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Assessment of Activity Concentration of Radionuclides from Farmland Soils around Some Mining Communities of Plateau State using a Bismuth Germanate Oxide (BGO) Spectrometer

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ABSTRACT
Mining activities can elevate the levels of naturally occurring radionuclides in surrounding agricultural soils, potentially increasing radiological exposure to farmers and food consumers. This study investigated the activity concentrations of 40K, 238U, and 232Th in farmland soils around selected mining communities within the Naraguta Sheet 168 of Plateau State, Nigeria, using a field-portable Bismuth Germanate Oxide (BGO) gamma-ray spectrometer. In situ measurements were conducted at fifty-six sampling points across Shen, Rayfield Resort, Bisichi, and Kuru farmlands, with Kassa serving as a control site. Radiological hazard indices, including absorbed dose rate (Dγ), radium equivalent activity (Raeq), external and internal hazard indices (Hex and Hin), annual effective dose equivalent (AEDE), and gamma activity index (Iγ), were evaluated to assess potential radiation risks. The results revealed notable spatial variations in radionuclide distribution, with 40K dominating across all locations. The greatest mean activity concentrations of 40K (1475.92 Bq kg^{-1}), 238U (24.14 Bq kg^{-1}), and 232Th (8.36 Bq kg^{-1}) were found in Bisichi farmland, with values for 40K surpassing the global average. Based on the result, Bisichi had radiological indices with the gamma activity index (Iγ) above unity and Hex and Hin below unity. This implies that although there is a risk to the gamma activity index (Iγ), there is no risk of occupational exposure to Hex and Hin. Additionally, farmlands in Shen, Rayfield, Kuru, and the control site recorded radionuclide concentration and radiological parameters largely within internationally recommended limits. Although most values remained below permissible exposure thresholds, the radiological indicators in mining-impacted farmlands highlight the need for continuous monitoring and appropriate environmental management strategies.

Keywords:
Natural Occurring Radionuclide,
Farmland Soil,
Mining Areas,
Bismuth Germanate Oxide Spectrometer.

INTRODUCTION

Naturally occurring radionuclides are present in the soil beneath our feet, even in the farmland areas that provide us with our food. For agricultural productivity, environmental stability, and ultimately human population viability, farmland soil is a vital substrate and an integral part of terrestrial ecosystems (Guerra, et al., 2024). Physical, chemical, and biological characteristics interact in a complex way to determine the health of farmland soil, affecting its capacity to sustain plant development, control water flow, cycle nutrients, filter pollutants, and store carbon (Smith, et al., 2021).

Anthropogenic activities on soil characteristic properties have been acknowledged as major environmental concern that threatens food security and ecosystem resilience, putting soil under unprecedented global pressures today (Durdu, et al., 2023: Mandal & Roy, 2024). In addition to endangering food productivity, anthropogenic activities compromise ecological processes essential to maintaining biodiversity and environmental health. Given the difficulties, maintaining and restoring soil health have become top priority in farmlands and environmental policy (Ayub, et al., 2020: Durdu et al., 2023).

Much has been discovered in the last few decades on the types and sources of radiation and radionuclides that humans are exposed to in the natural world. Both natural and artificial radioactive sources can expose the public to radiation. The majority of radiation exposure comes from naturally occurring radioactive sources. The primary sources of radiation are space radiation, terrestrial radiation, Radon, and Thoron radioactive gases that can build up in buildings, and radioactivity absorbed by food and drink (O'Connor, et al., 2014). Additionally, natural radioactive elements found in the Earth's crust can also produce external irradiation.

Plateau State is a highland region which is predominantly a Precambrian Basement Complex rocks intruded by Younger Granite complexes of Jurassic age **(**Ayeni et al., 2025). The native soil profile has been significantly disrupted by artisanal and mechanized tin mining, which has been practiced for more than a century in places including Bukuru, Ropp, Bisichi, Kuru, Jos South, and Barkin Ladi (Godwin et al., 2022).The region's historical reputation for tin (cassiterite) mining and the presence of elevated levels of Naturally Occurring Radioactive Materials (NORMs) are both largely due to this distinctive geological context.

In Nigeria, there exist about forty to fifty various types of untapped sub-terrain resources in the earth; however, informal or artisanal mining of these minerals have been carried out in certain communities without recourse to environmental remediation, leading to the accumulation of naturally occurring radioactive waste in the environment (Akpanowo, et. al, 2020). Isinkaye and Emelue (2015) also reported that 87% of the radiation doses that humans experience come from natural sources, primarily from Potassium (^{40}K), Thorium (^{232}Th), and Uranium (^{238}U) and their progenies. These primordial radionuclides mostly originate from soil and rocks, which also serve as a conduit for their migration into other environmental elements (Felix, et al., 2016).

