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Assessment of Soil and Plant Radiometric Characteristics in Abuni Mining Site, Awe Local Government Area of Nasarawa State, Nigeria

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Abstract
Natural resource extraction, a global practice, involves significant environmental alteration to achieve specific goals. Among these resources, mineral extraction is predominant, requiring processes such as extraction, grinding, ore concentration, and tailings dispersal. This study aims to conduct a radiometric assessment of soil and plants from a mining site in Abuni, Awe Local Government Area of Nasarawa State, Nigeria. Fifteen samples each of soil and plants were collected from farmland around the mining site and analyzed for activity concentration using a sodium iodide doped thallium detector. The study calculated soil-to-plant transfer factors and other radiological hazard indices to determine environmental safety levels. The mean activity values of 40K, 238U, and 232Th for soil (plant) were found to be 634.86 ± 75.858 Bq/kg (601.31 ± 87.79 Bq/kg), 32.00 ± 5.272 Bq/kg (26.35 ± 4.59 Bq/kg), and 63.0166 ± 9.622 Bq/kg (57.91 ± 7.99 Bq/kg), respectively. Transfer factors for 40K, 238U, and 232Th were 0.974457, 0.869418, and 0.915594, respectively. The annual effective dose rate ranged from 0.044782 mSv/y to 0.125382 mSv/y, with a mean value of 0.088581 mSv/y, within the recommended standard value set by ICRP. Excess life cancer risk ranged from 0.156735 to 0.438838, with a mean value of 0.310035. Consequently, mining activities in Abuni, Awe Local Government Area of Nasarawa State may pose no significant radiological hazard to the host communities. The study recommends further investigation into the elemental concentration of heavy toxic metals in water, soil, and edible plants in the area.

Keywords: Natural, Resource, Extraction, Global, Mining.

Introduction
Mining is important for the development and wellbeing of societies that are rich in minerals. While it has the potential to contribute to sustainable development, drive economic growth and infrastructural development, and creates job opportunities, mining also has a negative side that poses far-reaching challenges with high risks and consequences a for sustainability. (Carr, 1994; Jackson, 2013). Mining was at its peak as a driver for a number of innovations and technologies in the previous century. It represents the beginning of the revitalization and the Industrial Revolution, when abundant raw materials such as sand, gravel, rock, asbestos, limestone, and other minerals were exploited for aggregates, concretes, roofing slates, cement, and ceramics, among other things. They were consumed with a high level of contaminants, posing health risks and polluting the environment (Bates, 1969; Tatarinov, 1969; Harben & Bates, 1984; Bender, 1986).

Natural resource extraction occurs all around the world and involves altering the environment to reach specific objectives. Mineral resources are the most highly exploited natural resources, requiring extraction, grinding, ore concentration, and tailings dispersal, among other things. (Ferreira *et al.,* 2004). These

mining-related activities frequently result in a large amount of radioactive and chemical waste, as well as a range of damages and risks to plants, animals, and human life. Mineral extraction and processing began to create radioactive effects in both urban and rural regions due to a lack of comprehensive knowledge on the environmental and health consequences of mining (Carson, 2013). However, mining on any scale, whether little or huge, has the potential to devastate the environment by exposing it to dangerous radionuclides (Ahijjo *et al.,* 2015). Radionuclides have been recognized as sources of radiation in the environment. They produce radioactive radiation, which adds to the present worldwide burden of cancer and other disorders associated to them. (UNSCEAR, 2013). Mining is one of the most common sources of long-lived naturally occurring radioactive materials (NORMs) radiation exposure, and it can result in unnecessary public exposure dosages that may breach radiation safety regulations. These Long-lived radionuclides can be found in almost all minerals and rocks on the earth, and their distribution in the environment is largely governed by geological and geographical factors found at various levels in soils all over the world (Ademola *et al.,* 2014). Naturally occurring radioactive materials (NORMs) include primordial radionuclides such as Uranium, Thorium, and Potassium, which exist in varying amounts in all rare resources and serve as natural sources of background radiation in our environment (Furuta *et al.,* 2011). As a result of the release of these particles into the environment, humans are exposed to radiation both inside and externally. The NORMs ^{232}Th and ^{238}U, as well as their decay products and non-series ^{40}K, are disseminated by geological and geochemical processes in soils that originated from the earth crust (Alausa *et al.,* 2017).

Both natural and manufactured radionuclides continuously degrade in the human environment, posing major radiation exposure risks. Environmental radionuclides can enter the human body through a variety of routes and sources. Direct inhalation, rather than air emission, is the primary cause of human hazard. The radionuclides deposited on soils and on the foliage of crop plants, as well as their reception by the plant and water contamination, are other major sources of exposure. The root uptake of radionuclides and the subsequent translocation to the plant parts are being influenced by many factors, such as soil characteristics, plant types, physiological processes in each compartment, competing ions, climatic conditions, physico-chemical form of the radionuclides and agricultural practices. The modeling of the radionuclide uptake by the root is a compromise between availability of input parameter and scientifically based mechanistic approaches (Ibikunle *et al.,* 2019). Terrestrial pathways were determined to be more important than aquatic pathways in general.

All organisms on earth are continuously exposed to ionizing radiation coming from natural sources. Ionizing radiation is produced when heavy elements such as ^{238}U and ^{232}Th decays. The interaction of this ionizing radiation with specific biological material results in the production of ion pairs which affects the fundamental structures of biological materials. Due to NORMs in bedrocks, soil, sediments, and rivers, humans have always been exposed to ionizing radiation. (Okedeye *et al*., 2012). The energy transferred by ionizing radiation to the mass per unit volume, is called absorbed dose. The probability of affecting the human health is directly related to the absorbed dose. The worldwide average natural dose to humans is about 2.4 mSv/yr (UNSCEAR, 2000). It is therefore necessary to carry out an accurate evaluation of these radionuclides in the daily used food materials in order to determine the degree of risk and harmful effects to public health.

