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Evaluation of Radionuclides Transfer Factors around Ghumchi Uranium Mining Site in North-Eastern, Nigeria.

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Abstract: Notwithstanding the importance of mining towards economic development and sustainability, uncontrolled activities could have detrimental effects on the host community and the general public, ranging from environmental degradation, radiation exposure, and the transfer of natural radionuclides from soil to plants, among others. The present study assessed the radionuclides transfer factors from soil to plants around Ghumchi Uranium Mining sites of North Eastern Nigeria, thereby determining the activity concentration levels of natural radionuclides (^{40}K, ^{238}U, ^{232}Th) in soil and plant samples collected from the study area. The representatives' soil and plant samples were collected using a systematic random sampling technique and analyzed using a Sodium Iodide NaI (Tl) detector at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. The mean activity concentrations of radionuclides in soil samples were 367.52 Bq kg^{-1} for ^{40}K, 42.67 Bq kg^{-1} for ^{238}U, and 55.34 Bq kg^{-1} for ^{232}Th, which are slightly above the United Nations Scientific Community on the effects of Atomic Radiation (UNSCEAR's) world averages of 420 Bq kg^{-1}, 33 Bq kg^{-1}, and 45 Bq kg^{-1} respectively. Soil-to-plant transfer factors were 0.614 for ^{40}K, 0.600 for ^{238}U, and 0.827 for ^{232}Th, indicating moderate radionuclide uptake by plants grown near the mining sites. These results align with previous studies in Nigerian mining regions, confirming that geological formations and mining intensity influence radionuclide distribution. Overall, the findings underscore the need for continuous radiological surveillance, public health awareness, and environmental remediation measures to mitigate potential radiation exposure in uranium mining communities. Though high activity concentrations pose a 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, needs to establish the safety reserves from these mining areas for proper guidelines that will ensure suitable protection of the host communities.

Keywords: Natural Occurring Radionuclides, Activity Concentration, Uranium Mining, Transfer Factors, Radiation Exposure.

1 Introduction

Naturally Occurring Radioactive Materials (NORMs) are mostly found in rocks and minerals, which are widely disseminated in the soil's surroundings and are largely influenced by ecological and physical components that can be found at diverse stages. 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 aiding the discharge of radioactive materials from the host materials and generating an irrational radiation risk to humans as a result of the nature of the radioactive daughter products of ^{238}U, ^{232}Th, decay series, and ^{40}K [1]. Mining activities have had an adverse impact on humans and the environment, even at low concentrations. The activity concentrations of these radionuclides are low in their natural state, but can be enhanced above the background levels, as a result of human activities, thus leading to radiological concern and endangering the public [2]. Environmental concerns related to NORMs arising from mining activities can be linked to several factors that frequently contaminate the environment and expose the public to undue risk and unjustifiable radiation exposure, which contravenes the principles of radiation protection. Inhalation of radon's decay products and Ingestion of contaminated plants are some of the health hazards associated with exposure to NORMs, resulting in internal radiation exposure [2]. The physical removal of minerals

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from the ground's surface, known as mining, is one of the main ways that people are exposed to these radionuclides with lengthy half-lives.

[4]. Notable International standards, such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and International Commission for Radiological Protection (ICRP), have established stern guidelines for mitigating public and workers from unjustifiable radiation exposure [3]. Numerous research studies were reported in the previous literatures by several authors who have measured the activity concentration of NORMs resulting from mining activities at diverse part of Nigeria and other countries , some with values above or below the world averages due to the differences in the geological settings of the areas studied [4, 5, 6, 8, 9, 10].

The public's exposure to background radiation is significantly increased by the high concentration of these radionuclides in rocks and soils. By distressing the body's systems, high concentrations of radionuclides and the radiation released could have an adverse effect on human health. [11, 12, 13]. Thus, from the perspective of public health, assessing the NORMs level in ambient samples is significant [14, 15]. Thus, this study has been the first of its kind in the study area, aimed at evaluating the radionuclides transfer factors from soil to plants around the Ghumchi Uranium Mining site in Adamawa State, North-Eastern Nigeria, from the determined activity concentration of ^{238}U, ^{232}Th, and ^{40}K from representative soil and plant samples.

