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Radiological Hazard Assessment and Human Exposure to Natural Radionuclides in Soils of Udege Mbeki Mining Area, Nasarawa State, Nigeria

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ABSTRACT: Mining involves excavating soil with radioactive materials, which may get deposited in large amounts in the atmosphere or enter the food chain and cause harm to humans when inhaled or ingested. This study evaluated the risks of exposure to ionizing radiation from the primordial and most abundant radionuclides in the soil – radium-226, potassium-40, and thorium-232 in Udege Mbeki mining area of Nasarawa State, Nigeria. Twenty-one (21) soil samples were randomly collected in the mining site and analyzed using gamma ray spectrometer. The standards used to check for the calibration are the International Atomic Energy Agency (IAEA) gamma Spectrometric reference materials RGK-1 for K-40, RGU-1 for Ra-226 (Bi-214 peak) and RTG-1 for Th-232 (Ti-208). The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the samples ranged from 12.7462 to 430.8147 Bq/kg, 38.4147 to 725.4748 Bq/kg, and 22.3092 to 395.5596 Bq/kg respectively. The estimated effective dose in the soil samples was averaged at 148.8091 mSvy^{-1} in the dump, 67.1197 mSv/yr in the farmland, and 121.4909 mSv/yr in the surface soil. These values exceed ICRP's recommended reference level of 1 mSv/yr for public exposure and 20 mSv/yr for workers averaged over a period of five years. Also, with the mean external hazard index recorded at 1.314 and exceeding the recommended threshold limit of 1.0 we conclude that the mine is hazardous both for the public and for workers.

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The constant release of mining waste (tailings) into the biosphere may result in an accumulation of radioactive nuclides in the air, water and soil, which will impact both human and non-human biota (Aliyu *et al.*, 2015). The Nigeria Mining Corporation, currently being privatized by the bureau of public enterprises, was for many years the umbrella under which tin/columbite was being mined, implying that mechanized mining had for a long time been in practice in the Udege area (Aliyu *et al.*, 1996). Owing to the collapse, in the early 1970s, mechanized mining companies were abandoned in the Udege area in the 1980s, thus negative environmental impact became significant. The mining activities have defaced the area by leaving behind devastated landscapes, exposed fertile lands,

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artificial dams, abandoned ponds and mine tailings which often contain heavy metals and radionuclides. Consequently, there is a continuous exposure of humans to natural background radiation day after day from building materials, the ground, food, air, outer space as well as elements in their bodies (Saleh *et al*., 2013). The external exposure to natural radionuclides around such abandoned mining sites can vary significantly and may be up to 100 times higher than the average. Radon gas, which is formed during the decay of natural uranium in the soil, is a significant contributor to human exposure. The level of exposure from inhaling radon can vary depending on the local geology, building materials, and lifestyle factors. Approximately half of the average human exposure to natural radioactive sources can be attributed to inhalation of radon (UNSCEAR, 2008).

Surface and underground mining create huge amounts of waste rock, containing radioactive Radium and Lead, which is left as a waste rock dump. This heap emits Radon (Rn-222), which can cause lung cancer. The large volume of mined rocks also produces dust and releases radioactive noble gas, radon, which can easily be dispersed by wind. Radioactive tailings from the Udege Mbeki mining sites can leach into nearby water bodies and contaminate soil and drinking water sources, posing serious health risks to humans and animals (Uranium Mining in and for Europe, 2012). One of the radionuclides found naturally in the soil is Potassium-40; a very vital element required in the human body during biological processes which can present both external and internal health hazards owing to the strong association of gamma radiation with the electron-capture decay process, and this makes external exposure to this isotope a concern. The health hazard resulting from exposure to potassium-40 is associated with cell damage caused by the ionizing radiation that results from radioactive decay, with the general potential for subsequent cancer induction (Human Health Fact Sheet, 2005). Thorium, which is also a radionuclide found naturally in the soil is a weakly radioactive alpha emitter, so external exposure is unlikely to harm cells. Inside the body, thorium could cause cancer in internal organs. Thorium decay also produces radioactive radon gas, which could accumulate to dangerous levels in a confined space. Studies have found that thorium workers breathing dust may develop lung disease, lung cancer, pancreatic cancer, and genetic changes (U.S. Public Health Service, 1990).