MATERIALS AND METHODS

Fifteen samples each of plant and soil were collected from some selected mining sites in Abuni, Awe Local Government Area of Nasarawa State, Nigeria. Soil Samples were randomly collected within the Specific boundaries of the mining Area. Both plant and soil samples were collected from equidistance location with a distance of 500m from each other and at a depth of 20cm from the surface. Plant Samples were collected from Farms Lands randomly selected in the Study Area within the Specific boundaries of the Farms around the mining Sites and properly packed and marked with an identification code. Evaluation of radiological hazard effects depending upon the activity concentration of primordial radioactive elements, various radiological hazards delivered to the surrounding living biota are calculated based on the following hazard parameters; Gamma dose rate, Radium equivalent activity, External hazard indices, and Excess life cancer risk. the outdoor average dose rate (soil) from terrestrial gamma rays ranged from 45.56 nGy/h to 107.61 nGy/h, with a mean value of 78.49 nGy/h. This mean value is higher than the worldwide average of 59 nGy/h (UNSCEAR, 2000). The values for the radium equivalent ranged from 98.26 Bq/kg to 864.25 Bq/kg, with a mean value of 580.09 Bq/kg which shows that the

average values obtained from around the mining areas of Abuni, Awe Local Government Area of Nasarawa State are way higher than the suggested maximal permissible value of 370 Bq/kg. Therefore, the AEDE average values from Abuni, Awe Local Government Area of Nasarawa State were considered safe to the population.

The study area is located in Abuni town, Awe local Government area of Nasarawa State north Central, Nigeria. The town is 90 km north of Lafia the Capital of Nasarawa State. It is situated on longitude 080 30′ east and latitude 080 32′ north. The area is accessible through the major road from Abuja – Keffi – Akwanga – Lafia to Awe (Figure 1).

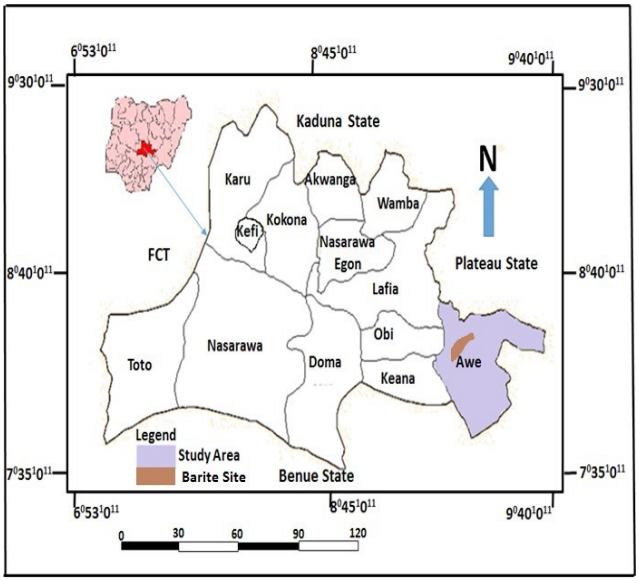


Figure 3.1: Map of the Study Area.

RESULT

The data of activity concentration for ^{238}U, ^{232}Th and ^{40}K of Mining Site in Abuni, Awe local government of Nasarawa State are presented in this section. Sodium Iodide (NaI) detector was used to determine the activity concentration of the soil sample collected at the Centre for Solid Minerals Research and Development, Kaduna, Nigeria. The data has been organized into two parts. Part 1 presents the activity concentration of ^{238}U, ^{232}Th and ^{40}K in the plant and soil sample collected from the study area which are presented in Tables 4.1, 4.2. Part 2 presents the calculated transfer factors, radiological hazard parameters (Gamma dose rate, Radium equivalent activity, External hazard indices, Annual gonadal dose rate, and Excess life cancer risk) which are presented in Tables 4.3, 4,4 and 4.5 respectively.

Table 1: Activity Concentration of ^{238}U, ^{232}Th and ^{40}K of the Plant Sample Collected from the Study Area.

S/N	Sample Code	Sampling Coordinates		Activity Concentration Bq/kg		
		Latitude	Longitude	^{40}K	^{238}U	^{232}Th
1	PS1	$10^0.89'98''$	$9^0.60'074''$	692.45±95.13	24.71±5.23	59.33±9.38
2	PS2	$10^0.89'99''$	$9^0.60'077''$	296.18±46.91	15.2±2.81	28.38±4.88
3	PS3	$10^0.89'92''$	$9^0.60'088''$	590.31±93.17	38.78±5.01	49.81±6.91
4	PS4	$10^0.89'72''$	$9^0.60'09''$	621.84±93.41	31.84±4.38	28.33±4.43
5	PS5	$9^0.784'595''$	$9^0.398'337''$	801.41±109.41	14.33±3.43	87.18±12.43
6	PS6	$9^0.78'474''$	$9^0.39'858''$	493.34±7.87	30.51±5.18	54.65±6.48
7	PS7	$9^0.78'469''$	$9^0.39'867''$	893.49±99.81	14.51±3.18	96.48±14.33
8	PS8	$9^0.78'445''$	$9^0.39'85''$	722.45±102.44	12.31±2.38	80.37±5.38
9	PS9	$10^0.22'34''$	$9^0.40'269''$	531.45±91.32	31.81±6.76	34.33±5.38
10	PS10	$10^0.22'367''$	$9^0.40'338''$	641.01±118.41	45.18±6.82	56.91±6.79
11	PS11	$10^0.22'071''$	$9^0.40'39''$	409.48±64.39	26.18±2.92	43.41±6.91
12	PS12	$10^0.22'166''$	$9^0.40'368''$	491.49±91.23	33.81±6.54	49.49±6.94
13	PS13	$9^0.78'41''$	$9^0.39'73''$	629.31±94.84	14.38±3.18	79.81±12.41
14	PS14	$9^0.78'386''$	$9^0.39'672''$	591.28±89.13	23.41±5.18	59.89±7.91
15	PS15	$9^0.78'474''$	$9^0.39'72''$	614.18±119.38	38.34±5.93	60.31±9.39
	Max			**893.49±99.81**	**45.18±6.82**	**96.48±14.33**
	Min			**296.18±46.91**	**12.31±2.38**	**28.33±4.43**
	Average			**601.31±87.79**	**26.35±4.59**	**57.91±7.99**