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2 Materials and Methods

2.1 Description of Study Area

Adamawa State is located in the North-Eastern Nigeria with a land mass of 39,742.12sq km, which covers about 4.4% of the land mass of Nigeria, and lies between latitudes 80N and 110N, longitude 11.50E and 13.50E, with a population of 3,168,101 based on the 2006 census, with 21 Local Government Areas (LGAs) and 37 Development Areas respectively [17].

In Adamawa State, the areas of Ghumchi and Mayo Lope have good uranium exploration potential, localized in the m ylonitized, sheared, and brecciated fine-grained to porphyritic granites. Analysis of cores from 40 drill holes gave values of 2000 ppm U.

Figures 1 (a – c) and Table 1 show the geographical map of Nigeria and Adamawa State, as well as the study area alongside the respective coordinates where samples were collected from Ghumchi uranium mining sites.

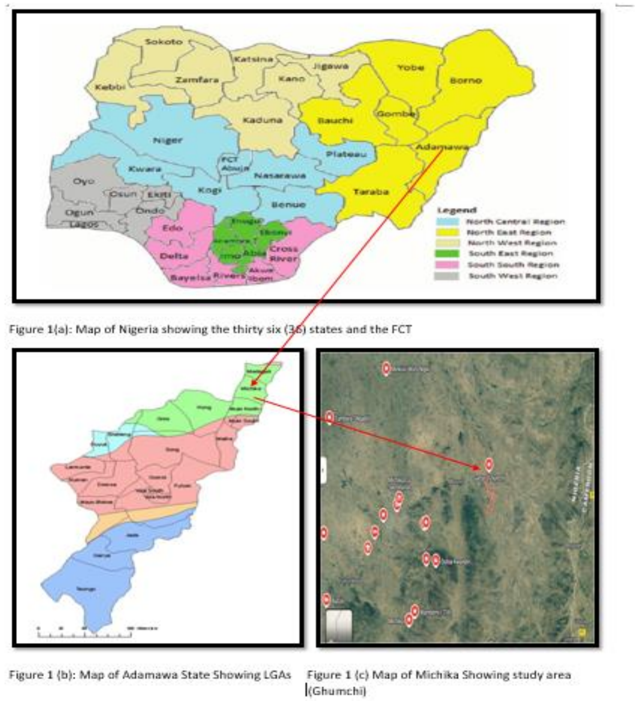

Fig.1: Geographical map of the study area.

2.2 Sample Collection and Preparation

A total of twenty representative soil and plant samples were obtained from the study area at 500 meters apart using regular stratified sampling. Composite samples were obtained and placed in well-labeled polyethylene bags to avoid cross-contamination during processing. Approximately 400 g of the dried samples were sealed and preserved for 28 days to attain secular equilibrium between ^{238}U, ^{232}Th, and ^{40}K and their daughter products. The coordinates of each sample collected from the Ghumchi Uranium mining site are presented in Table 1.

Table 1: Geographical Coordinates of Ghumchi Uranium Mining site alongside the sample code.

Mining Sites	Soil Sample Code *	Plant Sample Code **	Geographical Coordinates Latitude	Longitude
Ghumchi Uranium Mining site Michika LGA, Adamawa State (GH)	GH1-S	GH1-P	10º40'11".00	13º27'21".10
	GH2-S	GH2-P	10º40'09".40	13º27'23".80
	GH3-S	GH3-P	10º40'06".30	13º27'27".20
	GH4-S	GH4-P	10º40'02".40	13º27'29".10
	GH5-S	GH5-P	10º40'05".70	13º27'33".00
	GH6-S	GH6-P	10º40'09".20	13º27'35".60
	GH7-S	GH7-P	10º40'13".00	13º27'36".40
	GH8-S	GH8-P	10º40'16".00	13º27'38".20
	GH9-S	GH9-P	10º40'25".30	13º27'38".80
	GH10-S	GH10-P	10º40'29".30	13º27'39".90

2.3 *Sampling Analysis*

Representative soil and plant samples obtained from the study area were analyzed for Activity Concentration (AC) of ^{238}U, ^{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*

Figure 2 shows the summary of scenario description employed in this study from sample collection preparation, sample collection, sample preparation, and sample analysis stages, where activity concentration of ^{238}U, ^{232}Th, and ^{40}K from representative soil and plants samples obtained from Ghumchi Uranium mining site in Adamawa State, Nigeria.