Soils play a major role in element cycling and heavy metal accumulation, which is higher than in water and air (Ashraf *et al*., 2011). Soils also store many hazardous elements, including heavy metals, trace metals, and elemental and biological constituents (Zimmerman and Weindorf, 2010). Terrestrial ecosystems contain most of the radioactivity; natural or artificial, in the soil. Soil-based exposures are important for radiation risk assessment and radioactivity levels in the soil depend on the parent materials that make up the soil type (Gabdo *et al*., 2014). Therefore the objective of this paper is to evaluate the radiological hazards associated with human exposure to natural radionuclides in soils of Udege Mbeki mining area, Nasarawa State, Nigeria

MATERIALS AND METHODS

Materials: The materials employed in this research are: a highly sensitive and accurate radiation survey meter (Ludlum Micro R meter, model 19) and a Global Positioning System (GPS), the hand trowel, the pulveriser, the sieve and Sodium Iodide (NaI) detector. The Model 19 survey meter is a gamma µR/meter with a 2.5 cm x 2.5 cm NaI detector. It measures 0-50 µSv/h, or 0-5000 µR/hr. This aluminum-housed instrument has a separate battery compartment and metal handle, providing quality and durability. It measures 0 to 5000 µR/hr, and the rotary switch on the front panel sets the range of calibration labeled in black on the scale. If the rotary switch is on 25 or 250, readings are taken from the red scale. For example, if the switch is set to 500, readings range from 0-500 µR/hr. In this case, the 0-50 scale has each 10 divisions representing 100 divisions. This expands the scale from 0-10 to 0-500.

The Study Area: The area under study which is located in the north central part of Nigeria is a small town in Nasarawa State and has for a long time embraced the practice of mining (Aliyu *et al.,* 1996). It is situated approximately at latitude 8^{o} $21.97^{'}$ North and longitude 7^{o} $51.97'$ East, covering a total area of approximately 400 km^2. It falls within the tropical guinea-savannah and is characterized by two seasons known as dry season, lasting from November to March, and the rainy season lasting from April to October (Okegye & Gajere, 2015).

Sample Collection: With the survey meter held at about one meter (1 m) above the ground level, the background radiations for twenty-one different locations in the mining dumps, farmland and surface soils were taken in micro Roentgen per hour ($\mu R hr^{-1}$) which is the default calibration of the survey meter. The soil samples at each of these locations were collected using the hand trowel and the samples were packaged in sample bags and taken to a suitable location where they were then crushed into fine tiny pieces. The samples were then sieved to obtain fine powder and repackaged in bags which

were labelled D1 to D7, F1 to F7 and S1 to S7 with the coordinates of the points where each sample was collected from.

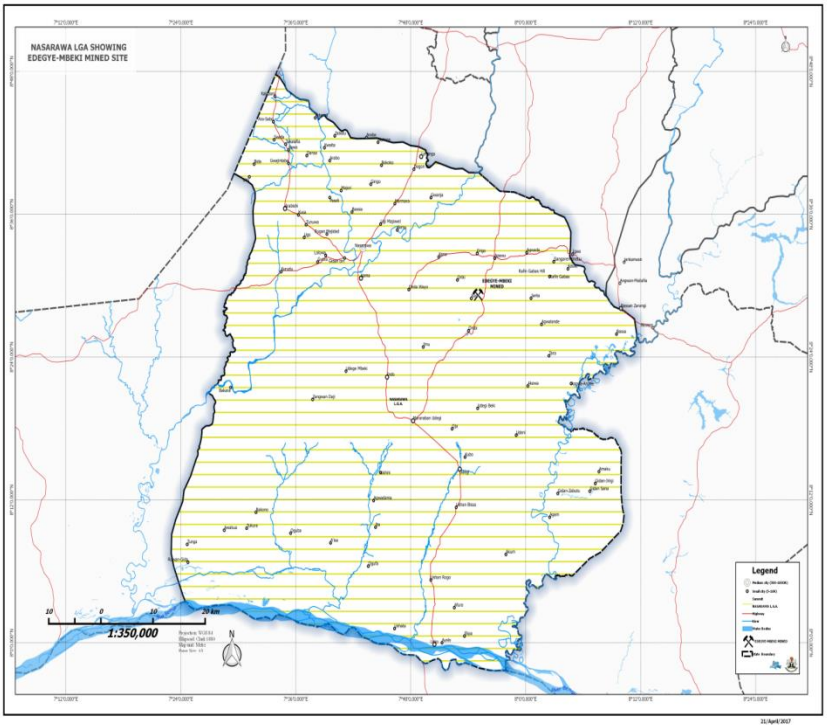

Fig. 1: Map of Nasarawa LGA showing Udege Mbeki mined site (NAGIS, 2018)

Sample Preparation: Each of the soil samples collected was dried and crushed into fine powder with the use of a pulveriser. Packaging of the samples into radon-impermeable cylindrical plastic containers which were selected based on the space allocation of the detector vessel measuring 7.6 cm by 7.6 cm in dimension (geometry) was also carried out. To prevent radon-222 escaping, the packaging in each case was triple sealed.

