Health Risks Assessment of Natural Radionuclides Distribution in Soil and Edible Plant Samples Within Otukpo LGA in Benue State, Nigeria

[1]Andrew Ichoja, [2]Elijah. E. Onwoke, [3]Onah. Emmanuel. Onah

[1,2,3]Department of Medical Physics,
[1,2,3]Faculty of Science, Federal University of Health Sciences,
[1,2,3]P.M.B 145, Otukpo, Benue State, Nigeria

Abstract - The activity concentration of natural radionuclides and their potential radiological health hazards have been analysed in soil and edible plant samples collected from various sections of the Otukpo Local Government Area of Benue State. The activity concentration of naturally occurring radionuclides (U–238, Th–232 and K–40) in each of the ten randomly selected samples of soil and edible plants was analysed using a High Purity Germanium Detector Gamma ray spectrometer with a model NaI(Ti) situated at the Nigeria Institute for Radiation Protection, University of Ibadan, Nigeria. The mean concentration activity of soil samples for U–238, Th–232 and K–40 was 25.7000 ± 6.215, 45.400 ± 5.564 and 174.100 ± 21.001 Bq/kg while the corresponding average activity concentration of the plant samples was found to be 27.800 ± 4.479, 35.400 ± 556 and 136.600 ± 14.100 Bq/kg respectively in order of K–40 > Th–232 > U–238. Radiological parameters such as radium equivalent (Ra_{eq}), internal health indices (H_{in}) and external health indices (H_{ex}), indoor annual effective dose rate ($AEDR_{in}$) and outdoor annual effective dose rate ($AEDR_{out}$), gamma index (I_{γ}) and alpha index (I_{α}), and excess lifetime cancer risks (ELCR) were determined in the sampled soil and plants to assess their health impacts. The results of the evaluated health indices were found to be reasonably lower than the permissible threshold prescribed by ICRP and may not pose any immediate health threat to the consumers. Annual effective dose (AED_{ing}) and the excess lifetime cancer risks due to ingestion of the plant samples ranged from 0.252 – 0.631 mSv/yr and $0.009 – 0.022 \times 10^{-3}$ respectively, with the Azadurachta Indica having the maximum value. The calculated average values for ADE_{ing} and ELCR for ingestion of the plant samples were found to be 0.002 mSv/yr and 0.001, respectively, which were far below the recommended safe limits of 1.0 mSv/y and 0.29×10^{3} respectively, indicating an insignificant possibility of radiological risks accruing from continuous consumption of plants cultivated on the sample soil. The average value of the natural radionuclide soil to

plant transfer factor follows the order Th–232 < U–238 < K–40. This signifies a conceivable high bio-accumulation of the radionuclides on plants, with the possibility of causing radiological health risks due to long-term consumption of the plants, and therefore should be regularly monitored.

Index-Terms: Natural Radionuclides, Specific Activity Concentration, Annual Effective Dose Rate, Excess Lifetime Cancer Risk, Transfer Factor.

I. INTRODUCTION

The constancy of human exposure to gamma radiation from natural radionuclides and their decay products has become an inescapable part of human existence due to the radioactive nature of our planet. Human exposure to primordial radionuclides series in Uranium-238, Thorium-232, and non-decay Potassium-40 can lead to human internal exposure with its attendant health consequences (Nduka et al., 2022). Environmental background radiation refers to the radioactivity profile associated with natural radionuclides, and it depends on the quantity of radioactive materials in the environment. Background radiation can be high or low in an environment depending on the level of environmental contamination, man-made or natural activities, soil formation, mineral deposits, and geological and geographical conditions of the soil (Ayaakaa et al., 2018). The continuous diffusion of the mineral deposit through leaching and rock weathering into oceans and seas is absorbed by aquatic plants and animals, and bio-accumulation of these radionuclides in edible plants may be toxic and hazardous to the environment and human health. According to Avwiri and Ononugbo (2012), measurement of the radioactivity of environmental samples like soil, plants, water, etc., is critical to assessing the activity concentration of natural radionuclides alongside their equivalent radiological health impacts. They account for more than 75 percent of naturally occurring radioactive materials. The three known types of radiation are primordial, cosmogenic, and anthropogenic. Primordial sources of radiation are predominantly present in the soil and environment, while the cosmogonic source is associated with the interaction of cosmic rays with some elements in the atmosphere, leading to the ejection or release of high-energy particles. Whereas, the anthropogenic source is due to human activities such as mining, oil exploration, and disposal of radioactive elements. Surface soil has proven over time to be a continuous pathway for the migration of natural radionuclides to biological systems with great consequences on the food chain (Egunyinka et al., 2009). The public, therefore, is at risk from the long-term consumption of plants cultivated on soil bedevilled with over-concentration of natural radionuclides(Eke et al., 2022). Other potential entry routes for radionuclides into humans are through ingestion and inhalation of polluted air released into the atmosphere, with a high possibility of causing cancer of the lungs. The spatial spreading of the radionuclides and their subsequent transfer from soil to plants and the terrestrial environment is characterized by the soil types, climatic conditions, competing ions, geological and geochemical processes, physicochemical effects, and agricultural practices due to earth formation. The presence and persistence of natural radionuclides in soils account for the pollution of food crops and edible plants. The long-term consumption of plants cultivated on soils with high-level concentrations of natural

radionuclides can lead to dysfunctional sensitive organs and chronic diseases in human beings (Eke et al., 2022; Jibiri et al., 2007; Popoola et al., 2019). The knowledge of the distribution and measurement of activity concentration together with the associated health effects of natural radionuclides in soils and plants is an important phenomenon in radiation protection dosimetry. One of the primary goals of the United Nations for sustainable food security is for all people to have access to sufficient, nutritionally adequate, and safe food. Consequently, the rising health risks associated with the potential consumption of food crops cultivated on soil with a high content of natural radionuclides and their possible migration from soil to plants has attracted the attention of the research community in recent times. The evaluations of the levels of radionuclides in soil and plant samples and their equivalent health impacts on the dwellers or inhabitants of the study locations were carried out using various analytical techniques. The measurement of environmental radioactivity of surface soil and vegetation samples in Egypt via gamma-ray spectrometric analysis by (Ebaid et al., 2000), showed low values of 214-Bi, 214-Pb, and 238-U. Assessment of natural radioactivity (Ra-226, Th-232, and K-40) and dose levels in soil samples of Homa Bay County, Kenya analyzed by (Otwoma et al., 2012), indicated an elevated level of natural radionuclides in the area. Faanu et al. (2011), investigated the determination of natural radioactivity and radiological health hazards in soil samples and rocks in Ghana. The report revealed that soil, rock, and waste materials used for the construction of the building do not pose any significant health hazards to the inhabitants of the study location. The study (Ilori & Chetty, 2020) on the measurement of natural radioactivity and soil-crops transfer of radionuclides in farm soils of South Africa showed that the activity concentration and soil-crops transfer factor for potassium-40 was higher due to bio-accumulation of the radionuclides on the growth of the crop

Based on scarcely available literature on natural radionuclides analysis and health risks assessment of soil samples and edible plants in Benue South senatorial district, Nigeria, the present research aims to evaluate the activity concentrations of the various primordial radioactive elements in selected soil samples and plants and their corresponding radiological health hazards. The outcome of the current study will help mitigate the environmental and human health impacts of bio-accumulated gamma dose exposure to the general population and the inhabitants of the study communities.

