Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/080111

Statistical Analysis of Naturally Occurring Radionuclides arising from Mining Activities in Adamawa State, Nigeria.

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Received: 9 Oct. 2022, Revised: 3 Nov. 2022, Accepted: 11 Dec. 2022
Published online: 1 Jan. 2023.

Abstract: Mining is important, but if the activities are not under control, the host community and the general public may suffer negative impacts such as radiation exposure, environmental degradation, and the transfer of natural radionuclides from soil to plants among others. This study, statistically analysed the distribution of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K from soil and plants samples obtained from four mine sites in Adamawa State, Nigeria. The representative soil and plants samples obtained from the four mining sites were analysed using Sodium Iodide NaI (Tl) detector at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples were found to be 107.60 Bq/kg, 84.89 Bq/kg, and 475.34 Bq/kg while that of plant samples were 99.02 Bq/kg, 73.24 Bq/kg and 269.4 Bq/kg respectively. These values were all higher than the United Nations Scientific Community on the effects of Atomic Radiation (UNSCEAR's) world standard values of 32 Bq/kg, 45 Bq/kg and 420 Bq/kg for soil and plants except for ^{40}K which was lower in plant samples. Though, high activity concentrations poses significant hazard to the host communities around the mining sites that have extreme values, the competent Authority saddled with the responsibility of ensuring compliance with radiation protection standards in Nigeria need to establish the safety reserves from these mining areas for proper guidelines that will ensure suitable protection of the host communities. Awareness for the communities around the mining sites is necessary, in order to understand the detrimental effects of the natural radionuclides in soil and plant present around the vicinity of the mines, which could results to harmful effects to both the public and the environmental.
Keywords: Mining, Natural Occurring Radionuclides, Activity Concentration, Radiation Exposure, Radiation Protection.

1 Introduction

Naturally Occurring Radioactive Materials are mostly found in the planet's, rocks, and minerals, which are extensively dispersed in the soil's surroundings and are primarily influenced by environmental and physical elements that can be found at different levels. These naturally occurring radioactive materials, which can be found in varying proportions in many kinds of rare resources and are commonly referred to as primordial radionuclides, include uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K) [1].

By facilitating the release of radioactive materials from the host materials and creating an unreasonable radiation risk to human due to the nature of the radioactive daughter products of ^{238}U, ^{232}Th, decay series and ^{40}K [1]. Mining activities have had a negative impact on humans and the environment even at low concentrations. The activity concentrations these radionuclides are low in their natural state, but human activities can enhance them to build up above the background levels, thus leading to a radiological concern and endangering the public [2]. Environmental problems associated with NORMs can be caused by a number of factors, and they frequently contaminate the environment and put people at risk of radiation exposure, due to the health risks associated with exposure to NORMs and inhalation of radon's decay products [3]. One of the most significant sources of exposure to these radionuclides with long half-lives is through mining, which entails physically extracting minerals from the surface of the ground (Soja et al., 2022). Prominent International regulatory agencies such as United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and International Commission for Radiological Protection (ICRP) has established stringent measures of mitigating public and workers from unjustifiable radiation exposure [2]. Many studies were reported in the literature to have measured the activity concentration of NORMs resulting from mining activities at different part of Nigeria, some with values beyond or below the world averages due to the differences in the mineral

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concentration and geological settings of the areas studied [4-15]. The large amount of these radionuclides in rocks and soils greatly enhances the background radiation dose that people are exposed to. High levels of radionuclides and the radiation they emitted, have the potential to affecting human health by disrupting the body systems [15,16]. Therefore, from the perspective of public health, assessing the NORMs level in ambient samples is significant. Thus, this study been the first of its kind in the study area, aimed at assessing and statistically analysing the distribution of the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K from representatives soil and plants samples from four mine sites in Adamawa State, Nigeria.

2 Materials and Methods

2.1 Description of Study Area

According to the 2006 census, the population of Adamawa State, which has a land area of 39,742.12 km^2 and is situated in northern Nigeria between latitudes 80 and 110 N and longitudes 11.50 and 13.50 E, was 3,168,101. There are 21 Local Government Areas (LGAs) and 37 Development Areas in the state [17]. Essentially, the state is a beautiful mountainous region crossed by the large river valleys of the Benue, Gongola, and Yadzaram. Solid minerals such uranium, granite, lead, zinc, marble, limestone, tin, barites, iron, silica, columbite, magnites, mercury, gold, and diamond are abundant in the region.