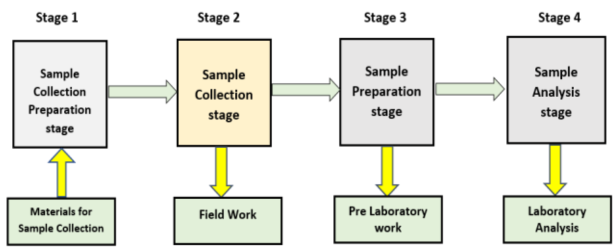

Fig.2: Scenario Description.

3 Results and Discussion

3.1 Activity Concentration of ^{238}U, ^{232}Th and ^{40}K in Soil Samples

The activity concentration of ^{238}U, ^{232}Th, and ^{40}K in soil samples obtained from Ghumchi Uranium mining sites in the study area is presented in Table 2.

Table 2: Activity Concentration of ^{238}U, ^{232}Th, and ^{40}K from soil samples.

Soil Sample	K-40 (Bq/Kg)	U-238 (Bq/Kg)	Th-232 (Bq/Kg)
GH1-S	241.19±9.36	32.42 ±1.74	4.39 ±0.15
GH2-S	236.4 ±29.13	14.01 ± 3.82	5.62 ±0.16
GH3-S	230.93 ±7.68	26.54 ±2.16	19.78 ±0.148
GH4-S	118.6 ±18.04	24.38 ±1.94	8.28 ±0.076
GH5-S	176.9 ±32.54	13.15 ±3.82	20.41 ±0.11
GH6-S	624.74±27.39	4.29 ±3.61	20.85 ±0.40
GH7-S	279.1 ±29.28	3.35 ±3.10	22.44 ±0.18
GH8-S	527.9 ±39.59	8.71 ±3.72	18.97 ±0.34
GH9-S	516.04 ±9.50	11.16 ±2.66	8.23 ±0.33
GH10-S	394.6 ±27.52	27.97 ±2.4	9.56 ±0.25
Average	**334.6382**	**16.60327**	**13.86329**
UNSCEAR	**420**	33	45
AC Ratio	**0.79**	**0.50**	**0.311**

From Table 2, the activity concentrations of natural radionuclides measured in soils from the Ghumchi uranium mining site, Adamawa State, show mean values of 334.64 Bq/kg for ^{40}K, 16.60 Bq/kg for ^{238}U, and 13.86 Bq/kg for ^{232}Th. Potassium-40 dominates the radioactivity, with several hotspots exceeding 500 Bq/kg (e.g., GH-6, GH-8, GH-9), indicating enrichment from K-bearing minerals in the local geology.

In contrast, ^{238}U and ^{232}Th are generally low, though some samples (GH-1, GH-3, GH-10) approach 30 Bq/kg, suggesting localized uranium - and thorium-rich mineralization. The heterogeneity across samples highlights the influence of geological variation and mining activity on radionuclide distribution. When compared with the global reference values reported by UNSCEAR ($^{40}K \approx 420$ Bq/kg, $^{238}U \approx 35$ Bq/kg, $^{232}Th \approx 45$ Bq/kg), Ghumchi soils exhibit slightly lower ^{40}K on average but much lower ^{238}U and ^{232}Th.

Compared to other Nigerian mining studies, such as in Adamawa and other regions where mean $^{238}U/^{226}Ra$ and ^{232}Th values are significantly higher (e.g., $^{226}Ra \approx 108$ Bq/kg, $^{232}Th \approx 85$ Bq/kg), Ghumchi presents relatively low radiological risk from uranium and thorium decay series. However, the elevated ^{40}K hotspots warrant further assessment of absorbed dose rates, annual effective doses, and hazard indices to establish potential risks for miners and nearby communities [12, 13, 14, 22].