II. MATERIALS AND METHOD

a. Study Area

Benue State is one of the thirty-six (36) states in Nigeria. It is geographically located in the middle belt region with three (3) senatorial districts, namely Benue West, North, and South senatorial areas. The state lies between latitudes 6˚30˚North and 8˚15˚North and Longitudes 7˚30˚East and 10˚00˚North. According to the national population census of 1991 and 2006, Benue state has a land mass of approximately 34,059 km^2 and a population of about 2,780,398 and 4,253,541 (Census 2006 and 2009), respectively. The present research took place in Benue State senatorial district, Nigeria. The chosen local government area for the study is Otukpo LGA, as depicted in Figure 1. Wet and dry seasons are the two main distinct seasonal periods in Benue State. The wet season occurs between April and October, with total annual rainfall in the region of 1120 to 1500 mm, while the dry season lasts from November to March. The type

of climate experienced in Benue state is typical of high temperatures with an annual mean value of 27-38 ℃. The local dwellers of the study sites are predominantly farmers, and there could be a significant migration of radionuclides from soil to plants that may require regular monitoring.

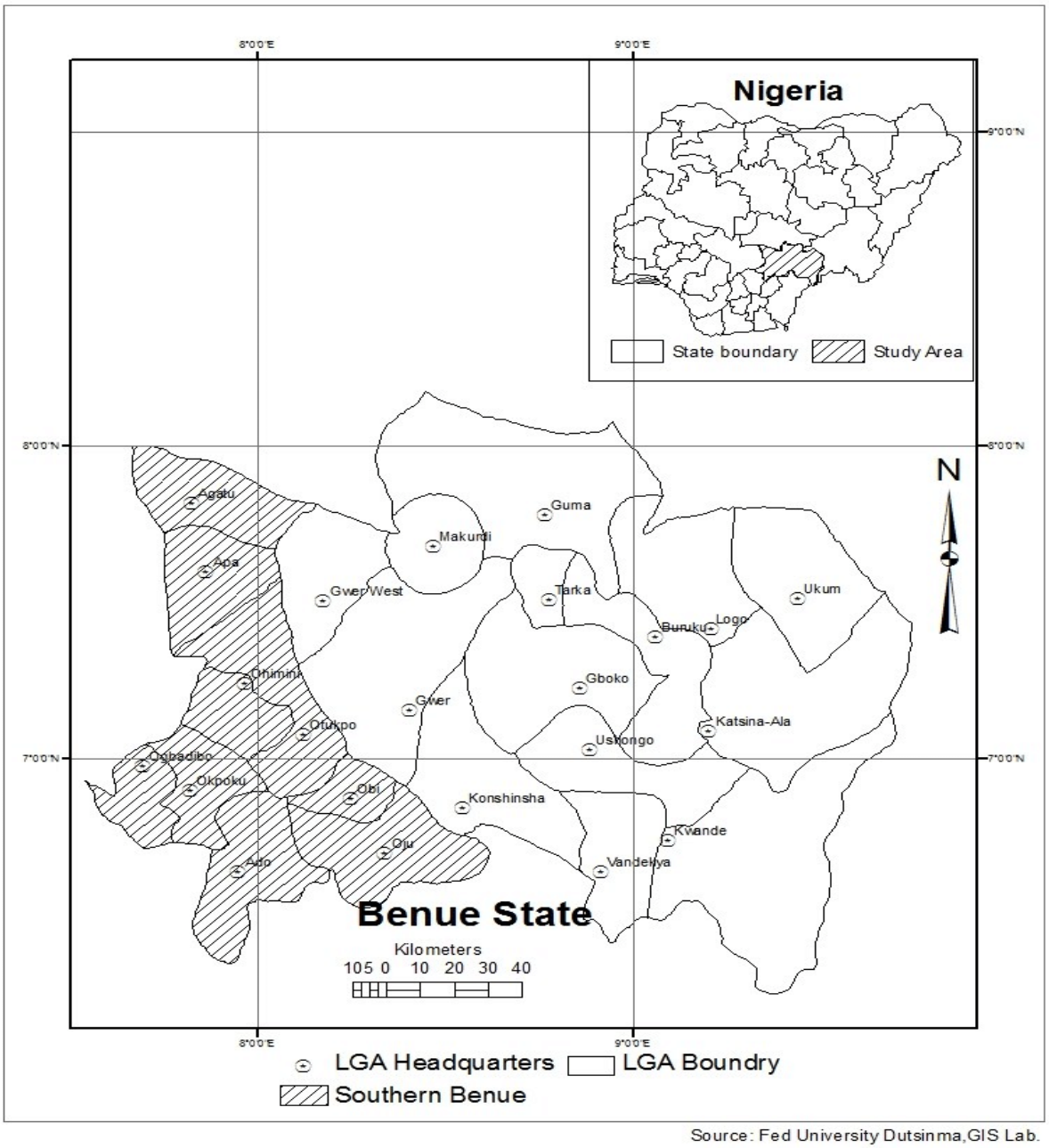


Figure 1. Geographical map of Benue South Senatorial District

b. Sample Collection and Preparation

A total of ten (10) samples each of soil and edible plant samples were collected randomly from different locations of the Otukpo local government area of the Benue South senatorial district. The leaf samples were obtained from different parts of the edible plant, whereas the soil samples were obtained at the same source using mechanical augers at a depth of about 20-30 cm. A global positioning system (GPS) was deployed to measure sampling point locations. The edible plant and soil samples were packaged separately in well-labelled and clean black

cellophane bags before being transported to the laboratory for further processing and preparation for radionuclide analysis.

The soil samples were then prepared for analysis following the standard procedure outlined by the International Atomic Energy Agency (IAEA). The samples were sundried for 72 hours, milled and sieved with a 1mm sieve, and oven-dried to a constant weight of 200g to remove any possible moisture content. The individual soil samples were stored in a well-labelled and hermetically sealed plastic container and stored for 4 weeks to obtain secular equilibrium radon and its short-lived daughter products, preparatory for gamma spectrometric analysis. The collected edible leaf samples, on the other hand, were chopped into small pieces on a tray and sundried for one week. The dried plant samples were pounded in a clean steel mortar into a fine powder. Again, the homogenous and equilibrium-size powder particles were sealed in clean polyethylene bags each, well labelled, and stored for 28 days for the daughter nuclides to perfectly reunite with the parent radionuclides in readiness for analysis.

c. Sample Analysis

The activity concentration of 238U, 232Th, and 40K of soil and plant samples in Bq/kg was analyzed using gamma-ray spectrometry (NAI TI, GC8023 HPGe model), Princeton Gamma Tech USA, with a germanium purity detector. The analytical instrument was available at the National Institute of Radiation Protection and Research (NIRPR) environmental radiation laboratory, University of Ibadan, Nigeria. The detector is shielded in a cylindrical lead container to prevent external radiation effects. It is attached with a multichannel analyzer, Gamma Spectral Components, and connected to a computer for data acquisition and analysis via Theremino software. To ensure the highest measure of accuracy, the efficient calibration of the gamma detector was carried out following the recommended procedure by the International Atomic Energy Agency (IAEA), as well as checking the background count before the actual counting.

d. Estimation of Health Risks Parameters

i. Activity Concentration of

The activity concentration of radionuclide, C ($Bqkg^{-1} or Bql^{-1}$) is the ratio of the net gamma counting rate for peak energy to the product of the detected efficiency of a specific γ-ray and the intensity of the γ-line as given in equation 1 (T. Sombo).

$$C = \frac{Ca}{\varepsilon \times I_{eff} \times W} \qquad (1)$$

Where Ca, ε, I_{eff}, and W are the net gamma counting rate (counts per second), detected efficiency of a specific γ-ray, intensity of the γ-line in radionuclides, and net weight of the sample (in kilogram, kg or litre, L) respectively.

ii. Determination of Radium Equivalent (Ra_{eq})

The radium equivalent represents the quantity of the gamma radiation dose from the mixture of radionuclides. It was calculated for both soil and plant samples based on an estimation of 370 Bq/kg of Uranium-238, 259 Bq/kg of Thorium-232, and 4810 Bq/kg of Potassium-40 (Doyi et al., 2017).