Where Ps1 to Ps15 are Plant Sample Collected from the Sample Site.

Table 4.1 presents the values of activity concentration of ^{40}K, ^{238}U, and ^{232}Th, in the plant samples collected from the study area. The activity of ^{40}K, ^{238}U, and ^{232}Th ranged from 296.18 ± 46.91Bq/kg to 893.49 ± 99.81Bq/kg with mean value of 601.31 ± 87.79 Bq/kg, 12.31 ± 2.38 Bq/kg to 45.18 ± 6.82 Bq/kg with mean value of 26.35 ± 4.59

Bq/kg, 28.33 ± 4.88 Bq/kg to 96.48 ± 14.33 Bq/kg with mean value of 57.91 ± 7.99 Bq/kg respectively. Ps15 was found to have the highest activity concentration of 38.34 ± 5.93 Bq/kg for ^{238}U, while Ps5 has highest activity concentration of 87.18 ± 12.43 Bq/kg for ^{232}Th, while Ps7 was found to have the highest concentration of 893.49±99.81 Bq/kg for ^{40}K. The least values for ^{40}K, ^{238}U, and ^{232}Th are found in Ps2 (296 ± 46.91 Bq/kg), Ps8 (12.31 ± 2.38 Bq/kg), and Ps4 (28.33 ± 4.43 Bq/kg) respectively. The figure 4.1 below represents the activity concentration in the plant samples.

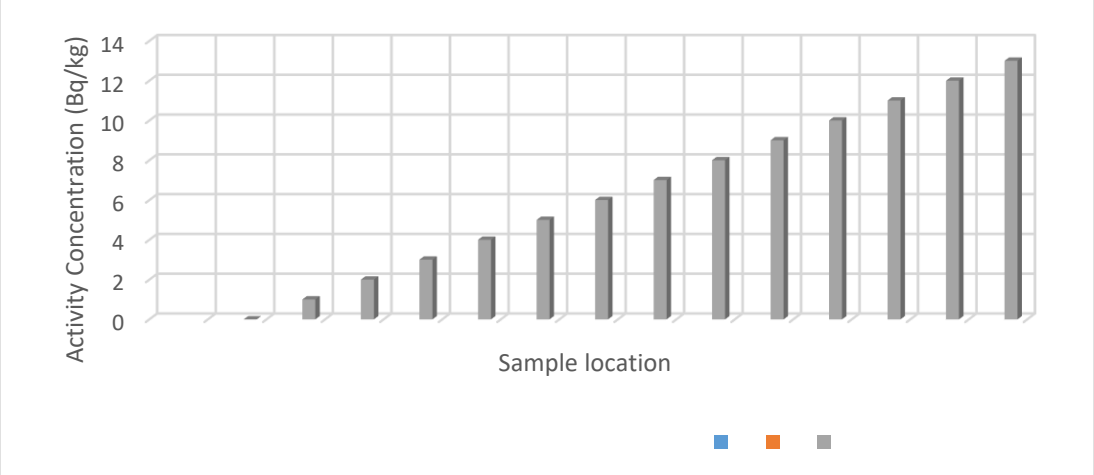


Figure 1: Activity of Radionuclides in Plant Samples.

Table 2: Activity Concentration of ^{238}U, ^{232}Th and ^{40}K of the Soil Sample Collected from the Study Area.

S/N	Sample Code	Sampling Coordinates		Activity Concentration Bq/kg		
		Latitude	Longitude	^{40}K	^{238}U	^{232}Th
1	Ss1	10^0.89′98″	9^0.60′074″	729.45±103.31	55.91±8.82	63.73±9.10
2	Ss2	10^0.89′99″	9^0.60′077″	336. 66±51.27	24.5±3.53	33.45±5.01
3	Ss3	10^0.89′92″	9^0.60′088″	610.38±91.54	46.73±7.53	52.41±7.86
4	Ss4	10^0.89′72″	9^0.6′009″	631.31±92.51	40.249±6.03	39.29±5.91
5	Ss5	9^0.784′595′′	9^0.39′8337′′	810.14±121.31	12.31±2.13	96.93±14.31
6	Ss6	9^0.784′74″	9^0.39′858″	521.33±8.23	33.41±6.81	58.7±8.71
7	Ss7	9^0.78′469″	9^0.39′867″	910.12±109.39	15.54±3.34	103.44±15.88
8	Ss8	9^0.78′445″	9^0.39′85″	731.23±98.33	11.45±1.94	87.21±12.87
9	Ss9	10^0.22′34″	9^0.40′269″	539.37±88.49	34.87±5.73	49.34±6.13
10	Ss10	10^0.22′367′′	9^0.40′338″	631.34±108.31	49.47±7.39	57.81±6.71
11	Ss11	10^0.22′071′′	9^0.40′39″	417.44±63.34	27.34±3.37	39.42±6.71
12	Ss12	10^0.22′16″6	9^0.40′368″	501.33±7.32	34.37±6.91	51.31±13.91
13	Ss13	9^0.78′41″	9^0.39′73″	639.14±98.21	15.14±3.39	89.39±13.91
14	Ss14	9^0.783′86″	9^0.39′672″	592.14±91.39	31.43±5.78	63.39±8.71
15	Ss15	9^0.78′474″	9^0.39′72″	623.32±97.43	47.31±6.39	59.43±8.61
	Max			**910.12±109.39**	**55.91±8.82**	**103.44±15.88**
	Min			**336. 66±51.27**	**11.45±1.94**	**33.45±5.01**
	Average			**634.86±75.858**	**32.00193±5.272**	**63.01667±9.622**