The sealing process included smearing of the inner rim of each container lid with Vaseline jelly, filling the lid assembly gap with candle wax to block the gaps between lid and container, and tight-sealing lid-container with masking adhesive tape. Radon and its short-lived progenies were allowed to reach secular radioactive equilibrium by storing the samples for 30 days prior to gamma spectroscopy measurements.

Evaluation of Radioactivity of the Samples: The analysis was carried out in the Centre for Energy Research and Training (CERT), Zaria, Nigeria using a 76 x 76 mm NaI (Tl) detector crystal optically coupled to a photomultiplier tube (PMT). The assembly has a preamplifier incorporated into it and a 1 kilovolt external source. The detector is enclosed in a 6 cm lead shield with cadmium and copper sheets. This arrangement is aimed at minimizing the effects of background and scattered radiation.

The data acquisition software is Maestro by Camberra Nuclear Products. The samples were measured for a period of 29000 seconds, for each sample. The peak area of each energy in the spectrum was used to compute the activity concentrations in each sample by the use of equation:

$$\text{C}\,(Bqkg^{-1}) = \frac{C_n}{C_{fk}} \qquad (1)$$

Where, C = activity concentration of the radionuclides in the sample given in $BqKg^{-1}$; $\boldsymbol{C_n}$ = count rate (counts per second)

$$\text{Counts per second (cps)} = = \frac{Net\ Count}{Live\ Time} \qquad (2)$$

Where: $\boldsymbol{C_{fk}}$ = Calibration factor of the detecting system (CERT). Calibration of the system for energy and efficiency were done with two calibration point sources, Cs-137 and Co-60. These were done with the amplifier gain that gives 72% energy resolution for the 66.16 KeV of Cs-137 and counted for 30 minutes.

The standards used to check for the calibration are the International Atomic Energy Agency (IAEA)

gamma Spectrometric reference materials RGK-1 for K-40, RGU-1 for Ra-226 (Bi-214 peak) and RTG-1 for Th-232 (Ti-208).

RESULTS AND DISCUSSION

The activity concentration in each soil sample collected from Udege Mbeki mining site was measured using a gamma-ray spectrometer and the radioactivity of natural radionuclides namely, radium, thorium and potassium was investigated in the soil samples. The primordial radionuclides of ^{226}Ra, ^{232}Th, and ^{40}K were the three most important radionuclides detected in the area. Background radiation in micro Roentgen per hour (μRhr^{-1}) and the coordinates of each point of collection is contained in Table 1.

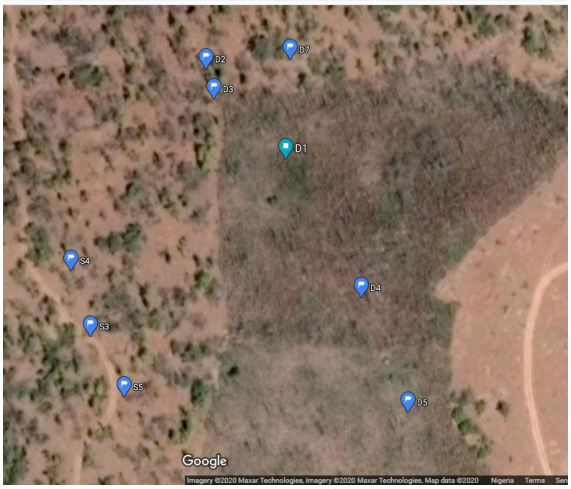

Fig. 2: Map showing the points of soil sample collection

Fig. 3: Map showing the points of soil sample collection

The collected samples were analyzed for thorium in Becquerel per kilogram (Bq/kg) and Counts Per Second (CPS). The activity concentration of the samples from the dump ranged from 38.4147 ± 2.3985 to 725.4748 ± 11.9923 Bq/kg, while the farmland ranged from 49.7385 ± 1.5728 to 384.5791 ± 7.5492 Bq/kg, and for the surface soils it ranged from 72.2683 ± 3.1455 to 739.5510 ± 12.3462 Bq/kg. Table 2 expresses in detail the result of the analysis.

