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Assessment of Radiological Hazards Associated with Zumba Mining Sites in Niger State, Nigeria

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Abstract: The assessment of radiological associated with Zumba mining sites in Niger State was was carried out using NaI(Tl) gamma ray spectroscopy. The results shows mean activity concentrations ^{40}K ^{226}, Ra and ^{232}Th is 197.2449 Bq.Kg^{-1}; 48.4357 Bq.Kg^{-1} and 40.6581 respectively. The total mean for the absorbed dose rate of all the 7 soil samples analysed is 46.0830 ŋGy.h^{-1} and also the annual effective dose in the study areas ranged from 0.0342 - 0.0893 mSvy^{-1} (i.e 34 – 89 μSv.y^{-1}), which had an mean annual effective dose of 0.0646 mSv.y^{-1} (ie 65μSv.y^{-1}). These results shows that the radiation exposure level for members of the public in the study areas is lower than the recommended limit value of 1 mSv.y^{-1} (UNSCEAR, 2000). Furthermore, the mean external hazard index (H_{ext}) is 0.1694 Bqkg^{-1} (ZB3) to 0.4269 Bqkg^{-1} (ZB7), while its maximum allowed value is (H_{ext} = 1) which corresponds to upper limit of Ra_{eq} (370 BqKg^{-1}) in order to limit the external gamma radiation dose from the soil materials to 1.5 mGy y^{-1}. The accepted index value should be equal to or less than unity ($H_{ext} \leq$ = 1). Therefore, it can be deduce said that no radiological hazard is conceptualize to dwellers in the study areas and the miners working on those mining sites. The entire environment is within the permissible dose limit for the workers of the mining sites and also for the agriculture and construction buildings. Therefore, the mining site is safe in terms of radiological hazards.

Keywords: Radionuclides, soil, mining, activity concentration, absorbed dose, Niger.

INTRODUCTION

The mining activities can lead to the release of naturally occurring radioactive materials (NORMS), posing radiological hazards to miners, nearby communities, and environment. This study assesses the radiological hazards associated with mining site in Zumba, focusing on the levels of radiation exposure and potential health risks. The activities of miners can lead to the significant environmental degradation and health risks, particularly due to the exposure to ionizing radiation. In Nigeria, where mining is a substantial economic activity, understanding the radiological hazards associated with the mining sites is crucial for environmental protection and public health. Therefore this study is geared towards protecting people and the environment from accumulation of higher doses of radiation, hence measurement of gamma radiation level in the Zumba mining sites of was performed in the laboratory using gamma spectroscopy system, to assess the concentrations of NORM (i.e. three most prominent primordial radionuclides, potassium, thorium and radium) by determining the base line radioactivity associated with their occurrences in the soil samples to analyzed their possible effects on human lives due to occupational and settlement exposures from the mining sites. Lastly an attempt was also made to proffer measures against its adverse effects in human and the environment.

MATERIALS AND METHODS

The study area is located in the Zumba mining site in Shiroro Local Government area in Niger State, Nigeria. The seven soil samples taken from Zumba mining sites and are labeled as ZB1, ZB2, ZB3……..….ZB7. The map of Zumba mining sites is shown in Figure. 1