Where Ss1 to Ss15 are Soil Sample Collected from the Sample Site.

Table 2 presents the values of activity concentration of ^{40}K, ^{238}U, and ^{232}Th, in the soil samples collected from the study area. The activity of ^{40}K, ^{238}U, and ^{232}Th ranged from 336.66 ± 51.27 Bq/kg to 910.12 ± 109.39 Bq/kg with

mean value of 604.5427 ± 87.79 Bq/kg, 11.45 ± 1.94 Bq/kg to 55.91±8.82 Bq/kg with mean value of 26.35 ± 4.59 Bq/kg, 33.45±5.01 Bq/kg to 103.44±15.88 Bq/kg with mean value of 57.91 ± 7.99 Bq/kg respectively. Ss1 was found to have the highest activity concentration of 55.91±8.82 Bq/kg for ^{238}U, while Ss7 has highest activity concentration of 103.44±15.88 Bq/kg for ^{232}Th, while Ss7 was found to have the highest concentration of 910.12 ± 109.39 Bq/kg for ^{40}K. The least values for ^{40}K, ^{238}U, and ^{232}Th are found in Ss2 (336.66 ± 51.27 Bq/kg), Ss8 (11.45 ± 1.94 Bq/kg), and Ss2 (26.35 ± 4.59 Bq/kg) respectively. The figure 4.2 below represents the activity concentration in the soil samples.

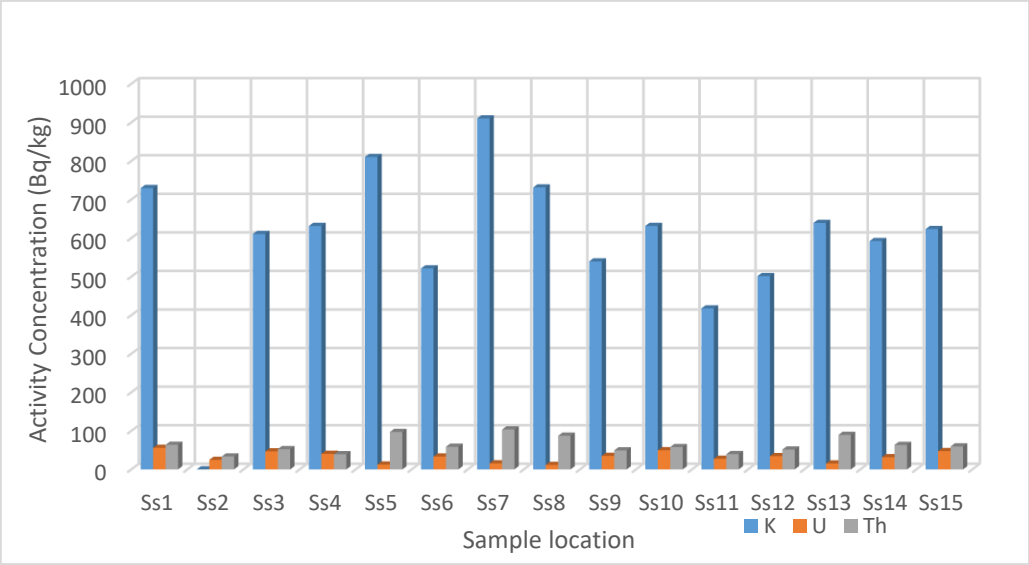


Figure 2: Activity of Concentration Level in Soil Samples.

Analysis of Results

The activity concentration of ^{40}K, ^{238}U, and ^{232}Th in the plant and soil samples from the study area is compared with results published by other authors and World average. The data analysis and results, transfer factor Gamma dose rate, Radium equivalent activity, External hazard indices, Representative level index, Activity utilization index, Annual effective dose rate, Annual gonadal dose rate, and Excess life cancer risk are calculated.

Transfer Factor

The uptake of radionuclide by plants from radioactive contaminated soil represents a key step of radionuclide input into the human food chain; this phenomenon is described by soil-plant transfer factor that is defined as the ratio between plant specific activity and soil specific activity. Plants are the primary recipients of radioactive contamination to the food chain following atmospheric releases of radionuclides. The transfer factor (TF) is a value used in evaluation studies on impact of routine or accidental releases of radionuclide into the environment for most important agricultural products is known.

Table 3: Activity Concentrations and Transfer Factors of Radionuclides.