2.2 Sample Collection and Preparation

A total of fifteen representative soil and plant samples were obtained from four mining sites at 500 meters apart using regular stratified sampling. Composite samples were obtained and placed in a well labeled polyethylene bags to avoid cross-contamination during processing. Sandstone fragments were crushed into a granular consistency with a mortar and pestle for uniformity, and air dried at room temperature for seven days to remove moisture content. Approximately 400 g of the dried samples were sealed in Marinelli beakers for 28 days to create secular equilibrium between ^{226}Ra, ^{232}Th, and ^{40}K and their daughter products. The coordinates of each sample collected from the four mining sites are presented in Table 1.

Table 1: Mining locations and Geographical Coordinates of samples collected.

Mining Sites	Soil Sample Code *	Plant Sample Code **	Geographical Coordinates Latitude	Longitude
Raycon Fufore	R-S 1	R-P 1	09^{0} 08' 36"	12^{0} 19' 09"
	R-S 2	R-P 2	09^{0} 08' 29"	12^{0} 19' 19"
	R-S 3	R-P 3	09^{0} 08' 23"	12^{0} 19' 04"
	R-S 4	R-P 4	09^{0} 08' 39"	12^{0} 19' 14"
NRC Demsa	NRC-S 1	NRC-P 1	09^{0} 21' 48"	12^{0} 11' 32"
	NRC-S 2	NRC-P 2	09^{0} 21' 42"	12^{0} 11' 28"
	NRC-S 3	NRC-P 3	09^{0} 21' 36"	12^{0} 11' 22"
	NRC-S 4	NRC-P 4	09^{0} 21' 53"	12^{0} 11' 19"
Ministry Demsa	M-S 1	M-P 1	09^{0} 21' 55"	12^{0} 11' 23"
	M-S 2	M-P 2	09^{0} 21' 51"	12^{0} 11' 20"
	M-S 3	M-P 3	09^{0} 21' 45"	12^{0} 11' 17"
	M-S 4	M-P 4	09^{0} 21' 59"	12^{0} 11' 13"
AG Vision Song	AG-S 1	AG-P 1	09^{0} 56' 15"	12^{0} 37' 46"
	AG-S 2	AG-P 2	09^{0} 56' 19"	12^{0} 37' 39"
	AG-S 3	AG-P 3	09^{0} 56' 11"	12^{0} 37' 44"

*S- Soil sample, **P- Plant sample

2.3 Sampling Analysis

Representatives soil and plant samples obtained from the study area were analyzed for Activity Concentration (AC) of ^{226}Ra, ^{232}Th, and ^{40}K using a well-calibrated NaI (Tl) detector at the Centre for Energy Research and Training (CERT) , Ahmadu Bello University Zaria, Nigeria.

2.4 Summary of Scenario Description

The structural diagram showing summary of scenario description for statistical analysis of radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K from representative soil and plants samples obtained from four mining sites in Adamawa State, Nigeria is presented in Figure 1.

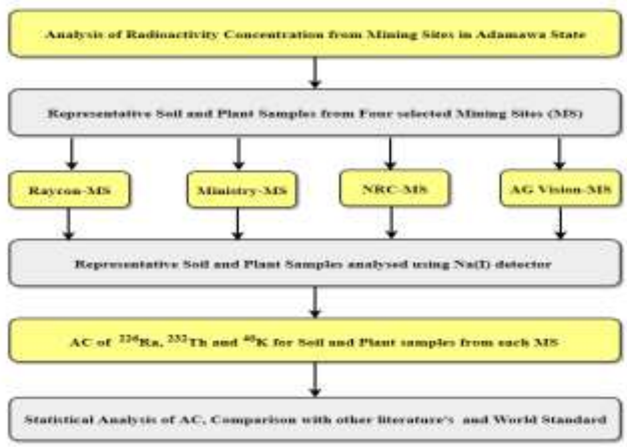

Fig. 1: Scenario Description.

2.5 Statistical Analysis

The statistical analysis to be perform in this study using the determine activity concentration of of ^{226}Ra, ^{232}Th and ^{40}K from representative soil and plants samples obtained from four mining sites in Adamawa State includes mean, median, standard deviation, standard error of mean, first, quartile, third quartile, maximum and minimum values as well as range.

3 Results and Discussion

3.1 Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in Soil Samples

The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples obtained from the four selected mining sites in the study area is presented in Table 2.

Table 2: Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K from soil samples.

