 in the study area also conformed to the findings of Akinloye et al. (2012). The concentration of K-40 recorded in this study is very high while the U-238 and Th-232 low when compared to others in literature (Table 2b).This high value recorded for the K-40 can be attributed to the use of NPK fertilizers on the farmland from which the cassava samples were collected.

Table 1: Activity Concentrations of Radionuclides in Soil Samples in Enugu

Sample Location	K- 40 ($Bqkg^{-1}$)	U-238 ($Bqkg^{-1}$)	Th-232 ($Bqkg^{-1}$)	Cs-137 ($Bqkg^{-1}$)
ENU1	1078.54±10.57	80.25±14.96	61.08±1.39	<DL
ENU2	377.43±4.12	57.73±3.3	23.05±0.855	<DL
ENU3	802.01±9.35	23.99±3.44	38.05±0.87	<DL
ENU4	689.81±2.76	76.82±15.38	34.8±1.53	<DL
ENU5	851.17±9.12	16.82±7.92	61.08±2.23	<DL
ENU6	269.53±2.07	12.28±5.54	23.05±1.53	3.21± 0.01
ENU7	284.09±2.29	78.58±17.12	8.25±0.04	<DL
ENU8	1392.75±11.57	11.79±4.16	17.47±1.14	<DL
ENU9	2193.37±12.82	24.96±13.72	22.12±1.03	<DL
ENU10	1340.37±11.05	31.6±12.74	27.89±0.66	<DL
ENU11	2402.71±17.45	8.96±0.04	12.38±1.98	<DL
ENU12	701.62±6.24	49.87±11.54	11.62±2.16	4.44± 0.02
ENU13	477.45±3.84	13.73±0.98	34.85±1.09	<DL
ENU14	595.77±7.67	17.41±2.14	38.05±0.42	<DL
ENU15	2344.54±14.6	48.19±10.84	34.87±0.93	<DL
ENU16	2559.87±19.7	59.53±14.88	61.08±1.38	<DL
ENU17	2516.02±16.55	44.01±10.76	23.05±1.32	6.48±0.03
ENU18	718.35±5.17	19.79±3.7	39.85±0.79	<DL
ENU19	632.74±3.97	31.97±7.7	17.69±1.99	<DL
ENU20	424.10±5.85	50.24±14.34	16.65±1.05	<DL
ENU21	1685.47±11.17	48.22±13.5	46.8±0.82	<DL
ENU22	348.16±3.05	49.52±16.72	79.6±1.90	<DL
ENU23	353.94±3.92	85.02±19.38	49.82±2.64	<DL
ENU24	1445.96±11.52	71.08±15.62	82.26±1.56	<DL
ENU25	1376.96±10.75	18.52±3.12	27.93±1.68	<DL
Range	269.53-2559.87	8.96-85.02	8.25-82.26	3.21-6.48
Mean	1136.74±27.07	41.66±0.04	36.44±0.04	4.76±0.01
World Average	420	33	45	53.65