Medicinal Plant	Sample ID	Activity Concentration		
		^{40}K	^{238}U	^{232}Th
Plant	PS1	692.45±95.13	24.71±5.23	59.33±9.38
Soil	SS1	729.45±103.31	55.91±8.82	63.73±9.10
TF	TF1	0.949277	0.44196	0.930959
Plant	PS2	296.18±46.91	15.2±2.81	28.38±4.88
Soil	SS2	336. 66±51.27	24.5±3.53	33.45±5.01
TF	TF2	0.879759	0.620408	0.84843
Plant	PS3	590.31±93.17	38.78±5.01	49.81±6.91
Soil	SS3	610.38±91.54	46.73±7.53	52.41±7.86
TF	TF3	0.967119	0.829874	0.950391
Plant	PS4	621.84±93.41	31.84±4.38	28.33±4.43
Soil	SS4	631.31±92.51	40.249±6.03	39.29±5.91
TF	TF4	0.984999	0.791076	0.721049

Plant	PS5	801.41±109.41	14.33±3.43	87.18±12.43
Soil	SS5	810.14±121.31	12.31±2.13	96.93±14.31
TF	TF5	0.989224	1.164094	0.899412
Plant	PS6	493.34±7.87	30.51±5.18	54.65±6.48
Soil	SS6	521.33±8.23	33.41±6.81	58.7±8.71
TF	TF6	0.94631	0.9132	0.931005
Plant	PS7	893.49±99.81	14.51±3.18	96.48±14.33
Soil	SS7	910.12±109.39	15.54±3.34	103.44±15.88
TF	TF7	0.981728	0.933719	0.932715
Plant	PS8	722.45±102.44	12.31±2.38	80.37±5.38
Soil	SS8	731.23±98.33	11.45±1.94	87.21±12.87
TF	TF8	0.987993	1.075109	0.921569
Plant	PS9	531.45±91.32	31.81±6.76	34.33±5.38
Soil	SS9	539.37±88.49	34.87±5.73	49.34±6.13
TF	TF9	0.985316	0.912245	0.695784
Plant	PS10	641.01±118.41	45.18±6.82	56.91±6.79
Soil	SS10	631.34±108.31	49.47±7.39	57.81±6.71
TF	TF10	1.015317	0.913281	0.984432
Plant	PS11	409.48±64.39	26.18±2.92	43.41±6.91
Soil	SS11	417.44±63.34	27.34±3.37	39.42±6.71
TF	TF11	0.980931	0.957571	1.101218
Plant	PS12	491.49±91.23	33.81±6.54	49.49±6.94
Soil	SS12	501.33±7.32	34.37±6.91	51.31±13.91
TF	TF12	0.980372	0.983707	0.964529
Plant	PS13	629.31±94.84	14.38±3.18	79.81±12.41
Soil	SS13	639.14±98.21	15.14±3.39	89.39±13.91
TF	TF13	0.98462	0.949802	0.892829
Plant	PS14	591.28±89.13	23.41±5.18	59.89±7.91
Soil	SS14	592.14±91.39	31.43±5.78	63.39±8.71
TF	TF14	0.998548	0.74483	0.944786
Plant	PS15	614.18±119.38	38.34±5.93	60.31±9.39
Soil	SS15	623.32±97.43	47.31±6.39	59.43±8.61
TF	TF15	0.985337	0.810399	1.014807

The soil-to-plant transfer factor (TF) was calculated from activity of soil and corresponding activity of plants using equation 1 and are presented in Table 4.3 above. The mean transfer factors of ^{40}K, ^{238}U, and ^{232}Th are 0.974457, 0.869418 and 0.915594 Bqkg^{-1}, and ranged from 0.879759 to 1.015317 Bq Kg^{-1}, 0.44196 to 1.164094 Bqkg^{-1} and 0.695784 to 1.101218 Bqkg-1 respectively. SS5 has the highest TF value for ^{238}U (1.164094 Bqkg^{-1}), ^{232}Th (1.101218 Bqkg^{-1}) at SS11and ^{40}K (1.015317 Bqkg^{-1}) at SS10, while the lowest TF value are observed for ^{238}U (0.44196 Bqkg^{-1}) at SS1, ^{232}Th (0.695784 Bqkg^{-1}) at SS9 and ^{40}K (0.879759 Bqkg^{-1}) at SS2. Transfer factor depends upon many factors such as: PH, electrical conductivity (EC), and bicarbonate contents of soil, etc. Soil of all samples under study was geologically the same and climatic conditions are also similar. Organic fertilizer affects the ion exchange capacity, stable element content of soil, pH, as well as soil retention properties (Routson & Cataldo, 1978). Figure 4.3 shows the transfer factor for the radionuclides assessed.

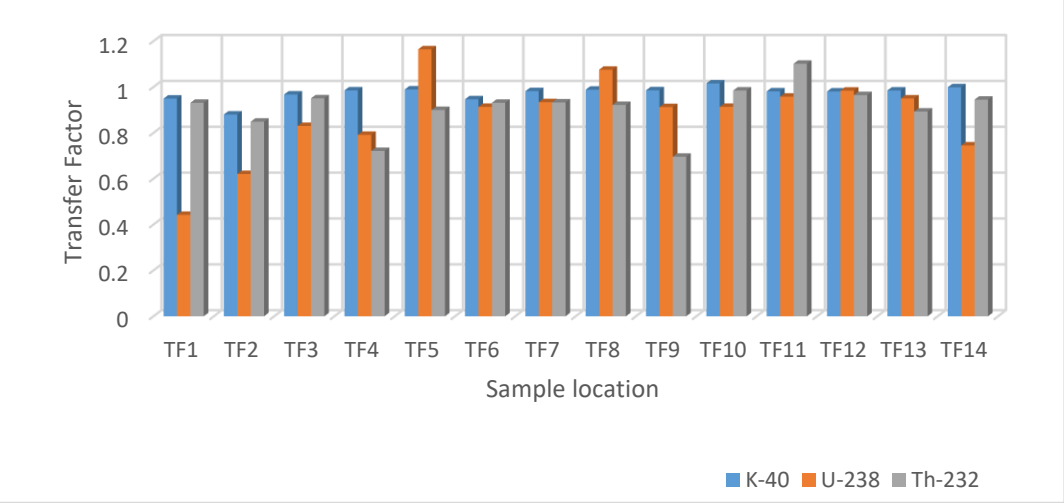


Figure 3: Soil to Plant Transfer Factors (TF) of Radionuclides.