Soil Sample	Ra-226 (Bq/Kg)	Th-232 (Bq/Kg)	K-40 (Bq/Kg)
R-Soil 1	88.29	78.72	1080.28
R-Soil 2	120.29	92.67	1074.70
R-Soil 3	104.59	92.79	941.28
R-Soil 4	121.72	76.67	342.61
Average	**108.72**	**85.21**	**859.72**
NRC-Soil 1	99.83	73.02	368.83
NRC-Soil 2	114.29	157.24	251.34
NRC-Soil 3	95.92	76.59	441.98
NRC-Soil 4	144.97	81.31	527.35
Average	**113.75**	**97.04**	**397.38**
M-Soil 1	104.91	110.64	295.05
M-Soil 2	124.40	92.40	352.96
M-Soil 3	110.38	52.92	261.69
M-Soil 4	122.64	60.00	208.01
Average	**115.58**	**78.99**	**279.43**
AG-Soil 1	89.37	82.49	174.07
AG-Soil 2	75.54	64.09	45.67
AG-Soil 3	96.80	81.74	764.32
Average	**87.24**	**76.11**	**328.02**
Overall Average	**107.60**	**84.89**	**475.3**
UNSCEAR	**32**	**45**	**420**
AC Ratio	**3.363**	**1.886**	**1.132**

From Table 2, the sequence of average activity concentration of ^{226}Ra from the four mining sites is M-Soil (115.58 Bq/kg) > NRC-Soil (113.75 Bq/kg) > R-Soil (108.72 Bq/kg) > AG-soil (87.24 Bq/kg), with an overall average value of 106.32 Bq/kg. The average values from the separate mining sites and the overall average were all higher than the recommended UNSCEAR world average value of 32 Bq/kg. The AC ratio for ^{226}Ra which is the ratio of the overall average and the UNSCEAR standard is 3.363

The sequence of average activity concentration of ^{232}Th from the four mining sites is NRC-Soil (97.04 Bq/kg) > R-Soil (85.21 Bq/kg) > M-Soil (78.99 Bq/kg) > AG-soil (76.11 Bq/kg), with an overall average value 84.34 Bq/kg for the four (4) mining sites. The average values from the separate mining sites and the overall average were all higher than the recommended UNSCEAR world average value 45 Bq/kg. The AC ratio for ^{232}Th is 1.886

The sequence of average activity concentration of ^{40}K from mining sites is R-Soil (859.72 Bq/kg) > NRC-Soil (397.38 Bq/kg) > AG-Soil (328.02 Bq/kg) > M-Soil (279.43 Bq/kg). The result shows that the average activity concentration of ^{40}K from mining site R-soil was beyond the UNSCEAR suggested value, while the average values from NRC-Soil, M-Soil and AG-Soil were all lower than the UNSCEAR recommended value of 420 Bq/kg. However, the overall average activity concentration of ^{40}K in representative soil samples for four (4) mining sites considered in this study is 466.14Bq/kg, higher than the UNSCEAR commended value of 420 Bq/kg. The AC ration of ^{40}K is 1.132

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K from the soil samples varies across each mining sites with their overall average values as 107.60 Bq/kg, 84.89 Bq/kg and 475.3 Bq/kg respectively which are all beyond the UNSCEAR's recommended boundaries of 32 Bq/kg, 45 Bq/kg and 420 Bq/kg. The pattern of activity concentration ratio from the representative soil samples obtained from four mining sites considered in this study were: ^{226}Ra > ^{232}Th > ^{40}K. The high activity concentration and concentration ratio implies that ^{226}Ra and ^{232}Th poses more risk to the public than ^{40}K due to their respective gaseous daughter products (Radon and Thoron) emanating thereof.

3.2 Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in Plant Samples

The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in plant samples d from the four selected mining sites in within the study area is presented in Table 3.

Table 3: Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K from plant samples.

Plant Sample Code	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg)
R-Plant 1	91.92	68.3	236.92
R-Plant 2	79.7	76.75	223.67
R-Plant 3	114.09	69.47	204.85
R-Plant 4	96.88	89.14	217.72
Average	**95.65**	**75.92**	**220.79**
NRC-Plant 1	84.57	92.2	246.25
NRC-Plant 2	121.72	93.58	253.27
NRC-Plant 3	91.88	54.18	139
NRC-Plant 4	92.6	68.38	231.66
Average	**97.69**	**77.09**	**217.55**
M-Plant 1	139.54	54.06	316.23
M-Plant 2	116.97	84.26	150.58
M-Plant 3	79.62	96.96	524.72
M-Plant 4	107.94	58.15	264.43
Average	**111.02**	**73.36**	**313.99**
AG-Plant 1	91.32	57.68	285.55
AG-Plant 2	79.5	77.38	233.32
AG-Plant 3	97.11	58.11	512.98
Average	**89.31**	**64.39**	**343.95**
UNSCEAR	**32**	**45**	**420**