Table 2a: Activity Concentrations of Radionuclides in Cassava Samples in Enugu

Sample Location	K- 40 ($Bqkg^{-1}$)	U-238 ($Bqkg^{-1}$)	Th-232 ($Bqkg^{-1}$)	Cs-137 ($Bqkg^{-1}$)
ENU1	2084.04±14.98	25.97±2.48	20.97±0.93	<DL
ENU2	2075.44±14.96	33.88±3.65	26.71±0.57	<DL
ENU3	756.6±8.63	14.03±1.72	11.95±0.58	3.61±0.01
ENU4	239.58±4.85	52.4±4.69	5.31±1.02	<DL
ENU5	252.52±5.34	47.12±3.96	4.98±1.49	3.07±0.01
ENU6	1238.01±11.04	17.21±2.77	14.04±1.02	<DL
ENU7	1949.66±15.65	28.62±3.56	23.88±1.36	<DL
ENU8	1191.44±10.83	17.17±2.08	14.95±0.76	7.66±0.03
ENU9	2135.74±14.49	30.38±2.86	24.678±0.69	<DL
ENU10	623.66±7.83	9.58±1.37	8.38±0.44	<DL
ENU11	424.4±6.33	8.18±0.52	7.03±1.32	6.29±0.03
ENU12	529.58±7.22	31.04±3.77	36.5±1.44	<DL
ENU13	2084.04±14.98	25.17±1.99	21.97±0.73	<DL
ENU14	2275.44±14.96	31.88±1.07	27.21±0.28	<DL
ENU15	458.76±6.72	8.8±1.92	7.72±0.62	<DL
ENU16	971.3±3.07	12.9±2.44	22.32±0.92	<DL
ENU17	301.26±5.84	5.56±0.38	6.23±0.88	<DL
ENU18	1435.32±11.88	13.88±1.85	11.61±0.53	4.43±0.02
ENU19	1145.86±10.62	12.78±3.85	10.99±1.33	<DL
ENU20	243.96±6.07	30.01±2.17	4.79±0.07	<DL
ENU21	1256.66±14.79	16.47±1.75	16.25±0.55	<DL

ENU22	266.56±6.34	5.26±0.36	5.97±1.27	4.27±0.02
ENU23	350.24±7.27	31.9±2.69	8.6±1.76	<DL
ENU24	958.7±12.02	17.24±2.81	14.34±1.04	<DL
ENU25	2236.46±18.37	32.98±2.06	27.93±1.12	<DL
Range	239.58-2275.44	5.26-52.4	4.79-36.51	3.07-7.66
Mean	1118.53±4.85	22.99±0.38	15.89±0.07	5.00±0.01

Table 2b: Comparison of radionuclides concentrations ($Bqkg^{-1}$) of ^{40}K, ^{226}Ra, ^{232}Th in Cassava

Study	^{40}K	^{226}Ra	^{232}Th	Location
Jibiri and Abiodun (2012)	479.87 ± 42.42	2.97 ± 1.02	0.67 ± 0.08	Ogun State, Nigeria
Jwanbot et al (2012)	17.97 ± 1.24	2.25 ± 0.40	2.62 ± 0.16	Jos, Nigeria
Doyi et al (2018)	27.2 ± 3.61	0.64 ± 0.21	0.57 ± 0.18	Ghana
Lopes et al (2018)	91.78 ± 5.02		1.09 ± 0.17	Brazil
Ononugbo et al (2019)	746.08 ± 0.48	24.83 ± 10.87	859.41 ± 2.47	Delta state, Nigeria
Avwiri et al (2021)	67.27 ± 4.55	77.51 ± 4.99	28.86 ± 5.79	Niger-Delta, Nigeria
Rilwan et al (2022)	223.79 ± 33.85	13.07 ± 2.88	19.11 ± 2.09	Jos, Nigeria
Amakom et al (2023)	242.19 ± 5.07	31.20 ± 4.73	145.19 ± 2.78	Enugu, Nigeria
Present Study	1118.53±4.85	22.99±0.38	15.89±0.07	Enugu, Nigeria

Table 3: Activity Concentrations of Radionuclides in Bitter leaf Samples in Enugu