Radiological Hazard

The radiological hazard assessment has been carried out by evaluating the Gamma dose rate, Radium equivalent activity, External hazard indices, Annual effective dose rate, Annual gonadal dose rate, and Excess life cancer risk for the soil samples are presented in Table 4.

Table 4: Calculated Radiological Hazards Parameters for Plant Sample.

S/N	Sample Code	D (nGy/h)	Ra_{eq} (Bq/kg)	HI(ex) (mSv/yr)	AEDE (mSv/yr)	ELCR (µSv/y)
1	PS1	76.12651	162.8706	0.439818	0.093362	0.326765
2	PS2	36.51463	78.58926	0.212232	0.044782	0.156735
3	PS3	72.61753	155.4622	0.419853	0.089058	0.311703
4	PS4	57.75213	120.2336	0.324717	0.070827	0.247895
5	PS5	92.69598	200.706	0.541945	0.113682	0.397888
6	PS6	67.6765	146.6467	0.396029	0.082998	0.290495
7	PS7	102.2361	221.2751	0.597483	0.125382	0.438838
8	PS8	84.35687	182.8678	0.493777	0.103455	0.362093
9	PS9	57.59301	121.8236	0.32901	0.070632	0.247212
10	PS10	81.97692	175.9191	0.475104	0.100536	0.351878
11	PS11	55.39012	119.7863	0.323494	0.06793	0.237757
12	PS12	66.00731	142.4254	0.38464	0.080951	0.28333
13	PS13	81.09103	176.9652	0.477845	0.09945	0.348075
14	PS14	71.64536	154.5813	0.417433	0.087866	0.307531
15	PS15	79.75163	171.8752	0.464167	0.097807	0.342326

The Gamma dose rate, Radium equivalent activity, External hazard indices, Annual effective dose rate, and Excess life cancer risk were calculated from the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th measured from plant sample are presented in Table 4.4. The value of gamma dose rate ranged from 36.51463 nGy/h to 102.2361 nGy/h, with a mean value of 72.22877 nGy/h. The values for the radium equivalent ranged from 78.58926 Bq/kg to 221.2751 Bq/kg, with a mean value of 155.4685 Bq/kg. The estimated external hazard index ranged from 0.212232 mSv/y to 0.597483 mSv/y, with mean value of 0.419836 mSv/y. The Annual effective dose rate was computed for the measured activity concentration of ^{40}K, ^{238}U, and ^{232}Th and the values ranged from 0.044782 mSv/y to 0.125382 mSv/y, with a mean value of 0.088581 mSv/y. The value of excess life cancer risk ranged from 0.156735 to 0.438838, with a mean value of 0.310035. Figure 4.4 below shows the hazard indices for all radionuclides.

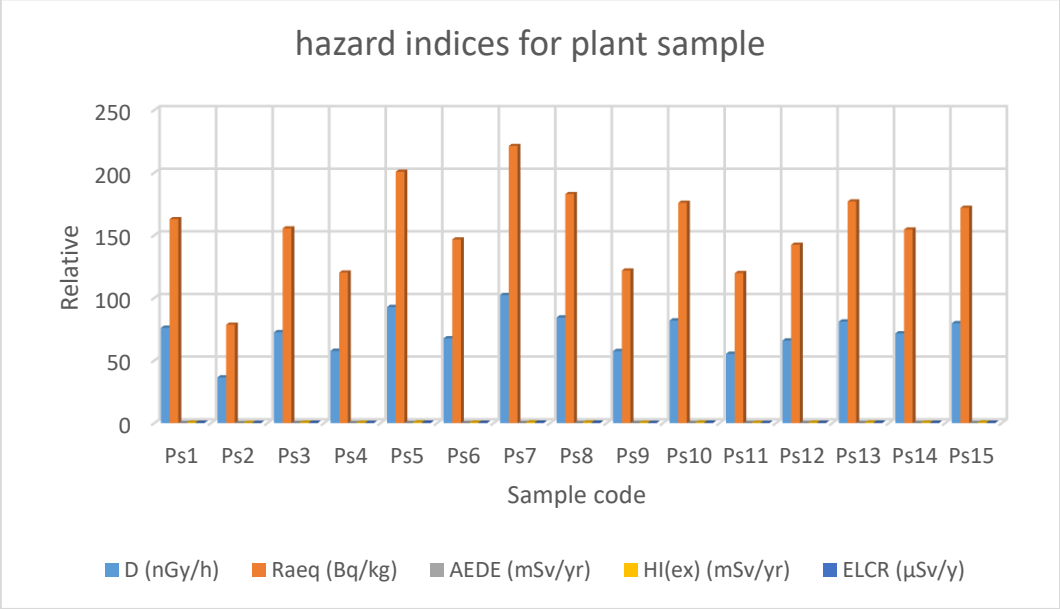


Figure 4: The Gamma Dose Rate, Radium Equivalent Activity, External Hazard Indices, Annual Effective Dose Rate, and Excess Life Cancer Risk were Calculated from the Activity Concentrations of ^{40}K, ^{238}U, and ^{232}Th Measured from Plant Sample.