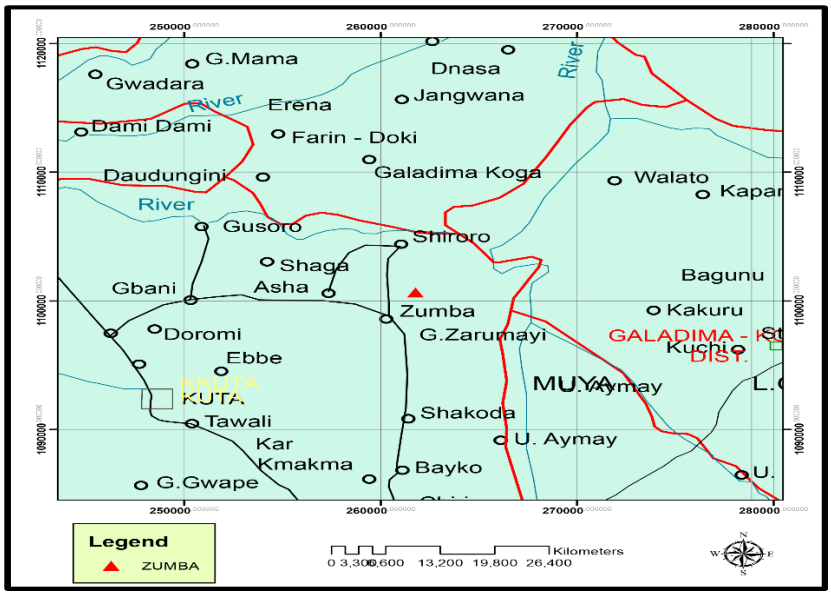

Fig.1: Map showing Zumba Mining Site.

The methodology that was used in carrying out this study is; careful collection of soil samples (of about 1 kg each) from the mining site as shown in Map.1 The soil samples were collected at depths 6- 8 inches, which initially filled into polyethylene bags separately from respective points in equal measures sealed and labeled for easy of identification and transported laboratory for Laboratory analysis. In the laboratory, the soil samples were kept in an oven at a temperature of 105°C to allow it to dry overnight in order to remove likely moisture. After drying, the samples were pulverized and sieved with a mesh having holes each of diameter of 2mm in order to remove organic materials, stones and lumps, the homogenized samples were packed to fill cylindrical plastic beakers of 7cm by 6cm diameter which is the same as geometry of the counting detector. This satisfies the selected optimal sample container height.(Ibeanu IGE et al (2000)). The soil samples were carefully sealed using vaseline, candle wax and masking tape in order to prevent trapped radon gas from escaping.They were then weighed on a digital weighing balance with a precision of ±0.01g. Each plastic beaker can accomodates approximately 300g of the soil sample. The sealed soil samples were kept for a minimum period of 30 days so as to allow for ^{226}Ra and its short-lived progenies in other to reach its secular radioactive equilibrium before gamma counting(Okeyode IC, Akanni AO (2009;2(7)). The NaI(TI) detector spectroscopy system carried out the analysis.

Calibration and Background Radiation

In using the gamma spectrometer to identify samples of unknown composition, its energy scales were calibrated, the calibration was performed using peak of known source such as

^{137}Cs and ^{60}Co. Which is counted for 30 minutes to give 1173.2 keV and 1332.4 keV respectively. The gamma spectrometer system employed consists of a 3'×3' NaI(Tl) detector, a product of Princeton Gamma Tech, USA. The detector is hold in a cylindrical lead shield to reduce the effect of background radiation. The standards used for calibration is the IAEA Gamma Spectrometric reference materials RGK-1 for ^{40}K, RGU -1 for the ^{226}Ra (Bi – 214 peak) and RTG -1 For ^{232}Th (Ti -208).The background area count was done for 29000 seconds for the three radionuclides (i.e. ^{40}K, ^{226}R & ^{232}Th) were measured and the results evaluated as shown in Table 1 below:-

Table 1: Background count rate used in the evaluations of the samples.

Serial	Isotope	Background Count (CPS)	Background Count (Bq/kg)
1.	^{40}K	0.2219± 0.017	345.1011±25.5940
2.	^{226}R	0.0229± 0.0109	26.5353± 12.6304
3.	^{232}Th	0.01202± 0.0078	137.0582± 8.8940

The peak area of each energy in the spectrum was used to compute the activity concentrations in each of the samples by the use of equation 1:-

$$C\ (Bq.kg^{-2}) = Cn\ /\ C_{fk} \quad (1)$$

Where,

c = activity concentration of the radionuclides in the sample given in $BqKg^{-1}$

cn = count rate = count per second (cps) = Net/Live time.

C_{fk} = calibration factor of the detecting system.