$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K$ (2)

where A_U, A_{Th}, and A_K are the respective activity concentrations of Uranium, Thorium, and Potassium.

iii. Determination of Internal and External Health Indices

The internal health index (H_{in}) is associated with the exposure of internal tissues and cells to radionuclides and their decay products (Sivakumar et al., 2014). It was assessed for soil and plant samples using Equation 3

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3)$$

The external health index (H_{ex}) is related to the assessment of health risks exposure to outdoor radionuclides and was estimated using equation (4) (Sivakumar et al., 2014).

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

iv. Determination of Alpha and Gamma Indices

The alpha (I_α) is a radiological parameter for assessing the environmental safety due to exposure to radiation, as established by (Joel et al., 2020)

$$I_\alpha = \frac{A_U}{200} \quad (5)$$

The gamma index (I_γ) was used to calculate the gamma radiation hazards corresponding to natural radionuclides in a specific sample via Equation 6

$$I_\gamma = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (6)$$

v. Determination of Absorbed Radiation Dose Rate

The absorbed dose rate of natural radionuclides was estimated using the conversion factors of 0.462, 0.604, and 0.0417 for Uranium-238, Thorium-232, and Potassium-40.

$$D(nGyh^{-1}) = 0.427A_U + 0.622A_{Th} + 0.0432A_K \quad (7)$$

vi. Determination of Internal and External Annual Effective Dose Rate

The internal and external effective dose rates of gamma radiation emission were estimated using equations 8 and 9, respectively.

$$AEDR_{indoor}(mSvy^{-1}) = D(nGyh^{-1}) \times 0.7(SvGy^{-1}) \times 0.2 \times 8670\ (h^{-1}) \times 10^{-6} \quad (8)$$

$$AEDR_{outdoor}(mSvy^{-1}) = D(nGyh^{-1}) \times 0.7(SvGy^{-1}) \times 0.8 \times 8670\ (h^{-1}) \times 10^{-6} \quad (9)$$

vii. Determination of Excess Lifetime Cancer Risks (ELCR)

The probability of the inhabitant in the study sites to develop cancer over a lifetime from exposure to gamma radiation was determined using equations 10 and 11

$$ELCR = AEDR_{in} \times DL \times RF \times 10^{-3} \quad (10)$$
$$ELCR = AEDR_{out} \times DL \times RF \times 10^{-3} \quad (11)$$

where DL is the duration of lifetime and RF is the fatal cancer risk factor

III. RESULTS AND DISCUSSION

The descriptive statistics (Table 1) showed that SO1, SO6, and SO8 recorded the lowest activity concentration of ^{238}U, ^{232}Th, and ^{40}K, whereas the highest values of activity concentration for the study samples were recorded at SO3, SO10, and SO4, respectively. The studied soil samples were ranged between 10.00 – 79.00±6.215, 17.00 – 82.00±5.564 and 89.00 – 297.00± 21.001 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. It can be observed from Figure 2 that the activity concentration varied with the different natural radionuclides across the study areas. The concentration values of ^{238}U, ^{232}Th, and ^{40}K at SO3, SO10, and SO4 were found to be higher than the recommended limits, and this might be attributed to the geological formation of the area. The average activity concentration of ^{238}U, ^{232}Th, and ^{40}K as recorded in Table 1 was 25.700±6.215, 45.400 ±5.564 and 174.100± 21.001 Bq/kg, respectively. The mean activity concentration as reported in the current study is below the recommended world values except for ^{232}Th, with the mean value of 45.400 ±5.564 and lower than those in (Onjefu et al., 2022; Ononugbo et al., 2013).

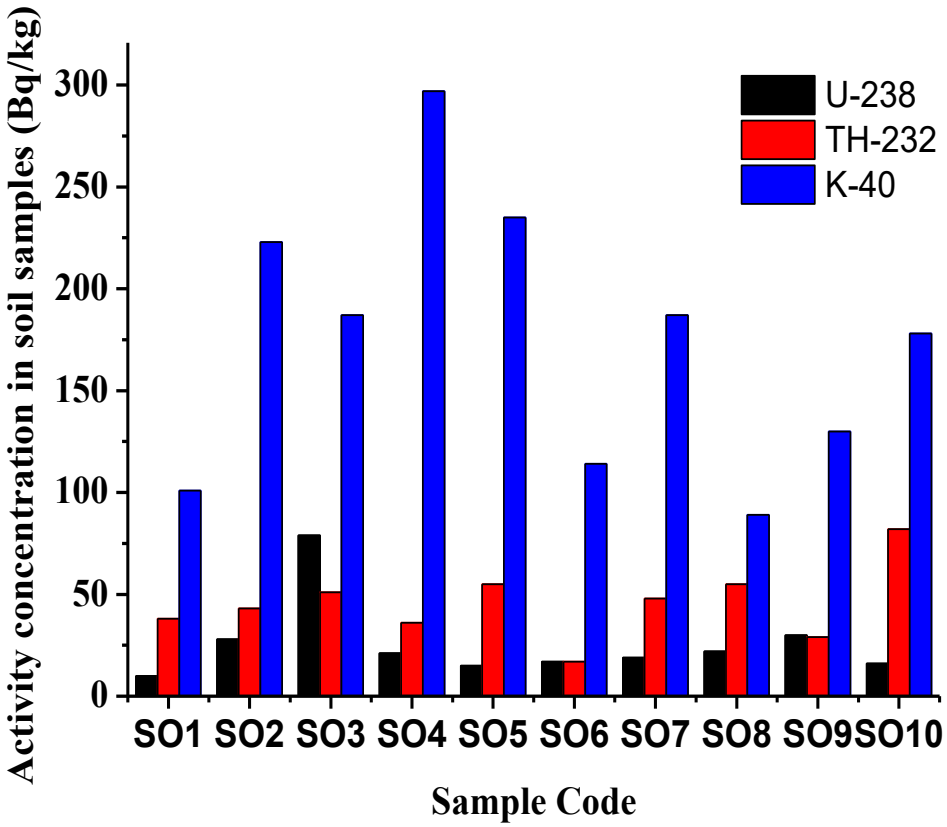


Figure 2. Activity concentration of natural radionuclides in soil samples

Similarly, the activity concentration of ^{238}U, ^{232}Th, and ^{40}K in the plant samples, as represented in Table 1 and Figure 3, respectively, ranges from 10.00 – 56.00, 19.00 – 60.00 and 75.00 – 207.00 Bq/kg with average values of 27.8000±4.479, 35.4000 ±4.556 and 136.6000± 14.100 Bq/kg, respectively. The highest values of the activity concentration were observed at PO2, PO9, and PO4. The mean values as recorded in Table 1 were also found to be below the acceptable limit, except for PO9, which is found to be relatively above the proposed safe limit. Consequently, the consumption of plants from the study areas might not pose any significant health risks to the consumers. It is worthy of note that 40-K has the highest concentration among the natural radionuclides under consideration. This could be linked to the leaching of inorganic potassium fertilizers from the farmland, as farming is the major activity the inhabitant of the study area is known for, and inorganic potassium fertilizers are used to enhance the fertility of the soil to boost crop yields. Similarly, the relatively high values of 238-U and 232Th may be due to the presence of uranium and thorium minerals deposit in the study area.