Table 5: Calculated Radiological Hazards Parameters for Soil Sample.

S/N	Sample Code	D (nGy/h)	Ra_{eq} (Bq/kg)	HI(ex) (mSv/yr)	AEDE (mSv/yr)	ELCR (µSv/y)
1	SS1	94.74141	708.7204	0.548823	0.116191	0.406668
2	SS2	45.56152	98.2563	0.265358	0.055877	0.195568
3	SS3	78.69775	591.6689	0.455551	0.096515	0.337802
4	SS4	68.65183	582.5424	0.391729	0.084195	0.294681
5	SS5	98.01578	774.7277	0.575946	0.120207	0.420723
6	SS6	72.62968	518.7751	0.425323	0.089073	0.311756
7	SS7	107.6092	864.2516	0.630596	0.131972	0.461902
8	SS8	88.45703	699.2074	0.519687	0.108484	0.379693
9	SS9	68.40303	520.7411	0.39688	0.083889	0.293613
10	SS10	84.09926	618.2701	0.488163	0.103139	0.360988
11	SS11	53.84801	405.1394	0.312879	0.066039	0.231137
12	SS12	67.77564	493.7674	0.395227	0.08312	0.29092
13	SS13	87.63838	635.1055	0.518931	0.10748	0.376179
14	SS14	77.50046	578.0255	0.452801	0.095047	0.332663
15	SS15	83.74538	612.2513	0.486913	0.102705	0.359469

The Gamma dose rate, Radium equivalent activity, External hazard indices, Annual effective dose rate, Annual gonadal dose rate, and Excess life cancer risk were calculated from the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th measured from soil sample are presented in Table 4.5. The value of gamma dose rate ranged from 45.56152 nGy/h to 107.49163 nGy/h, with a mean value of 78.49163 nGy/h. The values for the radium equivalent ranged from 98.2563 Bq/kg to 864.2516 Bq/kg, with a mean value of 580.0967 Bq/kg. The estimated external hazard index ranged from 0.26535 mSv/y to 0.630596 mSv/y, with mean value of 0.457654 mSv/y. The Annual effective dose rate was computed for the measured activity concentration of ^{40}K, ^{238}U, and ^{232}Th and the values ranged from 0.055877 mSv/y to 0.131972 mSv/y, with a mean value of 0.096262 mSv/y. The value of excess life cancer risk ranged from 0.195568 to 0.461902 with a mean value of 0.336917. The value of annual gonadal dose equivalent ranged from 180.009 to 390.293, with a mean value of 299.502. Figure 4.5 shows the hazard indices for soil samples collected.

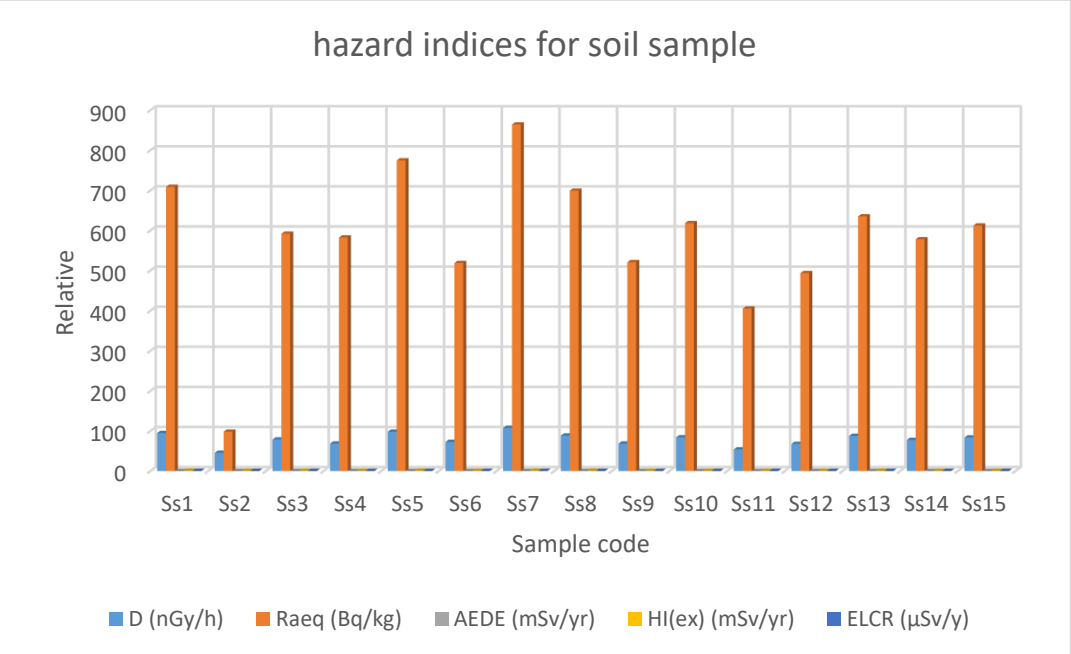


Figure 5: The Gamma dose rate, Radium equivalent activity, External hazard indices, Annual effective dose rate, and Excess life cancer risk were calculated from the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th measured from soil sample.