Table 1: Background radiation at Udege Mbeki mined site

S/No	Sample ID	Latitude (in degrees)	Longitude (in degrees)	Background Radiation (μRhr^{-1})
1	D1	8.400013	7.868830	80.0
2	D2	8.400350	7.868518	95.0
3	D3	8.400238	7.868548	70.0
4	D4	8.399485	7.869127	70.0
5	D5	8.399042	7.869317	68.0
6	D6	8.424392	7.889985	170.0
7	D7	8.400387	7.868845	100.0
8	F1	8.426038	7.888160	35.0
9	F2	8.426232	7.888177	30.0
10	F3	8.425822	7.888517	40.0
11	F4	8.425405	7.884120	45.0
12	F5	8.424563	7.888277	60.0
13	F6	8.426165	7.888087	40.0
14	F7	8.424758	7.888068	40.0
15	S1	8.425782	7.888520	45.0
16	S2	8.426438	7.887772	35.0
17	S3	8.399337	7.868065	65.0
18	S4	8.399587	7.867992	100.0
19	S5	8.399103	7.868195	55.0
20	S6	8.425213	7.888395	55.0
21	S7	8.424523	7.888202	50.0

Table 2: Activity Concentration of Thorium-232 (^{232}Th) in the soil samples collected from Udege Mbeki mining site

S/No	Sample ID	Th-232 (CPS)	Th-232 (Bq/kg)
1	D1	0.3779 ± 0.0074	430.8969 ± 8.4535
2	D2	0.0749 ± 0.0017	85.3615 ± 1.8873
3	D3	0.4426 ± 0.0090	504.6593 ± 10.2229
4	D4	0.3738 ± 0.0078	426.2179 ± 8.8861
5	D5	0.1664 ± 0.0038	189.7928 ± 4.2858
6	D6	0.0337 ± 0.0021	38.4147 ± 2.3985
7	D7	0.6362 ± 0.0105	725.4748 ± 11.9923
8	F1	0.0712 ± 0.0012	81.2330 ± 1.3368
9	F2	0.0618 ± 0.0026	70.4203 ± 2.9489
10	F3	0.2134 ± 0.0050	243.3846 ± 5.6619
11	F4	0.0436 ± 0.0014	49.7385 ± 1.5728
12	F5	0.3373 ± 0.0066	384.5791 ± 7.5492
13	F6	0.0822 ± 0.0022	93.6972 ± 2.5164
14	F7	0.1949 ± 0.0047	222.2703 ± 5.3081
15	S1	0.6486 ± 0.0108	739.5510 ± 12.3462
16	S2	0.0864 ± 0.0021	98.4941 ± 2.3591
17	S3	0.4162 ± 0.0090	474.5803 ± 10.2229
18	S4	0.0844 ± 0.0032	96.2136 ± 3.6173
19	S5	0.0708 ± 0.0030	80.7219 ± 3.3814
20	S6	0.0634 ± 0.0028	72.2683 ± 3.1455
21	S7	0.1273 ± 0.0033	145.1657 ± 3.8139
	Mean	**0.2194 ± 0.0048**	**250.1493 ± 5.4241**

The analysis of the soil samples was also made for potassium-40. The activity concentration in Becquerel per kilogram (Bq/kg) and Counts per Second (CPS) were obtained after analysis and the results are tabulated in table 3 with the average activity of 179.4876 ± 9.9237 Bq/kg.