3.2 Activity Concentration of ^{238}U, ^{232}Th and ^{40}K in Plant Samples

The activity concentration of ^{238}U, ^{232}Th, and ^{40}K in plant samples from the Ghumchi uranium mining site within the study area is presented in Table 3.

Table 3: Activity Concentration of ^{238}U, ^{232}Th, and ^{40}K from plant samples.

Soil Sample	K-40 (Bq/Kg)	U-238 (Bq/Kg)	Th-232 (Bq/Kg)
GH1-P	177.7±5.10	2.84±0.15	2.02±0.12
GH2-P	193.0±4.44	2.35±0.19	2.23±0.12
GH3-P	157.27±5.09	3.34±0.21	1.12±0.18
GH4-P	115.9±24.136	24.12±3.90	27.54±1.43
GH5-P	281.91±15.91	8.22±0.88	31.78±5.39
GH6-P	366.0±2.99	13.74±0.69	16.55±5.62
GH7-P	73.09±5.08	28.96±3.25	8.63±0.95
GH8-P	139.9±7.39	3.15±0.21	1.44±0.15
GH9-P	177.7±5.10	2.83±0.16	2.02±0.12
GH10-P	373.4±9.34	10.03±4.21	21.37±1.38
Average	**205.605**	**9.95896**	**11.47061**
UNSCEAR	**420**	33	45
AC Ratio	**0.48**	**0.30**	**0.25**

Table 3 presents the results of activity concentration levels of ^{238}U, ^{232}Th, and ^{40}K in plant samples collected from the Ghumchi Uranium mining site, Adamawa State. The plant samples collected from the Ghumchi uranium mining site show mean activity concentrations of 205.61 Bq/kg for ^{40}K, 9.96 Bq/kg for ^{238}U, and 11.47 Bq/kg for ^{232}Th**.**

Potassium-40 again dominates, consistent with its essential role in plant physiology, with some samples (GH-6 and GH-10) showing particularly elevated levels (>360 Bq/kg). Most plants recorded relatively low ^{238}U and ^{232}Th, except for GH-4 and GH-5, which exhibited unusually high values of both radionuclides (^{238}U ≈ 24–28 Bq/kg, ^{232}Th ≈ 27–32 Bq/kg), suggesting uptake from localized contaminated soils or possible root contact with mineralized zones. These results confirm variability in radionuclide bioaccumulation influenced by plant species, soil geochemistry, and mining-related exposure pathways.

When compared to global reference values and related Nigerian studies, the plant radionuclide levels from Ghumchi are relatively low on average. UNSCEAR reports that natural activity concentrations in vegetation are typically much lower than in soils, with ^{238}U and ^{232}Th often <10 Bq/kg, a pattern consistent with most of the Ghumchi plant samples except for a few outliers. Similar studies in mining areas of Nigeria have reported elevated uptake of U-series radionuclides and thorium in plants near tailings and mineralized soils, sometimes exceeding Ghumchi's values [1, 25]

Overall, while the majority of plant samples show radionuclide activities below international concern levels, the elevated values in a few samples highlight the need for continuous monitoring of edible plants around mining sites to assess potential radiological health risks to local communities.

The sequence of the AC ratio in the plant samples was: ^{40}K > ^{232}Th > ^{238}U. The results show that the public is more exposed to ^{40}K than ^{238}U and ^{232}Th. Comparing the AC ratio from representative soil and plant samples obtained from the Ghumchi uranium mining site considered in this study, the results imply that ^{40}K and ^{238}U present in soil samples have the affinity of being transferred into plants via a phenomenon described as transfer factors, which might result in contamination of plants and internal radiation hazard to the public when ingested.

3.3 Determination of Radionuclides Transfer Factors from Activity Concentration of ^{238}U, ^{232}Th, and ^{40}K in Soil and Plant Samples

The soil-to-plant transfer factor (TF) represents how efficiently radionuclides move from contaminated soils into plants around uranium mining sites. It is a key indicator of radionuclide mobility, bioavailability, and potential food-chain contamination**,** helping to assess environmental and health risks linked to mining activities and the consumption of local crops. Transfer Factors from the measured activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil and plant samples within the study area are presented in Table 4

Table 4: Radionuclide Transfer Factors from measured AC for ^{239}U, ^{232}Th, and ^{40}K in Soil and plant Samples from Ghumchi Uranium Mining site, Adamawa State.