Sample Location	K-40 ($Bqkg^{-1}$)	U-238 ($Bqkg^{-1}$)	Th-232 ($Bqkg^{-1}$)	Cs-137 ($Bqkg^{-1}$)
ENU1	101.66±0.12	10.17±0.06	5.82±0.03	3.85±0.01
ENU2	67.22±0.05	19.99±1.18	6.1±0.03	<DL
ENU3	55.19±0.04	18.37±1.12	5.61±0.05	<DL
ENU4	759.51±6.89	17.73±1.11	5.06±0.03	<DL
ENU5	394.402±3.67	17.83±1.11	13.09±0.07	<DL
ENU6	154.424±0.23	11.26±0.07	10.99±0.05	<DL
ENU7	179.353±0.36	10.35±0.06	8.13±0.06	4.11±0.01
ENU8	225.04±257	11.07±0.07	10.09±0.05	<DL
ENU9	141.911±0.21	11.08±0.07	8.61±0.04	<DL
ENU10	103.79±0.12	10.81±0.06	9.17±0.06	<DL
ENU11	75.07±0.08	11.71±0.07	8.2±0.04	<DL
ENU12	206.61±2.32	15.67±0.08	7.07±0.03	6.83±0.02
ENU13	44.32±0.02	15.04±0.08	6.65±0.03	<DL
ENU14	82.838±0.09	11.35±0.07	5.01±0.02	<DL
ENU15	259.76±2.67	15.94±0.08	8.33±0.04	<DL
ENU16	210.296±2.59	13.24±0.07	5.81±0.02	<DL
ENU17	134.25±0.19	13.78±0.07	6.58±0.03	<DL
ENU18	67.12±0.05	11.44±0.07	6.1±0.03	6.99±0.02
ENU19	186.05±0.76	13.32±0.07	6.45±0.03	<DL
ENU20	150.93±0.21	14.95±0.04	7.06±0.03	<DL
ENU21	161.69±0.24	15.67±0.09	7.13±0.03	<DL
ENU22	178.48±0.36	13.2±0.08	6.L1±0.03	7.81±0.03
ENU23	196.43±0.86	12.93±0.06	5.38±0.02	<DL
ENU24	177.80±0.36	12.66±0.04	10.06±0.05	<DL
ENU25	176.801±0.36	12.38±0.04	10.97±0.03	<DL
Range	44.33-759.51	10.17-19.99	5.01-13.09	3.85-7.81
Mean	196.104±0.02	13.78±0.06	7.69±0.02	5.89±0.01

Radiological Hazard Indices for soil samples

Table 4 presents the radiological parameters for the soil samples. The absorbed dose rate was recorded and observed to fall between 31.23 and 172.18 $nGyh^{-1}$ with a mean value of 88.54 $nGyh^{-1}$. The annual effective dose equivalent recorded an interval of 0.038 and 0.211 $mSvy^{-1}$ with a mean value of 0.11 $mSvy^{-1}$. It is the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body and represents the stochastic health risks to the whole body. It takes into account the type of radiation and the nature of each organ or tissue being irradiated, and enables summation of organ doses due to varying levels and types of radiation, both internal and external, to produce an overall calculated effective dose. This combines both internal and external exposures (Orosun, *et al*., 2016). The calculated radium equivalent activities of soil samples ranged between 65.99 to 343.99 $Bqkg^{-1}$ with a mean value of 176.69 $Bqkg^{-1}$. The values of radium equivalent indices for all examined soil samples have a value lower than 370 $Bqkg^{-1}$ recommended by UNSCEAR (2000). Similarly, table 4 shows the external and internal hazard indices which were calculated and estimated to be 0.178 to 0.929 $Bqkg^{-1}$ and 0.211 to 1.09 $Bqkg^{-1}$ with mean values of 0.49 and 0.59 $Bqkg^{-1}$ respectively. The Excess Lifetime cancer risk (ELCR) ranged between 0.133 to 0.738 (x10^{-3}) with mean values of 0.38 (x 10^{-3}) which implies that there is a possibility of persons in the investigated area having cancer over a lifetime exposure to low-level background radiation dose as the values are higher than the world permissible limit of 0.29 x 10^{-3}.