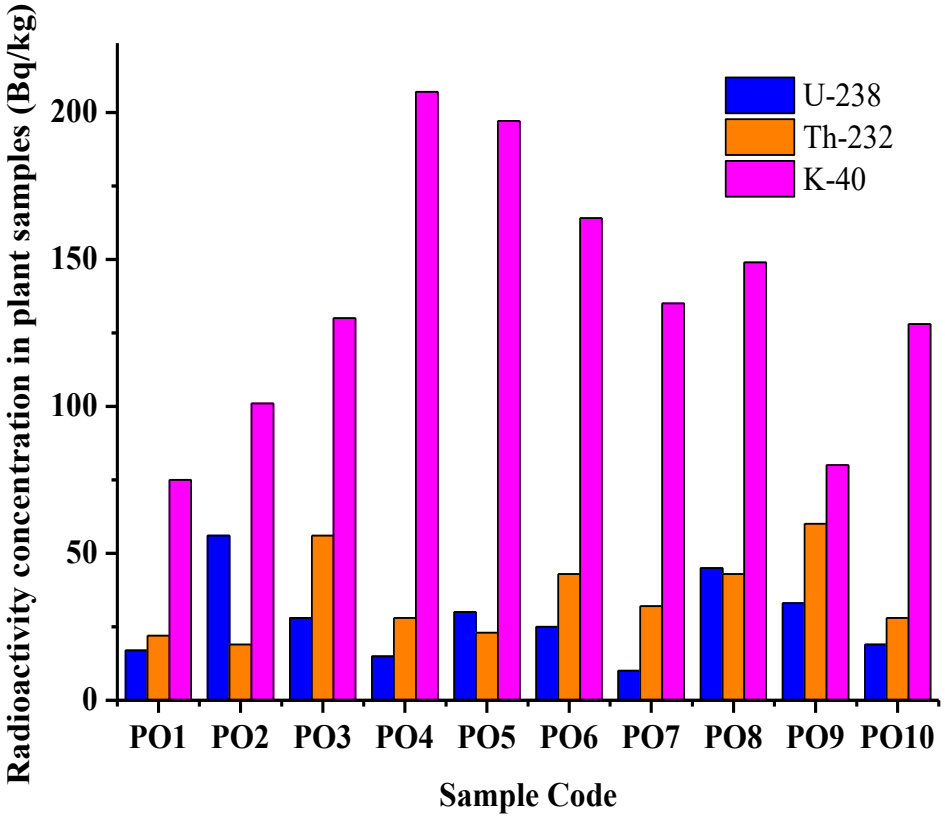
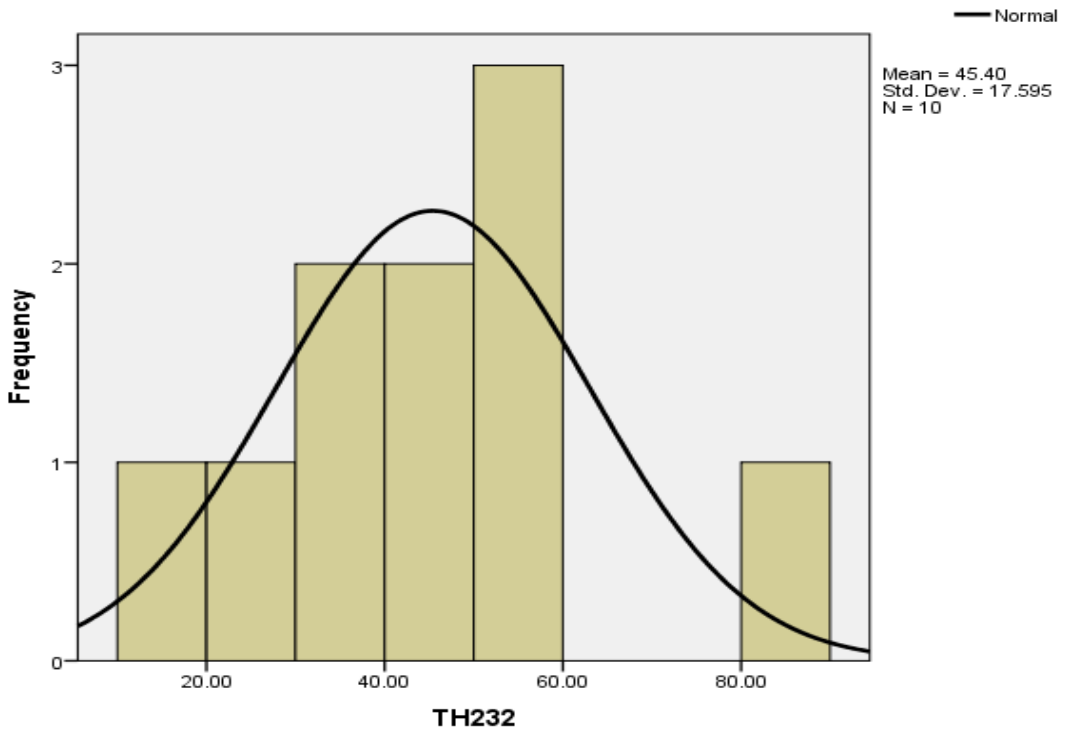
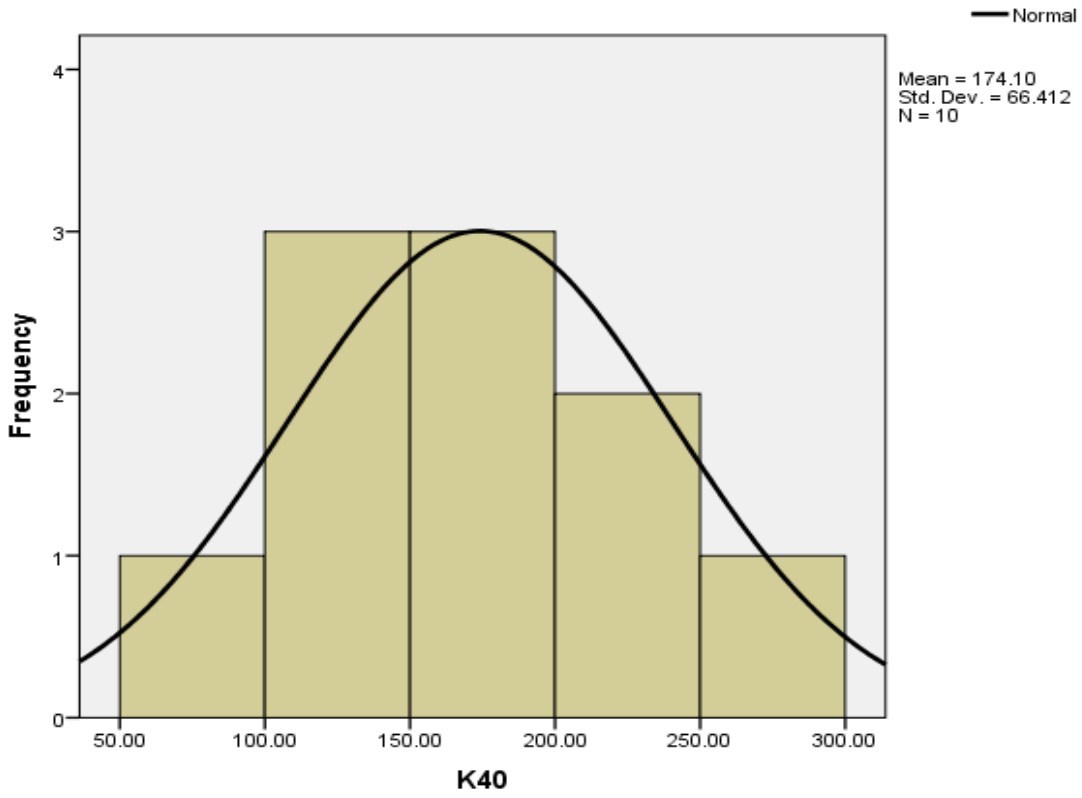