Overall Average	**99.02**	**73.24**	**269.4**
AC Ratio	**3.09**	**1.63**	**0.640**

From Table 3, the sequence of average activity concentration of ^{226}Ra in the plant samples from the four selected mining sites is M-plant (111.02Bq/kg) > NRC-Plant (97.67 Bq/kg) > R-Plant (95.65 Bq/kg) > AG-Plant (89.31 Bq/kg), with an overall average value 98.42 Bq/kg. Both the overall average values from the individual mining sites and the total average value from all the four mining site were all above the UNSCEAR recommended value of 32 Bq/kg. The AC ratio of ^{226}Ra from representative plant across mining locations is 3.092

The sequence of average activity concentration of ^{232}Th from representative plant samples obtained from the four mining sites is NRC-Plant (77.09 Bq/kg) > R-Plant (75.92 Bq/kg) > M-Plant (73.36 Bq/kg) > AG-Plant (64.39 Bq/kg). The overall average value from the four (4) mining sites is 72.69 Bq/kg. The average values from the separate mining sites and the total average were all above the UNSCEAR average value of 45 Bq/kg. The AC ratio of ^{232}Th from representative plant across mining locations is 1.63 2.423

The sequence of average activity concentration of ^{40}K in plant samples amongst the individual mining sites is AG-Plant (343.95 Bq/kg) > M-Plant (313.99 Bq/kg) > R-Plant (220.79 Bq/kg) > NRC-Plant (217.55 Bq/kg), with an overall average value 274.07 Bq/kg for the four (4) mining sites. The average values from the separate mining sites and the total average values were all lower than the UNSCEAR commended value of 420 Bq/kg. The activity concentration of ^{40}K in plant samples across mining locations is 0.64

The activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in the plant samples differs with respect to different mining sites with total average values 99.02 Bq/kg, 73.24 Bq/kg and 269.4Bq/kg respectively. The average values of ^{226}Ra and ^{232}Th were higher than the UNSCEAR's boundary standard limits 32 Bq/kg and 45 Bq/kg, while that of ^{40}K falls short of the UNSCEAR's limit of 420 Bq/kg.

The sequence of AC ratio in the plant samples were: ^{226}Ra > ^{232}Th > ^{40}K, the results shows that the public are more exposed to ^{226}Ra and ^{232}Th than ^{40}K. comparing the AC ratio from representative soil and plant samples obtained from four mining sites considered in this study, the results implies that ^{226}Ra and ^{232}Th presents in soil samples have the affinity of been transferred into plants via a phenomenon described as transfer factors which might result contamination of plants and internal hazard to the consumers when ingested.

3.3 Statistical Analysis of Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in Soil and Plant Samples

The descriptive statistical summary for the measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil and plants samples within the study area is presented in Table 4 and Table 5.

Table 4: Descriptive Statistics of AC for ^{226}Ra, ^{232}Th and ^{40}K in Soil Samples

Statistical Parameters	**Ra-226 (Bq/kg)**	**Th-232 (Bq/kg)**	**K-40 (Bq/kg)**
Mean	107.60	84.89	475.3
SE Mean	5.53	6.36	85.9
St Dev	17.65	24.63	332.6
Minimum	75.54	52.92	45.7
Q1	95.92	73.02	251.3
Median	104.91	81.31	353.0
Q3	121.72	92.67	764.3
Maximum	144.97	157.24	1080.3
Range	69.43	104.32	1034.6

Table 5: Descriptive Statistics of AC for ^{226}Ra, ^{232}Th and ^{40}K in Plants Samples

Statistical Parameters	**Ra-226 (Bq/kg)**	**Th-232 (Bq/kg)**	**K-40 (Bq/kg)**
Mean	99.02	73.24	269.4
SE Mean	4.54	3.92	28.6
St Dev	17.60	15.19	110.7
Minimum	79.50	54.06	139.0
Q1	84.57	58.11	217.7
Median	92.60	69.47	236.9
Q3	114.09	89.14	285.6
Maximum	139.54	96.96	524.7
Range	60.04	42.90	385.7

From Table 4 and 5, the average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples obtained from the four mining sites are 107.60 Bq/kg, 84.89 Bq/kg and 475.3 Bq/kg respectively, all beyond the UNSCEAR's recommended boundaries of 32Bq/kg, 45Bq/kg and 420Bq/kg, while that of plants samples are 99.02Bq/kg, 73.24Bq/kg and 269.4Bq/kg respectively with values of ^{226}Ra and ^{232}Th higher than the UNSCEAR's standards values of 32Bq/kg and 45Bq/kg, while that of ^{40}K falls short of the UNSCEAR's limit of 420Bq/kg.