Table 4: Estimated Radiological Parameters for Soil Samples in Enugu

Sample Location	Raeq ($Bqkg^{-1}$)	D ($nGyh^{-1}$)	$AEDE$ ($mSvy^{-1}$)	H_{ex} ($mSvy^{-1}$)	H_{in} ($mSvy^{-1}$)	ELCR (10^{-3})
ENU1	250.645	119.983	0.147	0.677	0.894	0.514
ENU2	119.756	56.725	0.070	0.323	0.480	0.245
ENU3	140.159	68.158	0.084	0.378	0.443	0.294
ENU4	179.805	85.912	0.105	0.486	0.693	0.368
ENU5	169.708	81.197	0.100	0.458	0.504	0.350
ENU6	65.997	31.227	0.038	0.178	0.211	0.133
ENU7	112.256	53.275	0.065	0.303	0.516	0.228
ENU8	144.017	74.375	0.091	0.389	0.421	0.318
ENU9	225.481	116.732	0.143	0.609	0.676	0.501
ENU10	174.698	87.815	0.108	0.472	0.557	0.378
ENU11	211.677	112.022	0.137	0.572	0.596	0.480
ENU12	120.571	59.539	0.073	0.326	0.460	0.256
ENU13	87.958	42.179	0.052	0.237	0.241	0.182
ENU14	117.699	56.518	0.069	0.318	0.365	0.242
ENU15	278.59	141.688	0.174	0.752	0.883	0.609
ENU16	343.987	172.181	0.211	0.929	1.090	0.738
ENU17	270.707	139.565	0.171	0.731	0.850	0.598
ENU18	132.089	63.845	0.078	0.357	0.410	0.273
ENU19	105.988	52.141	0.064	0.286	0.373	0.224
ENU20	106.705	51.236	0.063	0.288	0.424	0.221
ENU21	244.926	121.625	0.149	0.661	0.792	0.522
ENU22	190.157	86.828	0.106	0.514	0.647	0.371
ENU23	183.517	84.977	0.104	0.496	0.726	0.364
ENU24	300.051	144.219	0.177	0.810	1.002	0.619
ENU25	164.488	83.321	0.102	0.444	0.494	0.357
Range	65.99-343.99	31.23-172.18	0.038-0.211	0.178-0.929	0.211-1.09	0.133-0.738
Mean	179.69 ± 5.27	88.54 ± 2.69	0.11 ± 0.003	0.49 ± 0.014	0.59 ± 0.016	0.38 ± 0.012
World Average	370	59	1.00	1.00	1.00	0.29

Radiological Hazard Indices for food samples

Tables 5 and 6 presents the radiological parameters calculated for Cassava (*Manihot esculenta*) and Bitter leaf (*Vernonia amygdalina*), which are known to be the most common staple foods in the South Eastern part of Nigeria. The values obtained for the annual effective dose equivalent were observed to be higher than the UNSCEAR permissible limit of 1.1 $mSvy^{-1}$, ranging between 2.98 to 24.73 and 0.82 to 10.87 $mSvy^{-1}$ with mean values of 12.03 and 4.02 $mSvy^{-1}$ for cassava and bitter leaf respectively. Also, the calculated value for the excess lifetime cancer risk (ELCR) varied between 1.03×10^{-3} and 5.69×10^{-3} with a mean value of 2.93×10^{-3} and 1.03×10^{-3} and 5.7×10^{-3} with a mean value of 2.86×10^{-3} When compared with the recommended safe limit of 2.9×10^{-3} by UNSCEAR, it could be inferred that the ELCR values may determine the probability of being casino genic and the likes, such as skin cancer and cataracts.