Table 3: Activity Concentration of Potassium-40 (^{40}K) in the soil samples collected from Udege Mbeki mining site

S/No	Sample ID	K-40 (CPS)	K-40 (Bq/kg)
1	D1	0.0815 ± 0.0024	126.7764 ± 3.8076
2	D2	0.0438 ± 0.0023	68.1611 ± 3.6467
3	D3	0.1092 ± 0.0115	169.8933 ± 17.8581
4	D4	0.1927 ± 0.0120	299.6729 ± 18.7161
5	D5	0.0861 ± 0.0043	133.9626 ± 6.7571
6	D6	0.1279 ± 0.0021	198.8524 ± 3.3249
7	D7	0.1425 ± 0.0183	221.5906 ± 28.4228
8	F1	0.0143 ± 0.0022	22.3092 ± 3.4858
9	F2	0.0562 ± 0.0049	87.3599 ± 7.6152
10	F3	0.1238 ± 0.0070	192.4706 ± 10.8328
11	F4	0.1177 ± 0.0026	183.0858 ± 3.9685
12	F5	0.1042 ± 0.0086	162.0100 ± 13.2997
13	F6	0.0353 ± 0.0023	54.9150 ± 3.5394
14	F7	0.1321 ± 0.0044	205.4486 ± 6.9180
15	S1	0.1373 ± 0.0164	213.6000 ± 25.4733
16	S2	0.1885 ± 0.0024	293.1303 ± 3.8076
17	S3	0.2543 ± 0.0159	395.5596 ± 24.7761
18	S4	0.2135 ± 0.0049	332.0641 ± 7.6152
19	S5	0.0990 ± 0.0036	153.9658 ± 5.5773
20	S6	0.0913 ± 0.0011	141.9531 ± 1.7161
21	S7	0.0723 ± 0.0047	112.4578 ± 7.2398
	Mean	**0.1154 ± 0.0064**	**179.4876 ± 9.9237**

Table 4: Activity Concentration of Radium-226 (^{226}Ra) in the soil samples collected from Udege Mbeki mining site

S/No	Sample ID	Ra-226 (CPS)	Ra-226 (Bq/kg)
1	D1	0.1002 ± 0.0092	116.1146 ± 10.7084
2	D2	0.0159 ± 0.0017	18.3801 ± 1.9978
3	D3	0.2348 ± 0.0104	272.0262 ± 12.0270
4	D4	0.1996 ± 0.0093	231.2303 ± 10.7484
5	D5	0.0686 ± 0.0037	79.4742 ± 4.2754
6	D6	0.0134 ± 0.0026	15.5033 ± 3.0367
7	D7	0.3718 ± 0.0173	430.8147 ± 20.0184
8	F1	0.0165 ± 0.0041	19.1393 ± 4.7149
9	F2	0.0150 ± 0.0047	17.3413 ± 5.3942
10	F3	0.0712 ± 0.0067	82.5109 ± 7.7117
11	F4	0.0119 ± 0.0022	13.7452 ± 2.5572
12	F5	0.0780 ± 0.0073	90.3424 ± 8.4709
13	F6	0.0388 ± 0.0019	44.9914 ± 2.1577
14	F7	0.0595 ± 0.0073	68.9256 ± 8.5108
15	S1	0.2419 ± 0.0114	280.2973 ± 13.1858
16	S2	0.0219 ± 0.0032	25.3326 ± 3.7160
17	S3	0.4171 ± 0.0144	483.2781 ± 16.7020
18	S4	0.0279 ± 0.0017	32.3251 ± 1.9978
19	S5	0.0196 ± 0.0043	22.7354 ± 4.9946
20	S6	0.0110 ± 0.0024	12.7462 ± 2.7970
21	S7	0.0500 ± 0.0028	57.9774 ± 3.2765
	Mean	**0.0993 ± 0.0084**	**115.0110 ± 7.0952**

Table 4 shows the primordial radionuclide obtained after analysis of the soil samples for radium. Radium-226 (^{226}Ra) was the most important detected and its activity concentration in the dump, farmland and surface soils are shown in details.

For proper assessment of the radiological hazards associated with these radionuclides, the absorbed dose rate and the annual effective dose rate as well as the external hazard index were calculated and shown in tables 5, 6 and 7.

The absorbed dose rate was calculated in nano Gray per hour ($nGyh^{-1}$) using equation 3

$$D(nGyh^{-1}) = C_1 f + C_2 f + C_3 f \quad (3)$$

where D stands for dose rate, C represents the activity concentrations of the radionuclides 1, 2 and 3, and f is the dose rate conversion factor for the individual elements. For potassium, K = 0.0417, for Radium, Ra = 0.462, for Thorium, Th = 0.604 (UNSCEAR, 2000)

The Annual Effective Dose Rate was calculated in milli Sievert per year ($mSvy^{-1}$) with the aid of equation 4

$$E(mSvy^{-1}) = D(nGyh^{-1}) \times 3650(h) \times 0.2 \times 0.7(SvG^{-1}) \times 10^{-3} \quad (4)$$

where 0.2 is the outdoor occupancy factor, 0.7 SvG^{-1} is the conversion coefficient and 3650 (h) per year is the time spent while carrying or the mining activity (UNSCEAR, 2000)

The external hazard index (H_{ex}) was calculated using equation 5

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (5)$$

Where C represents the activity concentrations of the radionuclides Ra-226, Th-232 and K-40 in Bq/kg (Qureshi *et al., 2013)*.