One of the modern measuring instruments that potentially can be used to determine ^{40}K,^{232}Th, and ^{238}U in *situ* is the field-portable Bismuth Germanate Oxide (BGO) Spectrometer. BGO Spectrometer is the industry standard in portable handheld gamma ray survey devices for geophysical applications. It offers an integrated design with a large detector, direct Assay data, data storage, full weather protection, ease of use and the highest sensitivity in the market. The performance of the 103 cm^3 higher densities Bismuth Germanate Oxide (BGO) is approximately 80% of a 390 cm^3 Sodium Iodide (NaI) detector commonly used with larger portable units and approximately 3 times more than the same size (NaI) crystal.

The farmland soil is of particular interest to this study based on the fact that residents consume crops grown on the soil and could be susceptible to adverse health effects of such radiation. The study therefore aimed at determining the activity concentration of radionuclides present in farmland soils around mining areas in plateau state using a Bismuth Germanate Oxide.

MATERIALS AND METHODS

Study Area

The study took place majorly in the farmland of some communities within the Naraguta topographical sheet 168 (Shen, Rayfield resort, Bisichi, Kuru and Kassa communities of Plateau State), figure1, where mining exists as very common practice in and around the communities in many forms.

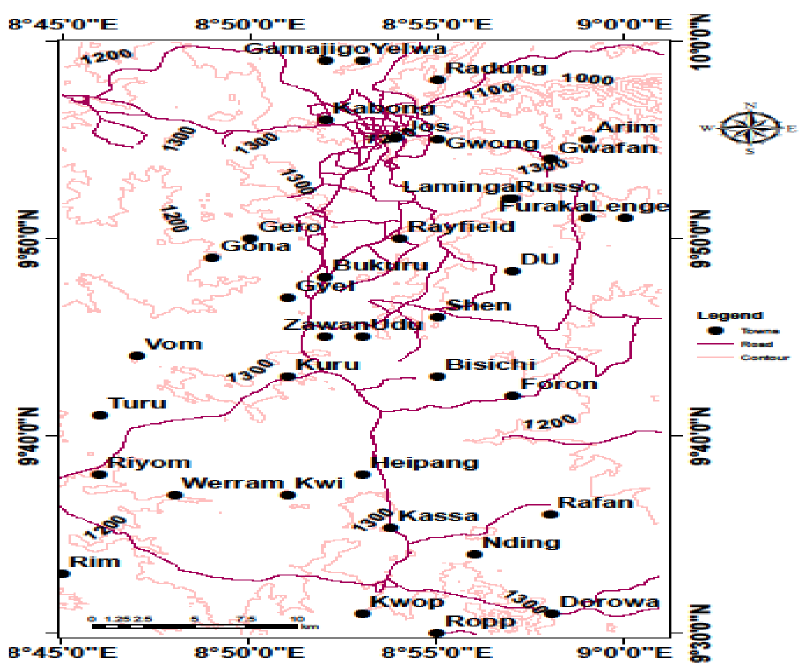

Figure 1: Topo Map of Naraguta Sheet 168

Evaluation of Radiological Parameters

Determination of Activity Concentrations of ^{226}Ra, ^{232}Th and ^{40}K

The activity concentrations of the radionuclides in the farmland soil were calculated by converting the measured radionucides in the BGO detector from K(%), eU (ppm), and eTh (ppm) to the commonly accepted conversion factors A_K (Bq/Kg), A_{Th} (Bq/Kg) and A_U (Bq/Kg) as described according to IAEA (2003), IAEA (2010) and Beretka & Mathew (1985) shown in equations 1, 2 and 3

$$A_K(Bq/Kg)=313\times K(\%) \quad (1)$$

$$A_{Th}(Bq/Kg)=4.06\times Th(ppm) \quad (2)$$

$$A_U(Bq/Kg)=12.35\times U(ppm) \quad (3)$$

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

Absorbed Dose Rate (D_γ)

External absorbed dose rate (D_γ) coming from terrestrial radionuclides in soil were calculated using equation 4 as described by Mbonu and Ben, 2021

$$D_\gamma\,(nGyh^{-1}) = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad (4)$$

Radium Equivalent Activity (Ra_{eq})

This index is mathematically calculated by equation 5 to address the levels of ^{238}U, ^{232}Th and ^{40}K taking into account the radiological risks associated with them (Mbonu and Ben, 2021);

$$Ra_{eq}\,(Bq.kg^{-1}) = A_U + 1.43A_{Th} + 0.077A_K \quad (5)$$

Internal Radiation Hazard Index (H_{in})

The Internal Hazard Index (H_{in}) measures the inner exposure to radon and its daughter isotopes which $H_{in} < 1$ (Yalcin et al. 2020), equation 6 was used to calculate for occupationally exposed workers at the farm according to the definition of Isinkaye & Emelue, 2015 and Oladejo et al. 2020.

$$H_{in}=\frac{A_U}{185\,Bq.Kg^{-1}}+\frac{A_{Th}}{259\,Bq.Kg^{-1}}+\frac{A_K}{4810\,Bq.Kg^{-1}}\leq 1 \quad (6)$$