Table 5: Estimated Radiological Parameters for Cassava Samples in Enugu

Sample Location	D ($nGy\ h^{-1}$)	$AEDE$ ($mSv\ yr^{-1}$)	CEDE ($mSv\ yr^{-1}$)	ELCR (10^{-3})
ENU1	115.25	0.147	21.47	3.969
ENU2	130.65	0.07	24.73	1.89
ENU3	46.44	0.084	9.11	2.268
ENU4	16.05	0.105	3.33	2.835
ENU5	16.18	0.1	3.31	2.7
ENU6	69.88	0.038	13.11	1.026
ENU7	111.87	0.065	21.21	1.755
ENU8	68.46	0.091	13.04	2.457
ENU9	121.15	0.143	22.78	3.861
ENU10	36.45	0.108	7.00	2.916
ENU11	26.40	0.137	5.21	3.699
ENU12	26.51	0.073	4.75	1.971
ENU13	115.25	0.052	21.47	1.404
ENU14	130.65	0.069	24.73	1.863
ENU15	28.59	0.174	5.66	4.698
ENU16	43.80	0.211	7.28	5.697
ENU17	19.45	0.171	4.01	4.617
ENU18	75.33	0.078	13.63	2.106
ENU19	62.01	0.064	11.43	1.728
ENU20	14.64	0.063	2.98	1.701
ENU21	71.83	0.149	13.79	4.023
ENU22	17.67	0.106	3.69	2.862
ENU23	18.98	0.104	3.59	2.808
ENU24	58.08	0.177	11.29	4.779
ENU25	128.74	0.102	24.48	2.754
Range	14.64-130.65	0.038-0.211	2.98-24.73	1.026-5.697
Mean	63.54 ± 4.31	0.11 ± 0.003	12.03 ± 8.17	2.93 ± 0.092
World Average	59	1.00	1.1	0.29

Table 6: Estimated Radiological Parameters for Bitter Leaf Samples in Enugu

Sample Location	D ($nGy\ h^{-1}$)	$AEDE$ ($mSvy\ r^{-1}$)	CEDE ($mSv\ yr^{-1}$)	ELCR (10^{-3})
ENU1	19.19	0.14715	4.632	3.97305
ENU2	17.81	0.06957	4.488	1.87839
ENU3	16.28	0.08359	4.231	2.25693
ENU4	56.82	0.10536	10.874	2.84472
ENU5	28.97	0.09958	5.599	2.68866
ENU6	14.45	0.0383	3.429	1.0341
ENU7	24.13	0.06534	5.610	1.76418
ENU8	27.70	0.09121	6.350	2.46267
ENU9	12.26	0.14316	2.812	3.86532
ENU10	10.88	0.1077	2.705	2.9079
ENU11	5.16	0.13738	0.925	3.70926
ENU12	15.99	0.07302	3.055	1.97154
ENU13	8.46	0.05173	1.992	1.39671
ENU14	6.13	0.06931	1.221	1.87137
ENU15	19.22	0.17377	3.659	4.69179
ENU16	14.27	0.21116	2.678	5.70132
ENU17	11.74	0.17116	2.437	4.62132
ENU18	4.57	0.0783	0.819	2.1141
ENU19	24.58	0.06395	5.410	1.72665
ENU20	11.29	0.06284	2.021	1.69668
ENU21	12.11	0.14916	2.133	4.02732

ENU22	24.01	0.10649	6.278	2.87523
ENU23	26.50	0.10422	6.994	2.81394
ENU24	16.76	0.17687	3.871	4.77549
ENU25	22.54	0.10218	5.867	2.75886
Range	4.57-56.82	0.038-0.21	0.82-10.87	1.03-5.70
Mean	18.49 ± 2.27	0.11 ± 0.003	4.02 ± 2.27	2.86 ± 0.09
World Average	55	0.48	1.1	0.29

CONCLUSION

The radionuclide contents of soil and food samples have been analyzed utilizing gamma spectrometry. The results obtained shown high values of ^{40}K making it the dominant radionuclide in the study areas. The results also indicated the presence of ^{137}Cs in two or three villages which could be due to the aged post-war activities in the study area, though with low concentration. The calculated radium equivalent, External hazard index (H_{ex}), and internal hazard index (H_{in}) were found below the international reference limits of 370 Bqkg^{-1} and 1.00 Bqkg^{-1} respectively, thereby showing that the use of soil for building purposes may not pose any radiological hazard risks to the dwellers. The annual effective dose equivalent (AEDE), and excess lifetime cancer risk for the food samples were all calculated and it suffices to say that the food samples may not be radiologically safe for consumption since they are above the world permissible values. It is, therefore recommended that appropriate measures should be taken to protect the populace from adverse health implications. It is also recommended that such study be routinely carried out in the study area.

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