The specific activity due to ^{232}Th, ^{40}K and ^{226}Ra, in the soil in the mining area of Udege Mbeki has been analyzed as shown in tables 1.3, 1.4 and 1.5. In the dump, the activity concentration of ^{232}Th was found between the ranges of (38.4147 ± 2.3985) to (725.4748 ± 2.3985) Bq/kg with an average of (342.9740 ± 6.8752) Bq/kg and ^{40}K ranged from (68.1611 ± 3.6467) to (299.6729 ± 18.7161) Bq/kg with an average of (174.1299 ± 11.7905) Bq/kg while ^{226}Ra ranged from (15.5033 ± 3.0367) to (430.8147 ± 20.0184) Bq/kg with a mean of (166.2205 ± 8.9732) Bq/kg. The activity concentration of these radionuclides in the farmland was observed to range from (49.7385 ± 1.5728) to (384.5791 ± 7.5492) with an average of (163.6176 ± 3.8420) Bq/kg for ^{232}Th and spanned between (22.3092 ± 3.4858) to 205.4486 ± 6.9180) with an average of (129.6570 ± 7.0942) Bq/kg for ^{40}K while for ^{226}Ra it ranged from (13.7452 ± 2.5572) to (90.3424 ± 8.4709) with an average of (48.1423 ± 5.6453) Bq/kg. In the surface soil, the activity concentration of the primordial radionuclides ^{232}Th, ^{40}K and ^{226}Ra respectively ranged from (72.2683 ± 3.1455) to (739.5510 ± 12.3462) with an

average of (243.8564 ± 5.5552) Bq/kg, (112.4578 ± 7.2398) to (395.5596 ± 24.7761) with an average of (234.6758 ± 10.8865) Bq/kg and (12.7462 ± 2.7970) to (483.2781 ± 16.7020) with an average of (130.6703 ± 6.6671) Bq/kg.

It follows that there is variation in the activity concentration of the different radionuclides in the various locations where the soil samples were obtained. In the dump, sample D6 is observed to have the lowest ^{232}Th activity concentration while D7 has the highest ^{232}Th activity concentration. On the other hand, D2 has the lowest ^{40}K activity concentration while D4 has the highest ^{40}K activity concentration. Sample D6 contains the lowest activity concentration for ^{226}Ra while D7 has the highest ^{226}Ra activity concentration.

Table 5: Evaluation of radiation hazard indices for the radiological assessment of the soil in dumps

ID	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)	Absorbed Dose Rate (nGyh^{-1})	Annual Effective Dose Rate (mSvy^{-1})	External Hazard Index
D1	430.8969 ±8.4535	126.7764 ±3.8076	116.1146 ±10.7084	319.1941 ±10.2120	163.1082 ±5.2183	2.0039 ±0.0624
D2	85.3615 ±1.8873	68.1611 ±3.6467	18.3801 ±1.9978	62.8922 ±2.2150	32.1379 ±1.1319	0.3934 ±0.0134
D3	504.6539 ±10.2229	169.8933 ±17.8581	272.0262 ±12.0270	437.5749 ±12.4758	223.6008 ±6.3751	2.7190 ±0.0757
D4	426.2179 ±8.8861	299.6729 ±18.7161	231.2303 ±10.7484	376.7604 ±11.1134	192.5246 ±5.6789	2.3329 ±0.0673
D5	189.7928 ±4.2858	133.9626 ±6.7571	79.4742 ±4.2754	156.9382 ±4.8456	80.1954 ±2.4761	0.9754 ±0.0295
D6	38.4147 ±2.3985	198.8524 ±3.3249	15.5033 ±3.0367	38.6571 ±2.9903	19.7538 ±1.5280	0.2316 ±0.0182
D7	725.4748 ±2.3985	221.5906 ±28.4228	430.8147 ±20.0184	646.4635 ±17.6771	330.3428 ±9.0330	4.0115 ±0.0693
Mean	**342.9740 ±6.8752**	**174.1299 ±11.7905**	**166.2205 ±8.9732**	**291.2115 ±8.7899**	**148.8091 ±4.4916**	**1.8097 ±0.0480**