External Hazard Index (H_{ex})

External Hazard Index (H_{ex}) is a widely used hazard indexes (mirroring the outer openness). Its calculated based on the definition by Oladejo et al. (2020) according to equation 7 for which $H_{ex} < 1$;

$$H_{ex}=\frac{A_U}{370\,Bq.Kg^{-1}}+\frac{A_{Th}}{259\,Bq.Kg^{-1}}+\frac{A_K}{4810\,Bq.Kg^{-1}}\leq 1 \quad (7)$$

Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent were estimated for outdoor exposures ($AEDE_{out}$) by applying a dose conversion factor of 0.7 $SvGy^{-1}$ and occupancy factor of 0.2 according to Eke et al. (2015) and Zubair, 2020 as described using equation 8.

$$AEDE_{(out)}\ (\mu Sv.y^{-1}) = D_{out}\ (nGyh^{-1}) \times 8760hy^{-1} \times 0.7(Sv.Gy^{-1}) \times 0.2 \times 10^{-3} \quad (8)$$

Gamma Activity Index (I_γ)

Gamma activity concentration index I_γ was evaluated to assess gamma radiation level linked with different activity concentrations of measured radionuclides using equation 9 (Oladejo et al. 2020).

$$I_\gamma=\frac{A_K}{3000\,Bqkg^{-1}}+\frac{A_{Th}}{200\,Bqkg^{-1}}+\frac{A_U}{300\,Bqkg^{-1}}<1 \quad (9)$$

Where the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in $Bqkg^{-1}$ that will generate 1 mSv y^{-1} dose rate are represented by A_U, A_{Th} and A_K respectively. A standard dose of 200 criteria of 1 mSv y^{-1} is equivalent to $I_\gamma<1$ of a gamma activity concentration (Gbenu et. al. 2015).

Methodology

Sampling Location Determination

The sampling locations were chosen due to the existence of an active mining site situated close to the farmland. The sampling geographical coordinates in the farmland, their evaluated activity of radionuclides and their corresponding evaluated radiological parameters are presented in table 1.

Radioactivity Measurement

The farmland soils were scooped down to a depth of about 10cm at each location point prior to measurement. The radiometric survey measurements were achieved using a portable gamma-ray spectrometer; model RS-230 BGO detector Super-SPEC portable radiation detector with high accuracy, probable measurement and errors about 5%. This detector is full assay capability with data on K(%), eU (ppm), and eTh (ppm), with no radioactive sources required for proper calibration. The measurements are based on the detection of γ-radiation as emitted in the decay of ^{214}Bi (^{238}U series).

RESULTS AND DISCUSSION

Activity Concentration of In-situ Radiation Measurements

Fifty six (56) sampling points were investigated for across farmlands in Shen (SA4), Rayfield resort (SA5) Bisichi (SA6), Kuru (SA9) and SA13 in Kassa serving as a control point farmland located outside mining areas within the Naraguta sheet 168.

The activity concentrations of ^{40}K, ^{232}Th and ^{238}U measured in farmland soils around some communities around mining areas of Plateau State show considerable spatial variation across all the investigated locations including the control site. The highest activity concentrations were consistently recorded in Bisichi farmland (SA6), where mean values of ^{40}K (1475.92 $Bqkg^{-1}$), ^{232}Th (8.36 $Bqkg^{-1}$) and ^{238}U (24.14 $Bqkg^{-1}$) were significantly seen to be at its peak when compared to other locations. These values exceeded the world average value for ^{40}K (400 $Bqkg^{-1}$), indicating strong enrichment associated with intensive mining activities taking place, fertilizer and pesticides application, excavation, erosion, weathering, or sediment re-deposition and the underlying geological formations rich in potassium-bearing minerals (Figure 2). Bisichi's high activity concentrations of radionuclide are attributable to its location and the anthropogenic enhancement and redistribution of NORMs through long-term tin mining activities. Similar elevated values in mining environments have been reported in previous studies within Plateau State and other mineralized regions of Nigeria (Ngadda & Peter, 2015: Abba et al. 2018 and Mangset et al. 2022).

In contrast, farmlands in Rayfield resort (SA5), Kuru (SA9) and the control site Kassa (SA13) generally exhibited a lower activity concentration, which falls below global average limits. Akerrger et al. (2023) have documented similar observations of lower activity concentration values in Benue State. This suggests limited influence of mining activities and reflects background terrestrial radioactivity levels dominated by natural soil composition rather than anthropogenic enhancement.

The dominance of ^{40}K seen in table 1 across all the sampling locations aligns with its natural abundance in soils and its essential role in plant nutrition, while relatively lower concentrations of uranium and thorium indicate localized enrichment controlled by mineralogy and mining disturbance rather than uniform distribution **(**$^{40}K > ^{232}Th > ^{238}U$). Additionally, uranium may be linked to refractory minerals like zircon or monazite which encourages disequilibrium at both the micro and macro levels of this mineralogical separation.