The minimum/maximum values of activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples are 75.54 Bq/kg/114.97 Bq/kg, 52.92 Bq/kg/157.24 Bq/kg, and 45.7Bq/kg/1080.3 Bq/kg, while that of plant samples are 79.50 Bq/kg/139.54 Bq/kg, 54.06 Bq/kg/96.96 Bq/kg, and 139.0 Bq/kg/524.7 Bq/kg respectively.

The spread and distribution of the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples shows that 95.92 Bq/kg, 73.02 Bq/kg and 251.3 Bq/kg fall below 25th percent (first quartile-Q1) 104.91 Bq/kg, 81.31 Bq/kg and 353.0 Bq/kg fall half of data set (median), and 121.72 Bq/kg, 92.67 Bq/kg and 764.3 Bq/kg falls below the 75th percent (third quartile-Q3) of the activity concentrations values

The spread and distribution of activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in plant samples shows that 84.57

Bq/kg, 58.11 Bq/kg and 217.7 Bq/kg fall below 25th percent (first quartile-Q1), 92.60 Bq/kg, 69.47 Bq/kg and 236.9 Bq/kg fall half of data set (median), and 114.09 Bq/kg, 89.14 Bq/kg and 285.6 Bq/kg falls below the 75th percent (third quartile-Q3) of activity concentrations values

3.4 Comparism of Mean Activity Concentrations from Soil and Plants Samples with Reference Standard

The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil and plants samples collected at different sampling points from the four selected mining locations considered in this study was compared with the reference standard and the result are presented in Figure 2.

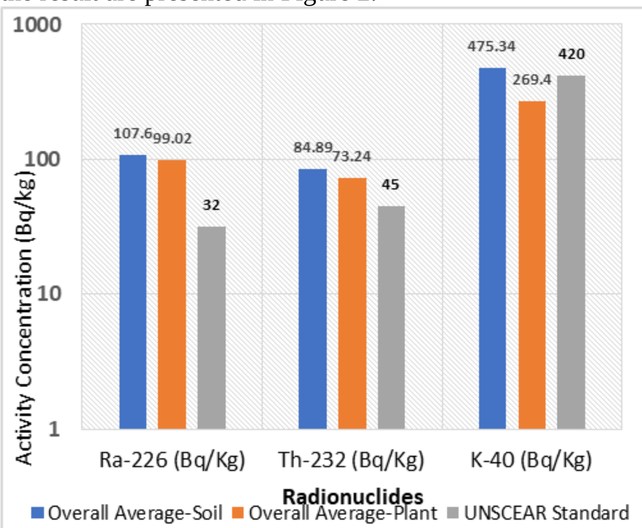

Fig.2: Comparison of Average AC in Soil and Plants with UNSCEAR Reference Standard.

3.5 Comparism of Mean Activity Concentrations from Soil Samples with Other Studies

The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil and plants samples collected at different sampling points from the four selected mining locations considered in this study was compared with that of other regions/countries and world average and the result are presented in Table 6.

Table 6: Comparism of Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples with other studies