Table 6: Evaluation of radiation hazard indices for the radiological assessment of the surface soil

ID	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)	Absorbed Dose Rate (nGyh^{-1})	Annual Effective Dose Rate (mSvy^{-1})	External Hazard Index
S1	739.5510 ±12.3462	213.6000 ±25.4733	280.2973 ±13.1858	585.0933 ±14.0130	298.9827 ±7.1606	3.6574 ±0.0886
S2	98.4941 ±2.3591	293.1303 ±3.8076	25.3326 ±3.7160	201.2113 ±3.3005	102.8190 ±1.6866	0.5096 ±0.0199
S3	474.5803 ±10.2229	395.5596 ±24.7761	483.2781 ±16.7020	526.4158 ±14.9241	268.9985 ±7.6262	3.2208 ±0.0898
S4	96.2136 ±3.6173	332.0641 ±7.6152	32.3251 ±1.9978	111.2451 ±3.4254	56.8462 ±1.7504	0.5279 ±0.0209
S5	80.7219 ±3.3814	153.9658 ±5.5773	22.7354 ±4.9946	65.6802 ±4.5824	33.5626 2.3416	0.4051 ±0.0277
S6	72.2683 ±3.1455	141.9531 ±1.7161	12.7462 ±2.7970	55.4582 ±3.2637	28.3391 ±1.6678	0.3430 ±0.0199
S7	145.1657 ±3.8139	112.4578 ±7.2398	57.9774 ±3.2765	119.1551 ±4.1192	60.8883 ±2.1049	0.7406 ±0.0251
Mean	**243.8564 ±5.5552**	**234.6758 ±10.8865**	**130.6703 ±6.6671**	**237.7513 ±6.8040**	**121.4909 ±3.4769**	**1.3435 ±0.0417**

In the farmland, sample F4 appears to record the lowest thorium concentration while F5 has the highest. Similarly, sample F1 has the lowest ^{40}K activity concentration while sample F7 records the highest. It is also observed that sample F4 shows the lowest ^{226}Ra activity concentration while sample F5 is observed to have the highest. Sample S6 is observed to have the lowest ^{232}Th activity concentration for surface soil while sample S1 records the highest. Consequently, the activity concentration for ^{40}K shows sample S7 to have the lowest while sample S3 has the highest, while sample S6 records the lowest activity concentration of ^{226}Ra with sample S3 having the highest. The external hazard index which is expected to lie within the limits $0 \leq H_{ex} \leq 1$ for the radiation hazard to be insignificant was observed to range between 0.2316 ± 0.0182 to 4.0115 ± 0.0693 with an average of 1.8097 ± 0.0480 in the dump, 0.2673 ± 0.0138 to 1.7627 ± 0.0548 with an average of 0.7888 ± 0.0316 in the

farmland, and for the surface soil, 0.3430 ± 0.0199 to 3.6574 ± 0.0886 with 1.3435 ± 0.0417 as mean. Only the farmland falls within safe limit, and this may be attributed to less mining activity within the farming area compared to the surface soils and the dumps.

Table 7: Evaluation of radiation hazard indices for the radiological assessment of the soil in the farmland

ID	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)	Absorbed Dose Rate (nGyh^{-1})	Annual Effective Dose Rate (mSvy^{-1})	External Hazard Index
F1	81.2330	22.3092	19.1393	58.8374	30.0659	0.3700
	±1.3368	±3.4858	±4.7149	±3.1311	±1.6000	±0.0186
F2	70.4203	87.3599	17.3413	54.1884	27.6903	0.3369
	±2.9489	±7.6152	±5.3942	±4.5908	±2.3459	±0.0275
F3	243.3846	192.4706	82.5109	193.1504	98.6999	1.2027
	±5.6619	±10.8328	±7.7117	±7.4342	±3.7989	±0.0450
F4	49.7385	183.0858	13.7452	44.0270	22.4978	0.2673
	±1.5728	±3.9685	±2.5572	±2.2969	±1.1737	±0.0138
F5	384.5791	162.0100	90.3424	280.7798	143.4784	1.7627
	±7.5492	±13.2997	±8.4709	±9.0279	±4.6133	±0.0548
F6	93.6972	54.9150	44.9914	113.8027	58.1532	0.4948
	±2.5164	±3.5394	±2.1577	±2.6644	±1.3615	±0.0163
F7	222.2703	205.4486	68.9256	174.6621	89.2523	1.0872
	±5.3081	±6.9180	±8.5108	±7.4266	±3.7950	±0.0449
Mean	**163.6176**	**129.6570**	**48.1423**	**131.3497**	**67.1197**	**0.7888**
	±3.8420	**±7.0942**	**±5.6453**	**±5.2246**	**±2.6698**	**±0.0316**