Figure 3 illustrates a positive correlation between the activity concentration of ^{40}K (A_k) and the absorbed dose rate across all the study locations. This relationship indicates that ^{40}K is a major contributor to the external gamma dose in farmland soils**.** As the activity concentration of ^{40}K increases, the absorbed dose also increases proportionally, confirming its significant radiological influence compared to other radionuclides. The strength of this correlation demonstrates that variations in absorbed dose rates among locations are largely controlled by differences in potassium content in the soils.

Figure 4 presents a strong linear relationship between AEDE(out) and Ra_{eq} for farmlands across the study locations. This correlation confirms that radium equivalent activity is a reliable index for assessing radiation hazard, as increase in Ra_{eq} directly translate into higher annual effective dose equivalents. The observed trend indicates that external radiation exposure to farmers and the public is primarily influenced by the combined contributions of ^{238}U, ^{232}Th, and ^{40}K. The linearity of the relationship suggests consistency in radionuclide distribution and validates the use of Ra_{eq} as a predictor of radiological risk in agricultural soils.

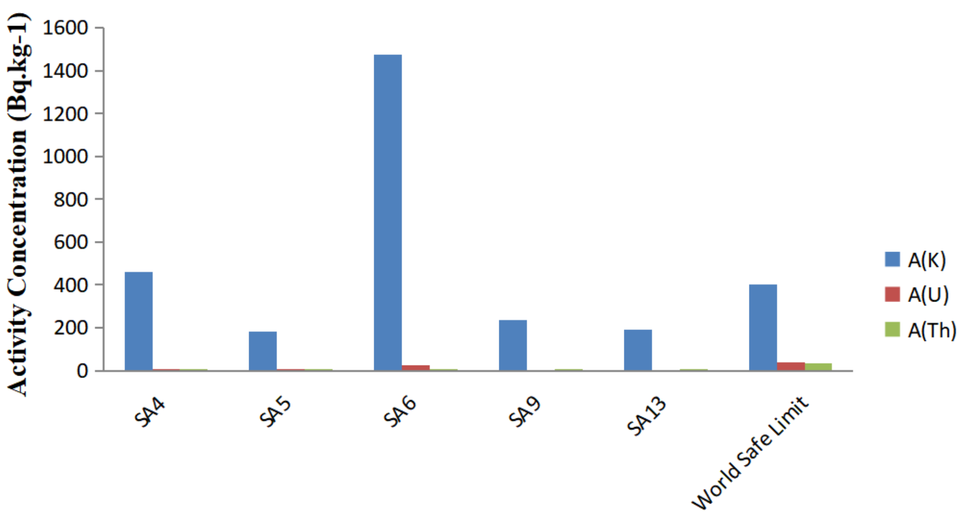

Figure 2: Mean Activity Concentration of ^{40}K, ^{238}U and ^{232}Th in farmland soils across the study locations