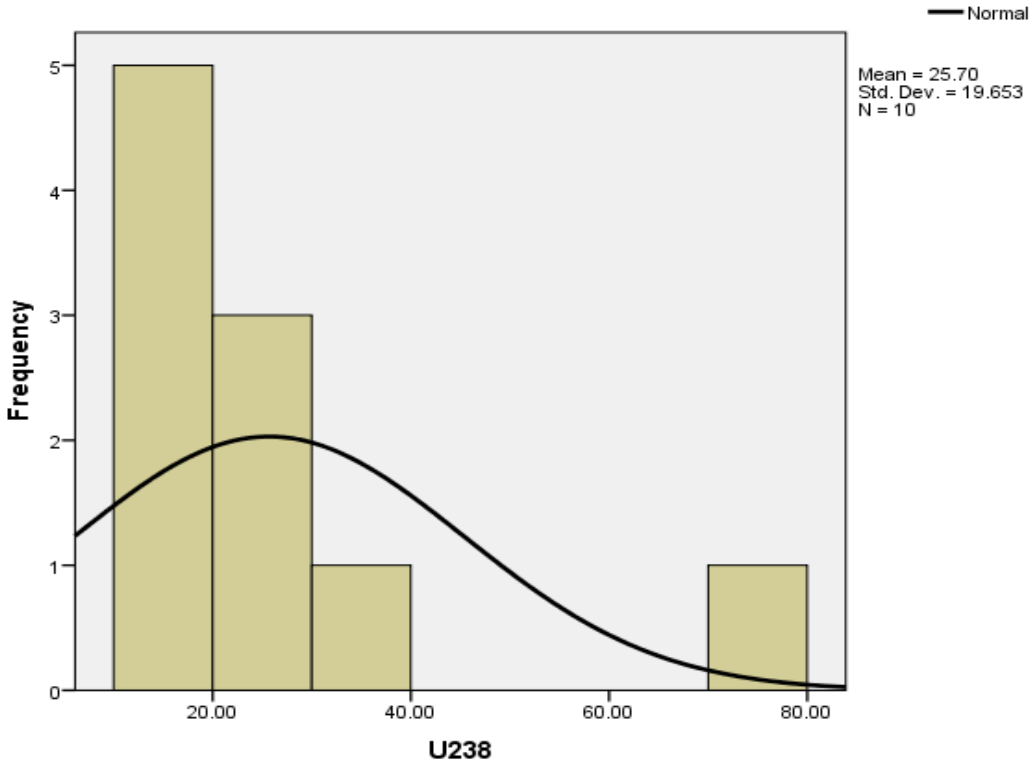
Figure 3. Activity concentration of natural radionuclides in plant samples

The descriptive statistical analysis of the activity concentrations of ^{238}U and ^{232}Th, as depicted in Table 1, is very close to each other compared to the ^{40}K radionuclide. All the radionuclides (^{238}U, ^{232}Th, and ^{40}K) revealed negative skewness, displaying a negatively skewed distribution, whereas the existence of a positive skewness suggests a positively skewed distribution. The observed positive and negative kurtosis, which reflect normal and flat distributions, respectively, as indicated in Figure 4 (soil samples) and Figure 5 (plant samples), clearly showed the distribution of uranium, thorium, and potassium in the study sites. The activity

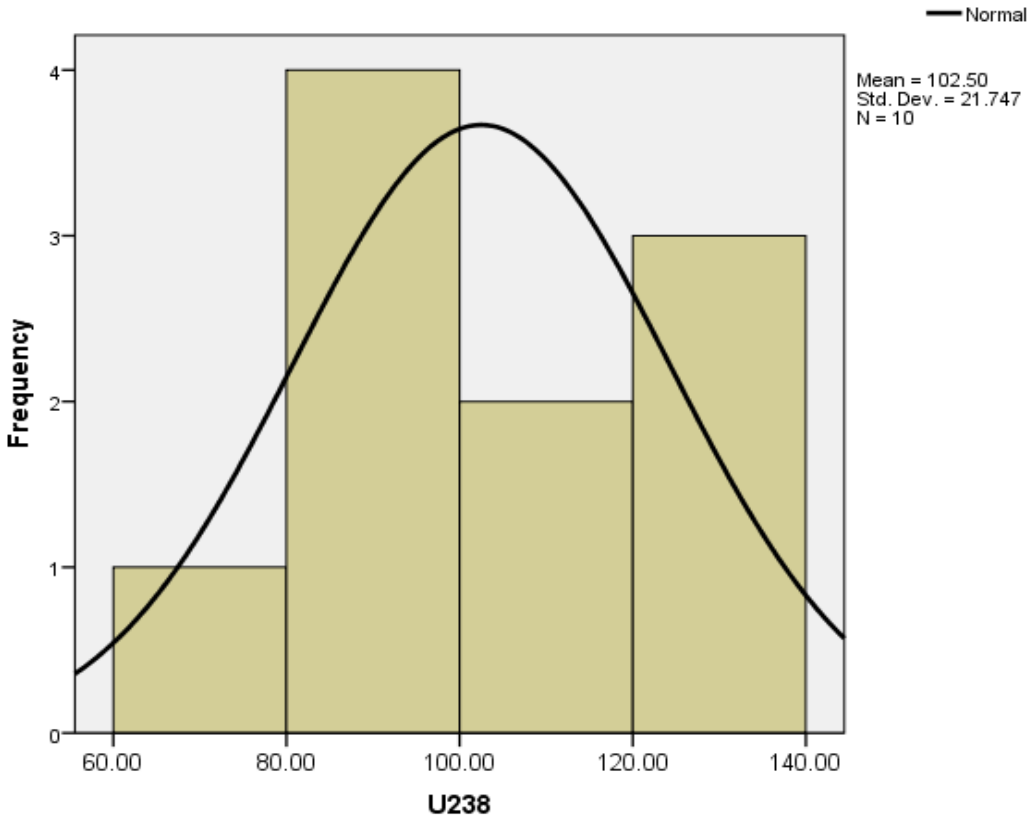
concentration of radionuclides in the soil samples is of the order $^{238}U<^{232}Th<^{40}K$ while that of the plant samples is $^{232}Th<^{238}U<^{40}K$. The results of the activity concentration of the analysed samples showed that activity concentration is higher in plant samples than in soil samples. This result is in good agreement with (Nduka et al., 2022; Tyovenda et al., 2022).