Table 4: Comparison of the results of the present study (soil) with similar published data

Reference	Country	^{238}U	^{232}Th	^{40}K
Present study	Nigeria (Niger State)	32.00193	63.0166	634.86
Ademola and Ademonehin (2010)	Nigeria (Ondo State)	39.8	17.7	384.2
Innocent *et al*. (2013)	Nigeria (Zamfara State	12.1	60.1	426.5
Faanu *et al.* (2011)	Ghana	13.6	24.2	162.1
UNSCEAR (2000)	World Average	35	30	420

Higher activity concentration was determined by Ademola and Ademonehin (2010), while lower activity concentration was determined by Ademola and Obed (2012) and Innocent *et al*. (2013); in Nigeria' and Ephraim (2011) in Ghana for ^{238}U and compared to this study. The activity concentration of ^{238}U estimated in this study is lower than the world average (UNSCEAR, 2000). The average activity concentration of ^{232}Th obtained in this study is higher than that obtained in Nigeria by Ademola and Ademonehin (2010) and Faanu *et al.,* (2011). ^{232}Th concentration in the study site is also higher than that which is obtained by Innocent *et al*. (2013), and the world's average (UNSCEAR, 2000). Similar to what was obtained in this study, other studies as can be seen in Table 4.6 also indicated that concentrations of ^{40}K in soil samples are significantly higher than the concentration of ^{238}U and ^{232}Th. The average activity concentration of ^{40}K in this study is as well higher than the world average.

Discussion of Findings

Radionuclide activity concentrations in the plant and soil samples varied within the study area due to the differences in geological structure or formation of the area. The activity of ^{40}K, ^{238}U, and ^{232}Th in the sampled plant and soil ranged from 296.18 ± 46.91Bq/kg to 893.49 ± 99.81Bq/kg with mean value of 601.31 ± 87.79 Bq/kg, (plant) 336.66 ± 51.27 Bq/kg to 910.12 ± 109.39 Bq/kg with mean value of 604.5427 ± 87.79 Bq/kg (soil), 12.31 ± 2.38 Bq/kg to 45.18 ± 6.82 Bq/kg with mean value of 26.35 ± 4.59 Bq/kg, (plant), 11.45 ± 1.94 Bq/kg to 55.91±8.82 Bq/kg with mean value of 26.35 ± 4.59 Bq/kg(soil), and 28.33 ± 4.88 Bq/kg to 96.48 ± 14.33 Bq/kg with mean value of 57.91 ± 7.99 Bq/kg (plant), 33.45±5.01 Bq/kg to 103.44±15.88 Bq/kg with mean value of 57.91 ± 7.99 Bq/kg(soil) respectively. Ps15 (38.34 ± 5.93 Bq/kg) and Ss1 (55.91±8.82 Bq/kg) were found to have the highest activity concentration of for ^{238}U, Ps5 (87.18 ± 12.43 Bq/kg) and Ss7 (103.44±15.88Bq/kg) has highest activity concentration for ^{232}Th, while Ps7 (893.49±99.81 Bq/kg) and (910.12±109.39Bq/kg) were found to have the highest concentration for ^{40}K. The least values for ^{40}K, ^{238}U, and ^{232}Th are found in Ps2 (296 ± 46.91 Bq/kg), Ss2 (336.66±51.27Bq/kg), Ps8 (12.31±2.38 Bq/kg), Ss8 (11.45 ±1.94 Bq/kg) and Ps4 (28.33±4.43Bq/kg), Ss2 (26.35±4.59 Bq/kg) respectively. Comparison of the soil results obtained in the mining site with published data from similar investigations in Nigeria, Ghana and the world average are presented in table 4.6 below.

The outdoor average dose rate (soil) from terrestrial gamma rays ranged from 45.56 nGy/h to 107.61 nGy/h, with a mean value of 78.49 nGy/h. This mean value is higher than the worldwide average of 59 nGy/h (UNSCEAR, 2000). The AEDE values for the Abuni, Awe Local Government Area of Nasarawa State were also calculated. They were found to be in the range 0.0559 to 0.1319 mSv/y with an average of 0.0963 mSv/y. Although some AEDE values were below the worldwide average of 0.48 mSv. The International Commission on Radiation Protection (ICRP) recommends the AEDE limit of 1 mSv/y for individual members of the public and 20 mSv/y for radiation workers. In South Africa, the dose constraint applicable to the average member of a critical group from a single source within the exposed population is 0.25 mSv per annum. This means that the AEDE average values from Abuni, Awe Local Government Area of Nasarawa State were considered safe to the population.

Higher activity concentration was determined by Ademola and Ademonehin (2010), while lower activity concentration was determined by Ademola and Obed (2012) and Innocent *et al*. (2013); in Nigeria' and Ephraim (2011) in Ghana for ^{238}U and compared to this study. The activity concentration of ^{238}U estimated in this study is lower than the world average (UNSCEAR, 2000). The average activity concentration of ^{232}Th obtained in this study is higher than that obtained in Nigeria by Ademola and Ademonehin (2010) and Faanu *et al.,* (2011). ^{232}Th concentration in the study site is also higher than that which is obtained by Innocent *et al*. (2013), and the world's average (UNSCEAR, 2000). Similar to what was obtained in this study, other studies as can be seen in Table 4.6 also indicated that concentrations of ^{40}K in soil samples are significantly higher than the concentration of ^{238}U and ^{232}Th. The average activity concentration of ^{40}K in this study is as well higher than the world average.

Conclusion

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil and plant samples in Abuni, Awe Local Government Area of Nasarawa State was done using NaI (Tl) gamma ray spectrometry. The results obtained showed that the distribution of natural radionuclides in the soil samples was not uniform and artificial radionuclide was not detected in any sample measured. The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the soil samples from the study

area were estimated and were found to be higher than the world average. The results in this study area show that there are higher levels of the natural radionuclides in the areas than the worldwide average. Therefore, mining activities in Abuni, Awe Local Government Area of Nasarawa State may pose a significant radiological hazard to the host communities if not checked.

Recommendations

It is recommended that elemental concentration of heavy toxic metals should be carried out to investigate the presence of heavy metal in water, soil and some edible plant in the area.

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