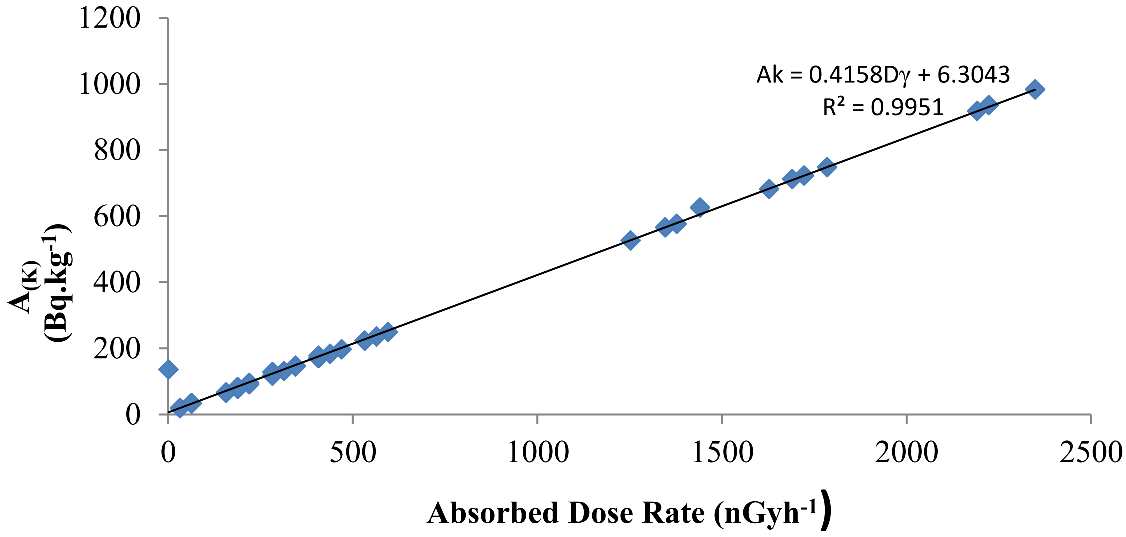

Figure 3: Correlation between Ak and Absorbed dose for all the study locations

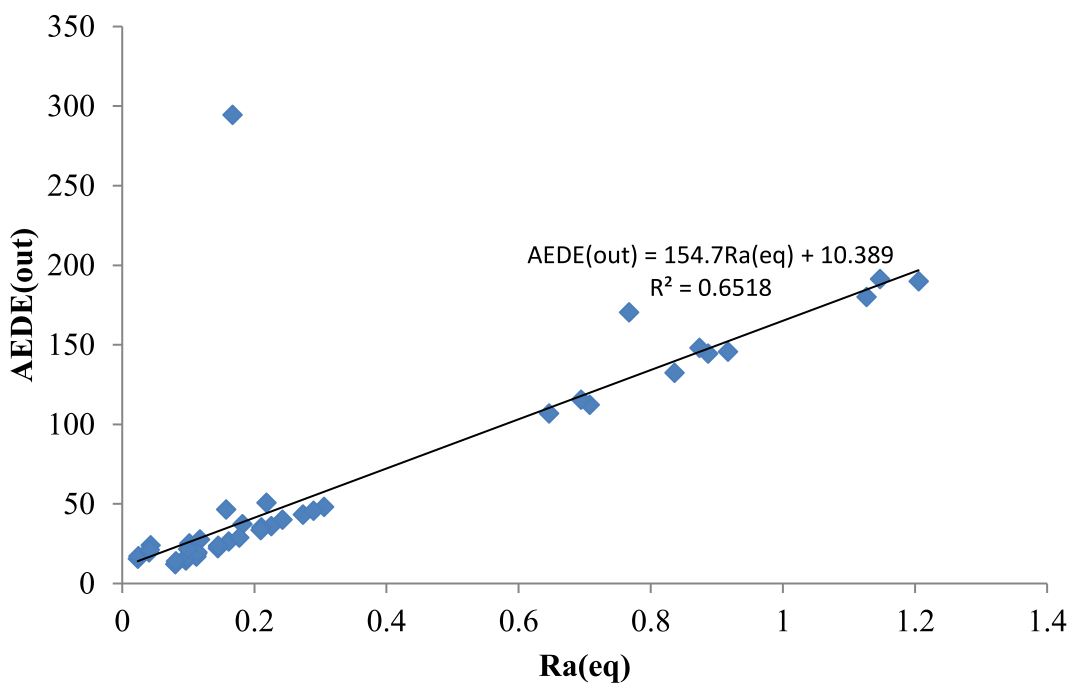

Figure 4: Correlation between $AEDE_{(out)}$ and $Ra_{(eq)}$ ($Bq.kg^{-1}$) in farmlands across all the study locations

Absorbed Dose Rate (Dγ)

The calculated absorbed dose rates ranged from 19.12 $nGyh^{-1}$ to 631.66 $nGyh^{-1}$, with mean values in SA6 far exceeding the global average of 59 $nGyh^{-1}$. This elevated dose rate confirms that soils in Bisichi farmland contribute significantly to external gamma radiation exposure, attributable to the high concentrations of ^{40}K and associated radionuclides. Other locations recorded absorbed dose rates below or moderately above the world average, suggesting minimal radiological impact to farmers and residents in those areas.

Radium Equivalent Activity (Raeq)

The radium equivalent activity values provide a single index to assess overall radiological risk. Mean Ra_{eq} values for SA6 (149.74 $Bqkg^{-1}$) were well below the recommended safety limit of 370 $Bqkg^{-1}$, despite being higher than other sites. This indicates that the affected farmland around the mining site do not pose immediate radiological hazards based on international guidelines. All other sampling locations recorded Ra_{eq} values significantly lower than the permissible limit, confirming their radiological safety for agricultural use.

External and Internal Hazard Indices (H_{ex} and H_{in})

The calculated external (H_{ex}) and internal (H_{in}) hazard indices across most locations were less than unity, satisfying the safety condition ($H_{ex} < 1$ and $H_{in} < 1$). However, mean values in SA6 approached or slightly exceeded unity, indicating a potential internal exposure risk due to radon inhalation and its progeny, especially for farmers with prolonged occupational exposure. This highlights the need for caution and periodic monitoring in mining-dominated farmlands to prevent long-term radiological health effects.

Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalents for all locations were below the recommended public exposure limit of 1 mSv y^{-1}. Nonetheless, these doses suggest no immediate health threat but reinforcing the need for continuous radiological assessment.

Gamma Activity Index (I_γ)

The gamma activity index values further confirm that SA6 exhibits the highest radiological significance in various sampling points with mean I_γ values exceeding unity. This implies, an enhanced gamma radiation level is capable of contributing to increase external exposure. Conversely, all other locations recorded I_γ values below unity, indicating compliance with international safety standards.

CONCLUSION

The investigation of farmland soils around some mining communities within the Naraguta Sheet 168 of Plateau State shows that mining activities significantly influence the concentration of naturally occurring radionuclides**,** particularly in areas closest to active or historical mining sites.