The gross area count G_c is related to the area count through the expression (Okeyode IC and Akanni AO -2009).

$$N_c = G_c - B_c \quad (2)$$

Where B_c is the background area count, (area count recorded by the detector in the absence of the samples).

Using equation (2), the net area counts N_c was calculated from the gross area counts G_c generated by the gamma spectroscopy system, the sample was measured for 36000s (10 hours) to obtain the back ground contribution. Consequently, the net count per second (cps) was also calculated for the three radionuclides (^{40}K, ^{226}R &^{232}Th).The activity concentration of the measured sample was obtained using equation (3).

$$A = \frac{C_{net}}{P_\gamma \times \varepsilon \times m \times t} \quad (3)$$

Radiological Parameters

The activity concentrations obtained using equation (3), the following assessment criteria were used to quantify exposure to radiation in the Zumba mining Site. Table.2. Presents the values of the conversion factor (σ) for the ^{40}K, ^{226}R and ^{232}Th (Umar AM, Onimisi MY, Jonah SA 2012).

Table 2: presents the values of the conversion factor (σ) for the ^{40}K, ^{226}R and ^{232}Th.

Serial	Nuclides	CPS/Bq-kg^{-1}	Gamma ray line (KeV)
1.	^{40}K	0.000643	1460
2.	^{226}R	0.000863	1764
3.	^{232}Th	0.000877	2614.5

All the raw data obtained from the detector were converted to conventional units using calibration factors to determine the activity concentrations of ^{40}K, ^{226}R and ^{232}Th respectively. Using equation (3), the activity concentrations were calculated and the results obtained are presented in Table (3), and Figure (3).

RESULTS AND DISCUSSION

Activity Concentrations

The activity concentrations for the natural radionuclides in the measured samples were computed using the following relation (Okeyode IC and Akanni AO (2009).

$$A_c=\frac{Nc}{Lt}\sigma - 1 \quad (4)$$

Where L_t is the lifetime of the counting, and σ is the conversion factor, it is constant for each radionuclide at a constant geometry and it is the characteristics of the efficiency of NaI (TI) detector assembly used in the analysis of the sample.

Table 3: Activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the Soil Samples in (Bq/Kg).

Sample ID	Activity ^{40}K(Bq/Kg)	Activity ^{226}Ra(Bq/K)	Activity ^{232}Th(Bq/Kg)	Total Activity(Bq/Kg)
ZB1	141.9906$\pm$ 8.0871	86.0950$\pm$6.2572	28.6203$\pm$ 2.2805	256.7059 $\pm$ 16.6248
ZB2	105.2877 $\pm$ 1.0886	38.8181$\pm$1.5064	34.8916$\pm$ 2.3945	178.9974 $\pm$ 4.9895
ZB3	37.6361$\pm$ 7.7760	26.8830$\pm$ 2.2016	23.0331$\pm$ 1.9384	87.5522 $\pm$ 11.916
ZB4	190.046$\pm$ 7.1540	54.5771$\pm$2.8969	47.4344$\pm$ 3.3067	292.0575 $\pm$ 13.3576
ZB5	65.4743$\pm$2.4883	34.9942$\pm$ 2.8969	52.4515$\pm$ 2.3945	152.9200 $\pm$ 7.7797
ZB6	412.9082$\pm$ 3.2659	44.6118$\pm$ 1.8540	47.7765$\pm$3.4208	505.2965 $\pm$ 8.5407
ZB7	427.3716$\pm$ 4.0435	53.0707$\pm$ 4.2874	50.3991$\pm$ 2.5085	530.8414 $\pm$ 10.8394
Total	1380.7145	339.0499	284.6065	2004.3709
Mean	197.2449	48.4357	40.6581	286.3387

Absorbed Dose Rates (D)

The absorbed dose rate D (ŋGy.h^{-1}) due to gamma radiation in air at 1 meter height above the ground level due to activity concentrations of ^{40}K, ^{226}R and ^{232}Th for the 7 soil samples were evaluated using equation (5) as shown below. (UNSCEAR. No.224, NY 2000).