Country	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Reference
Nigeria (Adamawa)	107.596±11.2	84.856±6.23	475.343 ±12.3	Present Study
Nigeria (Ekiti)	76 ± 7	32 ± 2	593 ± 34	[3]
Nigeria (Taraba)	78 ± 3	31 ± 1	341 ± 19	[3]
Nigeria (Jos)	46.47 ± 5.19	396.17 ± 7.69	161.96 ± 7.56	[4]
Nigeria (Oyo)	3.16 ± 1.91	56.70 ± 8.78	381. 69 ± 12.53	[6]
Nigeria (Abia)	76.31 ± 2.21	47.15 ± 2.16	173 ± 4.07	[18]
Nigeria (Oyo)	32.66 ± 2.12	54.00 ± 1.50	76.31 ± 2.21	[7]
Nigeria (Kano)	62.73± 1.01	90.99± 1.02	411.27± 1.07	[9]
Nigeria (Anka)	41.60±11.06	151.15±21.09	380.34± 116.41	[13]
Nigeria	52.91	76.79	393.73	[14]
Nigeria (Osun)	-	23.23±7.67	270.14± 61.79	[12]
Gabon (South East)	2811±198	63±12	355±93	[20]
Nigeria (Kogi)	41.27±9.31	18.90±4.21	508.86± 54.02	[5]
Egypt (Aswan)	28.88±2.10	32.81±2.39	383.90± 27.95	[21]
Nigeria (osun)	53 ± 1.2	26 ± 2.7	505 ± 7.1	[22]
Bangladesh (Chittagong)	22.13±2.30	38.47±2.72	451.90± 24.90	[23]
Nigeria (Nasarawa)	32.52±4.65	56.23±2.30	403.96± 9.63	[8]
Nigeria (Zamfara)	18 ± 2	23 ± 3	252 ± 7	[24]
China	2 – 440	1-360	9-1800	[2]
India	7 – 81	14- 160	38 – 760	[2]
Japan	6 – 98	2 – 88	15 – 990	[2]
Spain	6 – 250	2 – 210	25 – 1650	[2]
World Average	32	45	420	[2]

Comparison of the results of Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples collected at different sampling points from the four selected mining locations in Adamawa State obtained in the mining site with published data from similar investigations in Nigeria, Gabon, Egypt, China, Pain, Japan and India and the UNSCEAR's world average were presented in Table 6. Higher activity concentration for ^{226}Ra was determined by [20] in Gabon, while that of ^{232}Th was determined by [4, 9, 13], and that of ^{40}K was determined by [3, 5, 9, 22] in Nigeria and [23] in Bangladash. The average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K obtained in this study is higher than that obtained in Nigeria by [3, 6, 7, 8, 12, 13, 14, 18] in Nigeria and [21] in Egypt. The average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K from this study are higher than the world average [2]. Average activity concentration values above the suggested UNSCEAR's world average value indicates high tendency of radiation exposure by the host communities

4 Conclusions

People and their environment are continually exposed to radiation from natural sources. The main sources of this radiation are Natural Occurring Radioactive Materials (NORM) found in rock, soil, and underground water. Materials derived from these geological mediums recollect these NORM in varying proportions The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K from representatives soil and plants samples from four selected mining locations in Adamawa State was determined using Sodium Iodide NaI detector system at the Centre for Energy Research and

Training (CERT) Laboratory, Ahmadu Bello University Zaria. Findings from this study shows that radionuclides activity concentrations in soil and plants samples varied within the study area due to the differences in geological and topographical settings of the study area. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples ranges from 75.54 Bq/kg to 144.97 Bq/kg with an average value of 107.60 Bq/kg for ^{226}Ra, 52.92 Bq/kg to 157.2 4Bq/kg with an average value of 84.89 Bq/kg for ^{232}Th, and 45.67 Bq/kg to 1080.28 Bq/kg with an average value of 475.34 Bq/kg for ^{40}K respectively while that of plant samples ranges from 79.50 Bq/kg to 139.54 Bq/kg with an average value of 99.02 Bq/kg for ^{226}Ra, 54.06 Bq/kg to 96.96 Bq/kg with an average value of 73.24 Bq/kg for ^{232}Th, and 139.30 Bq/kg to 524.74 Bq/kg with an average value of 296.41 Bq/kg for ^{40}K respectively. These findings reveals that the mean of ^{226}Ra, ^{232}Th and ^{40}K in soil samples are all above the UNSCEAR's world standard. The analysis of the activity concentration show varying distribution of natural radionuclides in soil and plant samples mainly because of geological formation and characteristics of each mining sites. The average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K from this study are higher than the recommended UNSCEAR's world average values. High activity concentration implies that mining activities has significant contribution to natural background radiation and such poses significant radiological hazard to the host communities in the end. The study therefore encourages more research on the entire mining sites across Adamawa State as well as each state of Nigeria as a whole. This will enable the country to establish a comprehensive data on radioactivity concentration in soil thereby ascertaining its associated health effect to the host communities and the public and will serves as a reference for further epidemiological findings by researchers and decision makers.

Footnotes

Competing Interests: All authors have declared that there is no financial relationships with any organizations that might have an interest in the submitted work and no other relationships or activities that could appear to have influenced the submitted work.

Funding: This study did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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