Farmlands located in Bisichi (SA6) recorded markedly high activity concentrations of ^{40}K**,** ^{238}U**,** and ^{232}Th compared to other locations. The mean values of absorbed dose rate (631.66 $nGyh^{-1}$), radium equivalent activity (149.74 Bq kg^{-1}), and gamma activity index (1.229) in SA6 exceed world average background levels, indicating significant radiological enhancement due to mining activities. In SA6, the internal hazard index (H_{in}) at some points exceeded the recommended safety limit of unity, while the external hazard index (H_{ex}) was approaching unity. These suggest a potential health risk to farmers and residents through prolonged exposure, inhalation of radon progeny, and food-chain transfer. Farmlands in Shen (SA4), Rayfield (SA5), Kuru (SA9), and the control site Kassa (SA13) generally recorded radionuclide concentrations and radiological parameters below international recommended limits, indicating minimal radiological risk in these areas despite proximity to mining zones. Furthermore, the annual effective dose equivalent (AEDE) values support this conclusion. While AEDE values in the farmlands remain below the recommended public exposure limit of 1 $mSv\cdot y^{-1}$, the farmers working regularly in these areas receives radiation doses considered safe for the general public.

Table 1: Results on Activity Concentrations of Radionuclide and Evaluated Radiological Indices from Shen farmlands

Sample Code	Location			Activity Concentration ($Bq.kg^{-1}$)			$Ra_{(eq)}$	D_γ	$AEDE_{(out)}$	H_{in}	H_{ex}	I_γ
	Longitude	Latitude	Elevation (ft)	$A_{(K)}$	$A_{(U)}$	$A_{(Th)}$	($Bq.\ kg^{-1}$)	($nGyh^{-1}$)	($\mu Sv.y^{-1}$)			
SA4	09^{0}49'08.8"	008^{0}56'08.8"	1294	438.20	0.406	1.235	35.913	183.663	0.2252	0.0981	0.0970	0.307
	09^{0}49'08.8"	008^{0}56'09.0"	1292	532.10	0.406	1.235	43.144	222.819	0.2733	0.1176	0.1165	0.370
	09^{0}49'08.9"	008^{0}56'09.0"	1293	532.10	0.406	1.235	43.144	222.819	0.2733	0.1176	0.1165	0.370
	09^{0}49'08.6"	008^{0}56'09.2"	1292	469.50	0.406	2.470	40.090	197.461	0.2422	0.1093	0.1082	0.340
	09^{0}49'08.3"	008^{0}56'09.3"	1291	406.90	0.406	2.470	35.269	171.357	0.2102	0.0963	0.0952	0.299
	09^{0}49'08.5"	008^{0}56'09.5"	1291	406.90	0.406	1.235	33.503	170.611	0.2092	0.0916	0.0905	0.286
	09^{0}49'08.7"	008^{0}56'09.6"	1292	406.90	0.406	1.235	33.503	170.611	0.2092	0.0916	0.0905	0.286
	09^{0}49'09.3"	008^{0}56'10.3"	1291	406.90	0.406	1.235	33.503	170.611	0.2092	0.0916	0.0905	0.286
	09^{0}49'09.1"	008^{0}56'19.4"	1293	406.90	0.000	13.585	50.758	177.883	0.2182	0.1370	0.1370	0.407
	09^{0}49'08.8"	008^{0}56'08.2"	1296	594.70	0.406	1.235	47.964	248.923	0.3053	0.1306	0.1295	0.412
Mean				**460.11**	**0.365**	**2.717**	**39.679**	**193.676**	**0.238**	**0.108**	**0.107**	**0.336**

Table 2: Results on Activity Concentrations of Radionuclides and Evaluated Radiological Indices from Rayfield farmlands