$$D\ (\text{ŋGy.h}^{-1}) = 0.0417A^{40}{}_{K} + 0.462A^{226}{}_{Ra} + 0.604A^{232}{}_{Th} \quad (5)$$

Where $A^{40}K$, $A^{226}R$ and $A^{232}Th$; are the activity concentrations of ^{40}K, ^{226}R and ^{232}Th respectively in Bq.kg^{-1}, Table (4) shows the results of the absorbed dose rates analyzed. The absorbed dose rates in air are usually related to human absorbed dose in order to assess

radiological implications. Hence, Table 4 below shows the external absorbed dose rate D (ŋGy.h^{-1}) for the 7 soil samples.

Table 4: Absorbed dose rate D (ŋGy.h^{-1}) of the investigated Soil Samples in air at 1m above the ground level due to activity concentrations of ^{40}K, ^{226}R and ^{232}Th in soil the sample.

Sample ID	^{40}K(ŋGy.h^{-1})	^{226}Ra(ŋGy.h^{-1})	^{232}Th(ŋGy.h^{-1})	Total D (ŋGy.h^{-1})
ZB1	5.9210± 0.3372	39.7759±2.8908	17.2867± 1.3774	62.9836 ± 4.6054
ZB2	4.3905 ± 0.0454	17.9340±0.6960	21.0745± 1.4463	43.399 ± 2.1877
ZB3	1.5694± 0.3243	12.4199±1.0171	13.9120± 1.1708	27.9013± 2.5122
ZB4	7.9249± 0.2983	25.2146±1.3384	28.6504± 1.9972	61.7899 ± 3.6339
ZB5	2.7303±0.1038	16.1673± 1.3384	31.6807± 1.4463	33.1229± 2.8885
ZB6	17.2183± 0.1362	20.6107± 0.8565	28.8570±2.0662	66.6860 ± 3.0589
ZB7	17.8214± 0.1686	24.5187± 1.9808	30.4411±1.5151	72.7812 ± 3.6645
Total	57.5758	156.6411	171.9024	368.6639
Mean	8.2251	22.3773	24.5575	52.6662

Annual Effective Dose Rates (E_d)

The Annual effective dose rates was estimated using the conversion coefficient from absorbed dose in air to effective dose of (0.7Sv.Gy^{-1}) and outdoor occupancy factor (0.2) and is calculated using formula below (UNSCEAR 2000; Harb *et al.*, 2010 and (Agbalagba et al, 2011)) were used .

Effective dose rate (mSv/yr) (E_d) =

$$D\ (ŋGy.h^{-1}) \times 8760\ (hr.y^{-1}) \times 0.2 \times (0.7 \times 10^3\ mSv) \times (10^9 ŋGy)^{-1} \quad (6)$$

Where 8760 (i.e. 365 x 24 hours of the day) is the numbers of hours in one year.

Therefore, equation (6) can be simplifies into, such that,

$$\text{Annual effective dose rate in } (mSv.y^{-1})\ E_d = D \times 1.21 \times 10^{-3}\ (\text{mSv/yr}) \quad (7)$$

D is the value of absorbed dose rate earlier calculated from equation (5). Results is shown in table 5

Table 5: Annual Effective Dose Rates (E_d) in $(mSv.y^{-1})$ for the Soil Samples.

Sample ID	^{40}K$(mSv.y^{-1})$	^{226}R$(mSv.y^{-1})$	^{232}Th$(mSv.y^{-1})$	Total D$(mSv.y^{-1})$
ZB1	0.0073	0.0488	0.0212	0.0772
ZB2	0.0054	0.0220	0.0258	0.0532
ZB3	0.0019	0.0152	0.0171	0.0342
ZB4	0.0097	0.0309	0.0351	0.0758
ZB5	0.0033	0.0198	0.0389	0.0406
ZB6	0.0211	0.0253	0.0354	0.0818
ZB7	0.0219	0.0301	0.0373	0.0893
Total	0.0706	0.1921	0.2108	0.4521
Mean	0.0101	0.0274	0.0321	0.0646