Sample ID	^{40}K	^{238}U	^{232}Th
TF-GH-1	0.736938	0.087520	0.460826
TF-GH-2	0.816714	0.167895	0.396299
TF-GH-3	0.681037	0.125904	0.056191
TF-GH-4	0.977072	0.988993	3.325817
TF-GH-5	1.593657	0.624931	1.55674
TF-GH-6	0.585931	3.197663	0.794006
TF-GH-7	0.261909	8.628023	0.384582
TF-GH-8	0.265069	0.361696	0.076106
TF-GH-9	0.344443	0.25416	0.246122
TF-GH-10	0.946273	0.358516	2.233805
Mean-TF	0.61441	0.599819	0.827409

Table 4. Present the soil-to-plant transfer factor of activity concentration for the Ghumchi uranium mining site, Adamawa State. The soil-to-plant transfer factor (TF) results for the Ghumchi uranium mining site in Adamawa State show significant variability in the uptake of naturally occurring radionuclides (^{40}K, ^{238}U, and ^{232}Th) from soil into plant tissues.

Potassium-40 (^{40}K) exhibited transfer factors ranging from 0.26 (TF-GH-7) to 1.59 (TF-GH-5), with a mean value of 0.61. This indicates a generally moderate level of mobility of potassium into plants, which is expected given that potassium is an essential nutrient and is actively taken up by plant roots. For uranium-238 (^{238}U), TF values showed extreme variability, ranging from 0.09 (TF-GH-1) to 8.63 (TF-GH-7), with a mean of 0.60.

The exceptionally high TF values in some samples (e.g., TF-GH-6 and TF-GH-7) suggest possible soil geochemical influences, such as low calcium competition or specific plant uptake mechanisms that enhanced radium bioavailability. Thorium-232 (^{232}Th), typically known for low mobility in soils, showed TF values ranging from 0.056 (TF-GH-3) to 3.33 (TF-GH-4), averaging 0.83. The elevated values in some cases (TF-GH-4 and TF-GH-10) point to localized conditions that may favor thorium uptake, although such behavior is unusual under normal soil-plant dynamics. When compared with international findings, the mean TF values for Ghumchi—0.61 (^{40}K), 0.60 (^{238}U), and 0.83 (^{232}Th)—are within the range reported in other mining and high background radiation areas.

For instance, Jibiri [7] reported TF values for crops in Jos Plateau within 0.2–1.5 for potassium and below 1.0 for thorium, while [25] observed lower thorium TF (<0.2) in southwestern Nigeria, highlighting the unusual bioavailability recorded in some Ghumchi samples. Overall, the results suggest that while potassium uptake aligns with nutritional requirements, the enhanced uptake of radium and thorium in certain samples may present potential radiological risks to the food chain. Continuous monitoring and species-specific studies are recommended to better understand the mechanisms influencing these transfer variations.

3.4 Comparison of Mean Activity Concentrations from Soil and Plant Samples with Reference Standard

The mean activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil and plant samples collected at different sampling points from the study location considered in this study were compared with the reference standard, and the results are presented in Figure 3.

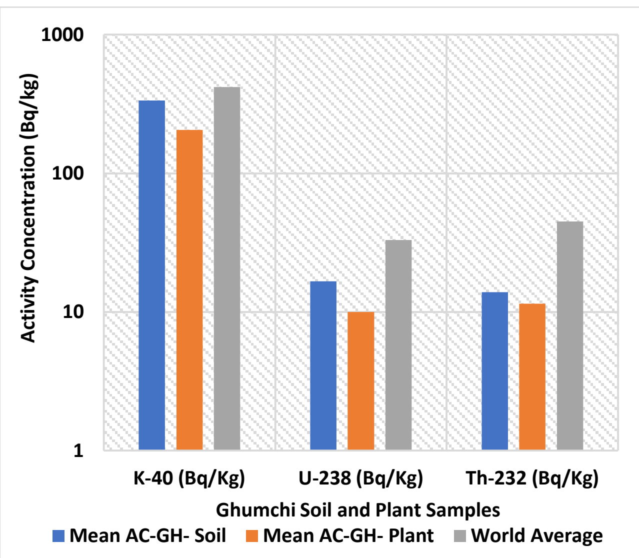

Fig. 3: Comparison of Average AC in Soil and Plants with UNSCEAR Reference Standard.