Sample Code	Location			Activity Concentration (Bq.kg^{-1})			$Ra_{(eq)}$	D_γ	$AEDE_{(out)}$	H_{in}	H_{ex}	I_γ
	Longitude	Latitude	Elevation (ft)	$A_{(K)}$	$A_{(U)}$	$A_{(Th)}$	(Bq. kg^{-1})	(nGyh^{-1})	(μSv.y^{-1})			
SA5	09^{0}50'27.2"	008^{0}55'00.3"	1303	62.60	16.240	0.000	21.060	33.607	0.0412	0.1008	0.0569	0.150
	09^{0}50'27.2"	008^{0}55'00.5"	1302	31.30	12.992	0.000	15.402	19.054	0.0234	0.0767	0.0416	0.108
	09^{0}50'27.1"	008^{0}55'00.1"	1301	62.60	19.082	0.000	23.902	34.920	0.0428	0.1162	0.0646	0.169
	09^{0}50'27.1"	008^{0}55'01.4"	1309	31.30	14.616	0.000	17.026	19.805	0.0243	0.0855	0.0460	0.118
	09^{0}50'27.1"	008^{0}55'01.4"	1309	62.60	14.616	0.000	19.436	32.857	0.0403	0.0920	0.0525	0.139
	09^{0}50'27.5"	008^{0}55'01.6"	1302	62.60	16.240	0.000	21.060	33.607	0.0412	0.1008	0.0569	0.150
	09^{0}50'27.5"	008^{0}55'01.6"	1304	281.70	0.000	1.235	23.457	118.215	0.1450	0.0633	0.0633	0.200
	09^{0}50'27.5"	008^{0}55'01.7"	1307	344.30	0.000	7.410	37.107	148.049	0.1816	0.1002	0.1002	0.304
	09^{0}50'27.4"	008^{0}55'02.1"	1305	281.70	0.406	0.000	22.097	117.656	0.1443	0.0608	0.0597	0.191
	09^{0}50'27.5"	008^{0}55'02.2"	1303	313.00	0.406	1.235	26.273	131.455	0.1612	0.0720	0.0709	0.224
	09^{0}50'27.9"	008^{0}55'02.1"	1304	344.30	0.406	1.235	28.683	144.507	0.1772	0.0785	0.0774	0.245
	09^{0}50'26.1"	008^{0}55'00.8"	1305	281.70	0.000	17.290	46.416	127.912	0.1569	0.1253	0.1253	0.361
Mean				**179.98**	**7.917**	**2.367**	**25.160**	**80.137**	**0.098**	**0.089**	**0.068**	**0.197**

Table 3: Results on Activity Concentrations of Radionuclides and Evaluated Radiological Indices from Bisichi Farmlands

Sample Code	Location			Activity Concentration (Bq.kg^{-1})			$Ra_{(eq)}$	D_γ	$AEDE_{(out)}$	H_{in}	H_{ex}	I_γ
	Longitude	Latitude	Elevation (ft)	$A_{(K)}$	$A_{(U)}$	$A_{(Th)}$	(Bq. kg^{-1})	(nGyh^{-1})	(μSv.y^{-1})			
SA6	09^{0}42'27.2"	008^{0}54'23.3"	1224	1627.60	1.624	3.705	132.247	681.697	0.8360	0.3615	0.3571	1.133
	09^{0}42'27.3"	008^{0}54'23.3"	1225	1377.20	0.812	3.705	112.155	576.905	0.7075	0.3050	0.3028	0.961
	09^{0}42'27.4"	008^{0}54'23.1"	1231	1721.50	1.218	7.410	144.370	722.904	0.8866	0.3931	0.3898	1.230
	09^{0}42'27.2"	008^{0}54'23.3"	1230	1784.10	1.218	4.940	145.658	747.516	0.9168	0.3966	0.3933	1.247
	09^{0}42'28.2"	008^{0}54'24.3"	1232	2222.30	2.436	12.350	191.214	935.284	1.1470	0.5229	0.5163	1.621
	09^{0}42'27.2"	008^{0}54'23.5"	1226	1345.90	1.218	7.410	115.449	566.279	0.6945	0.3150	0.3117	0.980
	09^{0}42'29.3"	008^{0}54'25.1"	1227	1439.80	1.218	40.755	170.362	625.575	0.7672	0.4633	0.4600	1.376
	09^{0}42'27.6"	008^{0}54'23.7"	1229	1252.00	1.624	6.175	106.858	526.564	0.6458	0.2929	0.2885	0.907
	09^{0}42'28.6"	008^{0}54'24.6"	1223	1690.20	3.654	9.880	147.928	712.469	0.8738	0.4093	0.3994	1.250
	09^{0}42'28.7"	008^{0}54'24.7"	1225	2191.00	2.436	6.175	179.973	918.502	1.1265	0.4925	0.4859	1.539
	09^{0}42'27.9"	008^{0}54'25.9"	1227	0.00	294.350	0.000	294.350	135.990	0.1668	1.5911	0.7955	1.962
	09^{0}42'28.5"	008^{0}54'24.1"	1229	2347.50	2.030	4.940	189.852	982.829	1.2053	0.5181	0.5126	1.628
	09^{0}42'55.1"	008^{0}54'01.1"	1252	187.80	0.000	1.235	16.227	79.059	0.0970	0.0438	0.0438	0.138
Mean				**1475.92**	**24.141**	**8.360**	**149.742**	**631.660**	**0.775**	**0.470**	**0.404**	**1.229**

Table 4: Results on Activity Concentrations of Radionuclides and Evaluated Radiological Indices from Kuru Farmlands