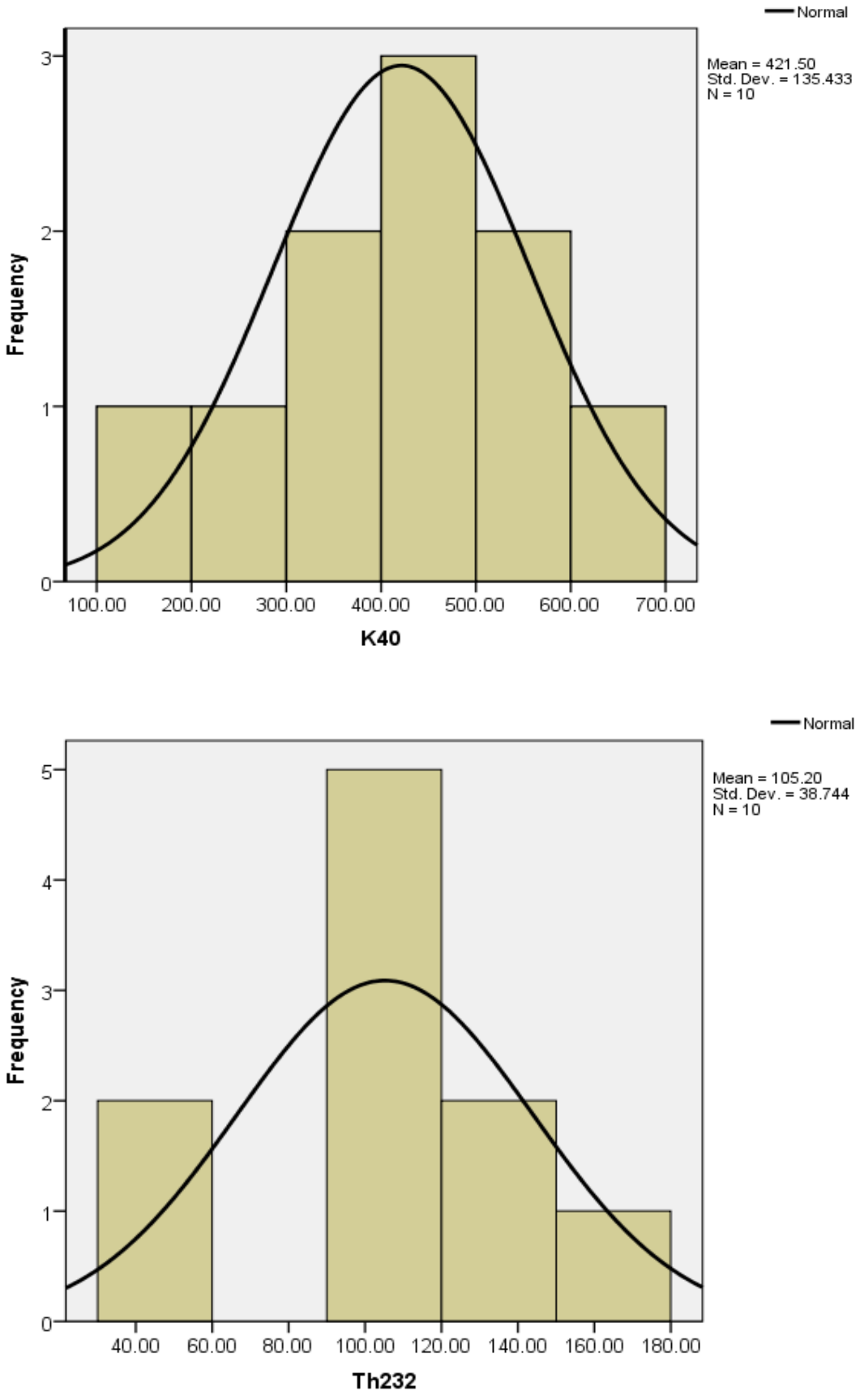






Figures 4: Frequency distribution histogram of natural radionuclides in soil samples





Figures 5: Frequency distribution histogram of natural radionuclides in plant samples

Table 1. Descriptive Statistics of Natural Radionuclides in Soil and Plant Samples

	Soil Samples				Plant Samples		
Code	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Code	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)
SO1	10.000	38.000	101.000	PO1	17.000	22.000	75.000
SO2	28.000	43.000	223.000	PO2	56.000	19.000	101.000
SO3	79.000	51.000	187.000	PO3	28.000	56.000	130.000
SO4	21.000	36.000	297.000	PO4	15.000	28.000	207.000
SO5	15.000	55.000	235.000	PO5	30.000	23.000	197.000
SO6	17.000	17.000	114.000	PO6	25.000	43.000	164.000
SO7	19.000	48.000	187.000	PO7	10.000	32.000	135.000
SO8	22.000	55.000	89.000	PO8	45.000	43.000	149.000
SO9	30.000	29.000	130.000	PO9	33.000	60.000	80.000
SO10	16.000	82.000	178.000	PO10	19.000	28.000	128.000
Mean	25.700	45.400	174.100	Mean	27.800	35.400	136.600
Minimum	10.000	17.000	89.000	Minimum	10.00	19.00	75.00
Maximum	79.000	82.000	297.000	Maximum	56.00	60.00	207.00
Range	69.000	65.000	208.000	Range	46.00	41.00	132.00
Variance	386.233	309.600	4410.544	Variance	200.622	207.600	1988.267
Skewness	2.642	.572	.424	Skewness	0.878	0.693	0.205
Kurtosis	7.602	1.458	-.463	Kurtosis	.365	-.859	-.765
MWV	50	30	400		50	30	400

SO = Otukpo Soil Sample, PO = Otukpo Plant Sample, and MWV = World Mean Value

The estimated radiological health risk parameters calculated from the activity concentration of radionuclides are presented in Table 2. The table contains the evaluated radiological health indices associated with the sampled soil from the study areas. It can be seen from the table that the absorbed dose rate (D) ranges from 22.281 to 72.335 nGy/hr, with the mean value of 103.350 ny/hr, which is higher than the recommended dose rate of 57 nGy/hr (El-Shanshoury & Arafat, 2018). The estimated Raeq varied between 55.709 and 133.260 Bq/kg with a mean value of 45.655. The observed values of radium equivalent (Raeq) are lower than the allowable permissible of 370 Bq/kg (UNSCEAR, 2000). The average value of Raeq, absorbed dose rate (D), indoor and outdoor annual effective dose rate ($AEDR_{in}$ and $AEDR_{out}$), external and internal hazard index and excess life cancer risk (ELCR) are 103.350 nGy/hr, 45.655 Bq/kg, 55×10^{-2} mSv/y, 224×10^{-2} mSv/y, 1.960, 0.223, 0.350, 0.741, 0.129 respectively. The recommended permissible limits for absorbed dose rate are 57 nGy/hr, for annual effective dose rate is 1.0 mSv/y, for radium equivalent is 370 Bq/kg, for excess life cancer risk is 0.29×10^{-3}. All the calculated radiological parameters are within the corresponding permissible limits except for ELCR, which is above the safe limits proposed by UNSCEAR 2000. Meanwhile, the estimated values for both internal and external health hazards (H_{in} and H_{ex}) are less than unity and hence do not pose any meaningful radiological health risks to the environment (Ichoja et al., 2024; Ocheje & Tyovenda, 2020).