3.5 Comparison 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 plant samples collected at different sampling points from the four selected mining locations considered in this study were compared with those of other regions/countries and the world average, and the results are presented in Table 6.

Table 5: Comparison of Activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil samples with other studies

Country	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Reference
Nigeria (Adamawa)	16.603±12.3	13.86±7.43	334.64± 9.3	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 ^{238}U, ^{232}Th, and ^{40}K in soil samples collected at different sampling points from Ghumchi uranium mining site in Adamawa State, with published data from similar studies in Nigeria, Gabon, Egypt, China, Pain, Japan, and India, and the UNSCEAR's world average are presented in Table 5. Higher activity concentration for ^{238}U 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 Bangladesh. The average activity concentration of ^{238}U, ^{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 ^{238}U, ^{232}Th, and ^{40}K from this study is higher than the world average [2]. Average activity concentration values above the suggested UNSCEAR's world average value indicate a high tendency of radiation exposure by the host communities.

4 Conclusions

Natural sources of radiation constantly expose people and their surroundings. Natural Occurring Radioactive Materials (NORM) in rock, soil, and subterranean water are the primary sources of this radiation. These NORM are recollected in varied amounts in materials originating from these geological media. The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K from representative soil and plant samples from the Ghumchi uranium mining site in the North-Eastern state of Adamawa were determined using a Sodium Iodide NaI detector system at the Centre for Energy Research and Training (CERT) Laboratory, Ahmadu Bello University, Zaria. Findings from this study show that radionuclide activity concentrations in soil and plant samples varied within the study area due to the differences in geological and topographical settings of the study area. The average activity concentration of ^{238}U, ^{232}Th, and ^{40}K in soil samples is 334.64 Bq/kg for ^{40}K, 16.60 Bq/kg for ^{238}U, and 13.86 Bq/kg for ^{232}Th. The plant samples show mean activity concentrations of 205.61 Bq/kg for ^{40}K, 9.96 Bq/kg for ^{238}U, and 11.47 Bq/kg for ^{232}Th**.** Potassium-40 (^{40}K) exhibited transfer factors ranging from 0.26 (TF-GH-7) to 1.59 (TF-GH-5), with a mean value of 0.61. ^{238}U, TF values showed extreme variability, ranging from 0.09 (TF-GH-1) to 8.63 (TF-GH-7), with a mean of 0.60. ^{232}Th, typically known for low mobility in soils, showed TF values ranging from 0.056 (TF-GH-3) to 3.33 (TF-GH-4), averaging 0.83. The transfer factor results for the Ghumchi uranium mining site show significant variability in the uptake of naturally occurring radionuclides (^{40}K, ^{238}U, and ^{232}Th) from soil into plant tissues. These findings reveal that the mean of ^{238}U, ^{232}Th, and ^{40}K in soil and plant samples are all below the UNSCEAR's world standard. The analysis of the activity concentration shows a varying distribution of natural radionuclides in soil and plant samples, mainly because of the geological formation and characteristics of the Ghumchi mining site. The average activity concentration of ^{238}U, ^{232}Th, and ^{40}K from this study is below the recommended UNSCEAR's world average values. Low activity concentration implies that mining activities have a significant contribution to natural background radiation and such poses a significant radiological hazard to the host communities in the long run, which has the tendency of resulting to stochastic effects. The study therefore encourages continued research on the entire mining sites across North Eastern States, thereby establishing comprehensive data on radioactivity concentration in soil and plants to ascertain the associated health hazards resulting from mining activities to the host communities and the public, thereby serving as a reference for further epidemiological findings by researchers and decision makers.

Footnotes

Competing Interests: All authors have declared that there are 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.

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