Sample Code	Location			Activity Concentration (Bq.kg^{-1})			$Ra_{(eq)}$	D_γ	$AEDE_{(out)}$	H_{in}	H_{ex}	I_γ
	Longitude	Latitude	Elevation (ft)	$A_{(K)}$	$A_{(U)}$	$A_{(Th)}$	(Bq. kg^{-1})	(nGyh^{-1})	(μSv.y^{-1})			
SA9	09^{0}42'02.7"	008^{0}53'00.2"	1254	187.80	0.000	0.000	14.461	78.313	0.0960	0.0390	0.0390	0.125
	09^{0}42'03.0"	008^{0}53'00.3"	1253	187.80	0.000	0.000	14.461	78.313	0.0960	0.0390	0.0390	0.125
	09^{0}42'02.6"	008^{0}53'00.2"	1253	219.10	0.000	0.000	16.871	91.365	0.1120	0.0456	0.0456	0.146
	09^{0}42'01.6"	008^{0}53'01.1"	1251	281.70	0.000	1.235	23.457	118.215	0.1450	0.0633	0.0633	0.200
	09^{0}42'01.7"	008^{0}53'01.2"	1250	219.10	0.812	1.235	19.449	92.486	0.1134	0.0547	0.0525	0.168
	09^{0}42'01.7"	008^{0}53'01.1"	1249	281.70	0.000	1.235	23.457	118.215	0.1450	0.0633	0.0633	0.200
	09^{0}42'01.8"	008^{0}53'01.3"	1240	563.40	0.406	1.235	45.554	235.871	0.2893	0.1241	0.1230	0.391
	09^{0}42'01.7"	008^{0}53'01.2"	1251	187.80	0.406	1.235	16.633	79.246	0.0972	0.0460	0.0449	0.140
	09^{0}42'01.8"	008^{0}53'01.4"	1251	219.10	0.000	1.235	18.637	92.111	0.1130	0.0503	0.0503	0.158
	09^{0}42'01.9"	008^{0}53'01.3"	1253	156.50	0.000	0.000	12.051	65.261	0.0800	0.0325	0.0325	0.104
	09^{0}42'01.9"	008^{0}53'01.4"	1252	187.80	0.000	7.410	25.057	82.788	0.1015	0.0677	0.0677	0.199

Sample Code	Location			Activity Concentration (Bq.kg^{-1})			$Ra_{(eq)}$ (Bq. kg^{-1})	D_γ (nGyh^{-1})	$AEDE_{(out)}$ (µSv.y^{-1})	H_{in}	H_{ex}	I_γ
	Longitude	Latitude	Elevation (ft)	$A_{(K)}$	$A_{(U)}$	$A_{(Th)}$						
	09^{0}42'01.8"	008^{0}53'01.4"	1255	219.10	0.000	0.000	16.871	91.365	0.1120	0.0456	0.0456	0.146
	09^{0}42'01.4"	008^{0}53'01.6"	1254	187.80	0.000	0.000	14.461	78.313	0.0960	0.0390	0.0390	0.125
	09^{0}42'01.7"	008^{0}53'01.7"	1251	219.10	0.000	7.410	27.467	95.840	0.1175	0.0742	0.0742	0.220
	09^{0}42'02.4"	008^{0}53'00.7"	1252	187.80	0.000	0.000	14.461	78.313	0.0960	0.0390	0.0390	0.125
Mean				**233.71**	**0.108**	**1.482**	**20.223**	**98.401**	**0.121**	**0.055**	**0.055**	**0.171**

Table 5: Results on Activity Concentrations of Radionuclides and Evaluated Radiological Indices from Kassa Farmlands

Sample Code	Location			Activity Concentration (Bq.kg^{-1})			$Ra_{(eq)}$ (Bq. kg^{-1})	D_γ (nGyh^{-1})	$AEDE_{(out)}$ (µSv.y^{-1})	H_{in}	H_{ex}	I_γ
	Longitude	Latitude	Elevation (ft)	$A_{(K)}$	$A_{(U)}$	$A_{(Th)}$						
SA13	09^{0}37'49.5"	008^{0}53'35.1"	1293	187.80	0.000	1.235	16.227	79.059	0.0970	0.0438	0.0438	0.138
	09^{0}37'49.7"	008^{0}53'35.0"	1293	187.80	0.000	1.235	16.227	79.059	0.0970	0.0438	0.0438	0.138
	09^{0}37'50.0"	008^{0}53'34.9"	1296	219.10	0.000	7.410	27.467	95.840	0.1175	0.0742	0.0742	0.220
	09^{0}37'50.1"	008^{0}53'35.1"	1296	156.50	0.000	1.235	13.817	66.006	0.0810	0.0373	0.0373	0.117
	09^{0}37'50.3"	008^{0}53'35.3"	1295	219.10	0.812	1.235	19.449	92.486	0.1134	0.0547	0.0525	0.164
	09^{0}37'49.1"	008^{0}53'35.4"	1295	187.80	0.000	4.940	21.525	81.296	0.0997	0.0581	0.0581	0.175
Mean				**193.017**	**0.135**	**2.882**	**19.119**	**82.291**	**0.101**	**0.052**	**0.052**	**0.159**
World Safe limit				**400.0**	**37.0**	**33.0**	**370.0**	**59.00**	**1000.0**	**1.0**	**1.0**	**1.0**

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