Table 2: Radiological parameters analysis of soil samples

Sample code	DR (nGy/hr)	Ra_{eq} (Bq/kg)	$AEDR_{out}$ (mSv/yr)	$AEDR_{in}$ (mSv/yr)	ELCR	H_{ex}	H_{in}	I_{γ}	I_{α}
SO1	31.434	81.511	0.039	0.154	1.349	0.164	0.222	0.514	0.050
SO2	47.227	103.889	0.058	0.232	2.027	0.227	0.364	0.765	0.140
SO3	72.335	174.799	0.089	0.355	3.105	0.306	0.663	1.161	0.395
SO4	43.096	90.575	0.053	0.211	1.850	0.210	0.314	0.698	0.105
SO5	49.425	102.428	0.061	0.242	2.121	0.256	0.342	0.807	0.075
SO6	22.281	55.709	0.027	0.109	9.564	0.102	0.181	0.359	0.085
SO7	44.903	94.493	0.055	0.220	1.927	0.227	0.327	0.731	0.095
SO8	46.325	110.660	0.057	0.227	1.988	0.234	0.350	0.756	0.110
SO9	35.747	85.176	0.044	0.175	1.534	0.162	0.301	0.577	0.150
SO10	63.783	133.260	0.078	0.313	2.738	0.339	0.440	1.045	0.080
Mean	103.350	45.655	0.056	0.224	1.96O	0.223	0.350	0.741	0.129

The varied activity concentration of natural radionuclides (238-U, 232-Th, and K-40) of the plant samples alongside the soil to plant migration of the radionuclides are shown in Table 3. The average Transfer Factor (TF) in the present study shows that the values for the uranium radionuclide (238-U) vary from 0.354 to 2.045, that of thorium (232-Th) vary from 0.341 to 2.529, while that of potassium radionuclide (K-40) varies from 0.453 to 1.674, with a mean value of 238-U (1.310), 232-Th (0.970), and K-40 (0.860). The high mean value of TF observed in 238-U could be due to the high uranium content in the soil. The observed variation in the Transfer Factor may be linked to different factors such as soil type, organic matter, pH, etc. According to Al-masri, the Transfer Factor increases with an increase in activity concentration in soil. However, the current result is in disagreement with the reported work, which suggests that activity concentration is not linearly related to Transfer Factor (Al-masri et al. 2008 and Onunogboel et al. 2019).

Table 3: Activity Concentration of Natural Radionuclides in Plant Samples and Soil-Plant Transfer Factor

Sample code	Activity concentration in Plants (Bq/kg)			Activity concentration in soil (Bq/kg)			Transfer factor (Tf)		
	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th	^{40}K
Vernonia Amygdalina	17.000	22.000	75.000	10.000	38.000	101.000	1.700	0.579	0.743
Telfairia Occidentalis	56.000	19.000	101.000	28.000	43.000	223.000	2.000	0.442	0.453
Oleracea Amaranthus	28.000	56.000	130.000	79.000	51.000	187.000	0.354	1.098	0.695
Mangifera Indica	15.000	28.000	207.000	21.000	36.000	297.000	0.714	0.778	0.697

Talinum Fruiticosum	30.000	23.000	197.000	15.000	55.000	235.000	2.000	0.418	0.838
Moringa Oleifera	25.000	43.000	164.000	17.000	17.000	114.000	1.471	2.529	1.439
Ocimum Gratissimum	10.000	32.000	135.000	19.000	48.000	187.000	0.526	0.667	0.722
Psidium Guajava	45.000	43.000	149.000	22.000	55.000	89.000	2.045	0.782	1.674
Azadurachta Indica	33.000	60.000	80.000	30.000	29.000	130.000	1.100	2.069	0.615
Anacardium Occidentale	19.000	28.000	128.000	16.000	82.000	178.000	1.188	0.341	0.719
Mean	25.700	45.400	174.100	27.800	35.400	136.600	1.310	0.970	0.860

Table 4 represents the calculated annual effective dose for ingestion and the excess lifetime cancer risk in plant samples. The total annual effective dose of radionuclides from consumption of plants in the study area is found to be 0.310 mSv/y, which is marginally above the recommended value of 0.3 mSv/y. The highest values of annual effective dose due to ingestion are found in Azadurachta Indica (0.631). The recorded high value may be attributed to geological formation and absorption rate of the radionuclides or transfer from soil to plants, leading to great health concerns (Nduka et al., 2022). The value of ELCR in the plant samples as recorded in Table 4 is 1.0×10^{-4} mSv/y which is far below 0.29×10^{-3} mSv/y and prolonged consumption of these plants could lead to cancerous diseases, leukaemia, chromosomal aberration, kidney disease, liver disease etc Despite the existing low concentration of radioactivity in the studied soil and plant samples, there is need for regular and strict monitoring of radioactive elements of the study location to check the potential radiological impacts of from possible anthropogenic activities that could increase the observed low concentration.

Table 4: Calculated Annual Effective Dose Due to Ingestion (AED_{ing}) and Excess Life Cancer Risk (ELCR) in Plant Samples

Plants	AED_{ing} (mSv/yr)				
	^{40}K	^{238}U	^{232}Th	Total ADE_{ing}	ELCR
Vernonia Amygdalina	0.019	0.031	0.202	0.252	0.0009
Telfairia Occidentalis	0.025	0.101	0.175	0.301	0.0011
Oleracea Amaranthus	0.032	0.050	0.515	0.598	0.0021
Mangifera Indica	0.051	0.027	0.258	0.336	0.0012
Talinum Fruiticosum	0.049	0.054	0.212	0.314	0.0011
Moringa Oleifera	0.041	0.045	0.396	0.481	0.0017
Ocimum Gratissimum	0.033	0.018	0.294	0.346	0.0012
Psidium Guajava	0.037	0.081	0.396	0.514	0.0018
Azadurachta Indica	0.020	0.059	0.552	0.631	0.0022
Anacardium Occidentale	0.032	0.034	0.258	0.324	0.0011
Mean	0.034	0.033	0.410	0.310	0.001

ADEing = Annual effective due to ingestion

IV. CONCLUSION

Radiation is a natural and unavoidable companion in our environment that silently reminds us of the dynamic processes that shape the Earth's environment. Human exposure to terrestrial radiation is primarily by gamma radiation from naturally occurring radionuclides belonging to the Uranium (U-238), Thorium (Th-232), and non-decaying Potassium (K-40), and is more than exposure from all artificial sources put together. The activity concentration of radionuclides in soil and plant samples is a fundamental factor for evaluating natural background radiation. The results of gamma ray measurements of ^{238}U, ^{232}Th, and ^{40}K of activity concentration of soil and plant samples are relatively within the permissible safe range, with the highest values being recorded for the ^{40}K radionuclide. The high ^{40}K values for both soil and plant samples may be due to continuous application of organic potassium fertilizer, as the inhabitants of the study area are predominantly farmers. However, the observed variation of the activity concentration may be due to physiochemical parameters of the soil, including soil type, pH, soil fertility, crop type, organic matter, etc. The Transfer Factor (TF) in the current work does not follow a linear relationship between TF and soil concentration, which is in agreement with other related reported literature. There may be less possibility of radiological health hazard exposure as seen in the present work, but continuous accumulation and exposure to children with developing and weak systems may result in dangerous health concerns. This underscores the importance of understanding and managing radiation exposure to minimize health risks.