Table 8: Comparison between the mean radiological hazard indices of natural radioactivity of soils in the present study and similar investigations performed in other states of Nigeria

State	Mean ^{226}Ra (Bq/kg)	Mean ^{232}Th (Bq/kg)	Mean ^{40}K (Bq/kg)	Mean H_{ex}	Reference
Sikiti	28.15	107.30	465.95	0.5873	Ibrahim
(Oyo State)	±16.93	±23.83	±129.19	±0.11	*et al* (2014)
Nasarawa Central	43.32	50.81	399.11	0.41	Ibrahim
(Nasarawa State)	±6.56	±3.71	±8.63	±0.032	*et al* (2013)
Kaduna North	212.4779	95.3643	360.3414	1.0136	Taiwo
(Kaduna State)	±9.42	±6.3107	±22.9079	--	*et al* (2014)
Jos	762.4	17258.3	5901.4	70.1693	Davou &
(Plateau State)	±151.31	±195.68	±280.15	--	Mangset (2015)
Ife-Central	24.00	128.00	850	0.74	Gbenu
(Osun State)	--	--	--	±0.03	*et al* (2016)
Ekiti	18.7	39.8	351.1	0.28	Fasae
(Ekiti State)	±6.2	±3.5	±3.1	±0.03	(2013)
Udege Mbeki	115.0110	250.1493	179.4876	1.3140	Present Work
(Nasarawa State)	± 7.0952	± 5.4241	± 9.9237	±0.0404	

Davou and Mangset, (2015) carried out an experiment on the "Evaluation of Radiation Hazard Indices and Excess Lifetime Cancer Risk due to Natural Radioactivity in Mined Tailings in some locations in Jos, Plateau State, Nigeria". This experiment saw samples taken from fourteen (14) different sites within Jos and analysis of the results showed that the radioactivity in the soil samples was very high compared to the standard or threshold limits of 400 Bqkg^{-1} for ^{40}K, 35 Bqkg^{-1} for ^{226}Ra and 30 Bqkg^{-1} for ^{232}Th as stipulated by UNSCEAR in the year 2000. The same applied to the external hazard index which was 70.1693 as against the standard limit which is 1. This is extremely on the high side. The results obtained by Davou and Mangset are similar to the results obtained from this research work carried out in Udege Mbeki, Nasarawa State. In this case, the mean radioactivity for ^{226}Ra, ^{232}Th and ^{40}K in the soil samples were 115.0110 Bqkg^{-1}, 250.1493 Bqkg^{-1} and 179.4876 Bqkg^{-1} respectively, and the mean external hazard index was 1.3140. These are also very high for ^{226}Ra and ^{232}Th except for ^{40}K which is within limit. Other results obtained as recorded on table 1.8 are within the safe limit for the external hazard index except for the research conducted by Taiwo *et al* (2014) in Kaduna North, Kaduna State, which is also above 1.

It is clear that mining within these high risk areas are uncontrolled and that has consequently given rise to a large accumulation of radioactive nuclides in the atmosphere, thereby posing serious health hazards which could include genetic mutation, cancer, asthma and pulmonary diseases to the people living, working or faming within the areas under study.

Conclusion: The results from our findings reveal that the proportion of accumulated radiation levels in the atmosphere owing to the mining activities in the site is significantly above the threshold levels as recommended by the International Commission on Radiation Protection (ICRP). Despite this eye-opener, it is crucial to acknowledge the challenges that becloud the safety of the workers and the public. A controlled approach to mining within the area may therefore be actualized through routine monitoring as well as sensitization schemes well mapped out by the government. Enforcement of post-mining land rehabilitation to restore the land to its natural state is also suggested. Navigating these hurdles would definitely be a significant stride towards ensuring a safer environment for all and sundry.

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Data Availability Statement: Data are available on request from the first author

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