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Declaration of competing interest

The authors declare that there is no competing financial interest or personal relationship to influence the present work.

REFERENCES

[1] Avwiri, G., & Ononugbo, C. (2012). Natural radioactivity levels in surface soil of Ogba/Egbema/Ndoni oil and gas fields. Energy Science and Technology, 4(2), 92-101.
[2] Ayaakaa, D., Sombo, T., & Utah, E. (2018). Radionuclide Content of Some Surface Soils Of Ushongo Local Government Area Of Benue State, North Central, Nigeria.
[3] Doyi, I., Essumang, D., Dampare, S., Duah, D., & Ahwireng, A. (2017). Evaluation of radionuclides and decay simulation in a terrestrial environment for health risk assessment. Scientific reports, 7(1), 16537.
[4] Ei-Taher A, Abbady Adel GE.(2012). Natural radioactivity levels and associated radiation hazards in Nile River sediments from
[5] Aswan to El-minia, upper Egypt. Indian Journal. 50:224-230.[6].
[6] Ferdous J, Begum A, Islam A (2015) Radioactivity of soil at the proposed Rooppur Nuclear Power Plant site in Bangladesh. Int. J Radiat Res, 13(2): 135-142.

[7] Ebaid, Y., El-Tahawy, M., El-Lakany, A., Garcia, S., & Brooks, G. (2000). Environmental radioactivity measurements of Egyptian soils. Journal of Radioanalytical and Nuclear Chemistry, 243(2), 543-550.

[8] Egunyinka, O., Olowookere, C., Jibiri, N., Babalola, I., & Obed, R. (2009). An evaluation of 238U, 40K, and 232Th concentrations in the top soil of the University of Ibadan (UI), southwestern Nigeria. Pac J Sci Technol, 10(2), 742-750.

[9] Eke, B., Ukewuihe, U., & Akomolafe, I. (2022). Evaluation of activity concentration of natural radionuclides and lifetime cancer risk in soil samples at two tertiary institutions in Owerri, Imo State, Nigeria. International Journal of Radiation Research, 20(3), 671-678.

[10] El-Shanshoury, G. I., & Arafat, A. (2018). Statistical analysis of natural radioactivity measurements for the soil of Marsa Alam-Shalateen Red-Sea coast area, Egypt. International Journal of Advanced Scientific and Technical Research, 1(8), 71-85.

[11] Hasan MM, Ali M, Paul D, Haydar M, Islam S (2013) Measurement of Natural Radioactivity in Coal, Soil and Water Samples Collected from Barapukuria Coal Mine in Dinajpur District of Bangladesh. Journal of Nuclear and Particle Physics, 3(4): 63-71.[8].

[12] Harb S., El-Kamel A. H., Abd El-Mageed A. I., Abbady A., and Rashed W. 2014. Radioactivity levels and soil-to-plant transfer factor of natural radionuclides from Protectorate Area in Aswan, Egypt.WorldJ.ofNuclearScienceandTechnology,4,-15.Publishedonline

[13] Faanu, A., Darko, E., & Ephraim, J. (2011). Determination of natural radioactivity and hazard in soil and rock samples in a mining area in Ghana. West African Journal of Applied Ecology, 19(1).

[14] Ichoja, A., Hashim, S., Agboola, O. O., Danladi, E., & Omotehinwa, F. H. (2024). Annual Effective Dose Analysis and Radiological Effects of Rn-222 in Southern Benue Groundwater Sources. Paper presented at the 2024 International Conference on Science, Engineering, and Business for Driving Sustainable Development Goals (SEB4SDG).

[15] Ilori, A. O., & Chetty, N. (2020). Soil-to-crop transfer of natural radionuclides in farm soil of South Africa. Environmental Monitoring and Assessment, 192, 1-13.

[16] Jibiri, N., Farai, I., & Alausa, S. (2007). Estimation of annual effective dose due to natural radioactive elements in the ingestion of foodstuffs in the tin mining area of Jos-Plateau, Nigeria. Journal of Environmental Radioactivity, 94(1), 31-40.

[17] Joel, E. S., De, D. K., Omeje, M., Adewoyin, O., Olawole, O. C., Akinwumi, A., . . . Adeyemi, G. A. (2020). Assessment of background radionuclides and gamma dose rate distribution in urban settings and its radiological significance. Scientific African, 8, e00377.

[18] Nduka, J., Ubong, I., Kelle, H., Umeh, C., & Osisiogu, S. (2022). Radiological risk of primordial radionuclides and heavy metal pollution from quarry soils and stone crushing sites at Umuaghara Community, Ezza North LGA in Ebonyi State. Eur. J. Environ. Earth Sci.(Galley Proof).

[19] Nduka, J. K., Umeh, T. C., Kelle, H. I., Ozoagu, P. C., & Okafor, P. C. (2022). Health risk assessment of radiation dose of background radionuclides in quarry soil and uptake by plants in Ezillo-Ishiagu in Ebonyi, South-Eastern Nigeria. Case Studies in Chemical and Environmental Engineering, 6, 100269.

[20] Ocheje, J. A., & Tyovenda, A. A. (2020). Determination of the transfer factor and dose rate of radionuclides in some selected crops in Kogi State, Nigeria. Journal of Applied Physics, 12(3), 7-12.

[21] Onjefu, S., Johannes, N., Abah, J., Onjefu, L., & Mwiya, S. (2022). Natural radioactivity levels and evaluation of radiological hazards in Usakos marble, Erongo region, Namibia.

[22] Ononugbo, C., Avwiri, G., & Egieya, J. (2013). Evaluation of natural radionuclide content in surface and ground water and excess lifetime cancer risk due to gamma radioactivity. EVALUATION, 4(6).

[23] Otwoma, D., Patel, J., Bartilol, S., & Mustapha, A. (2012). Radioactivity and dose assessment of rock and soil samples from Homa Mountain, Homa Bay County, Kenya.

[24] Popoola, F., Fakeye, O., Basiru, Q., Adesina, D., & Sulola, M. (2019). Assessment of radionuclide concentration in surface soil and human health risk associated with exposure in two higher institutions of Esan land, Edo State, Nigeria. Journal of Applied Sciences and Environmental Management, 23(12), 22679-22284.

[25] Sivakumar, S., Chandrasekaran, A., Ravisankar, R., Ravikumar, S., Jebakumar, J. P. P., Vijayagopal, P., .Jose, M. (2014). Measurement of natural radioactivity and evaluation of radiation hazards in coastal sediments of the east coast of Tamil Nadu using a statistical approach. Journal of Taibah University for Science, 8(4), 375-384.

[26] Tyovenda, A. A., Ocheje, J. A., Terver, S., & Uttah, E. U. (2022). Investigation of the radiological risk of farmlands and the transfer factor from soil to crops in Jalingo and Wukari LGA of Taraba State, Nigeria. Journal of Environmental Protection, 13(1), 1-14.

[27] UNSCEAR, S. (2000). Effects of ionizing radiation, Exposures from Natural Radiation Sources, Annex B. United Nations, New York.