Radium Equivalent

The Radium Equivalent in the soil samples isestimated using equation 8:-

$$Ra_{eq} = C_{Ra} + (C_{Th} \times 1.43) + (C_k \times 0.077) \leq 370 \text{ Bqkg}^{-1} \quad (8)$$

The value of this parameter should be less than 370 $Bqkg^{-1}$ so that the annual radiation dose is kept below 5 mGy y^{-1} (UNSCEAR 2000). The results calculated for Ra_{eq} is shown in Table 6, which shows the mean radium equivalents obtained is ranged from 62.7183 $BqKg^{-1}$ (ZB3) to 158.0490 $BqKg^{-1}$(ZB7).The results agreed with the Standard value for radium equivalent concentration of $\leq$ 370 $BqKg^{-1}$ which is normally used materials for dwellings Ahmad and Hussein, (1998),

Table 6: Radium Equivalent Ra_{eq} (Bqkg-1) for the Soil Samples investigated.

Sample ID	Radium Equivalent Ra_{eq} (Bqkg-1)
ZB1	137.9553
ZB2	96.8203
ZB3	62.7183
ZB4	137.0418
ZB5	115.0413
ZB6	144.7261
ZB7	158.0490

External Hazard Index

The external hazard index (H_{ext}) measures the risk of radiation exposure from sources outside the body, it is used to evaluate the gamma radiation hazards from material like building material or soil. the external exposure to gamma radiation in the air , the external hazards index is evaluated using the relation given below; Krisiuk et al (1971); supported by Stranden (1976) and Berektka and Mathew C (1985), the Standard limit of external gamma radiation dose from the soil materials is 1.5 mGy y^{-1} this index should be equal to or less than unity ($H_{ext} \leq = 1$). The maximum allowed value for H_{ext} = 1 which corresponds to upper limit of Ra_{eq} (370$BqKg^{-1}$). (Beretka and Matthew), (UNSCEAR 2000)

$$H_{ex} = C_{Ra}/370 + C_{Th} / 259 + C_k/4810 \quad (9)$$

The results obtained for the external hazards index is shown in table 7 below. The mean ranged from 0.1694 $Bqkg^{-1}$ (ZB3) to 0.4269 $Bqkg^{-1}$ (ZB 4).

Table 7: External Hazard index H_{ex} (Bqkg-1).

Soil Sample ID	H_{ex}
ZB1	0.3727
ZB2	0.2615
ZB3	0.1694
ZB4	0.3701
ZB5	0.3107
ZB6	0.3909
ZB7	0.4269

Internal Hazard Index

The Internal Hazard Index is measure used to assess the risk of radiation exposure from radioactive materials inside the body, it is evaluated based on the concentration of radionuclides, usually in building materials or food. The exposure to radon and its short lived progeny are also hazardous to the respiratory organs. The internal exposure to radon and its daughter progenies is evaluated using the equation (10) (UNSCEAR 2000):

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_k/4810 \quad (10)$$

The values of the indices for the H_{ex} and H_{in} be less than one for the hazard to be negligible (Agbalagba et al 2011). The results obtained for the Internal Hazard Index are shown in table 8 below. The mean ranged from 0.2420 $Bqkg^{-1}$ (ZB3) to 0.6054 $Bqkg^{-1}$ (ZB 1).

Table 8: Internal Hazard index H_{in} (Bqkg-1) for the Soil Samples investigated.

Sample ID	Internal Hazard Index H_{in}
ZB1	0.6054
ZB2	0.3664
ZB3	0.2420
ZB4	0.5176
ZB5	0.4053
ZB6	0.5114
ZB7	0.5704

Excess Alpha Radiations

The excess alpha radiation is the alpha particles emitted by a radioactive substance beyond the normal or background levels, alpha particles are high energy helium nuclei that can be harmful if inhaled or ingested. Hence due to radon inhalation originating from soil materials it is estimated using the relation below (Isinkaye and Shitta, 2009):

$$I_\alpha = C_{Ra}/ 200 \quad (11)$$

The results shows that, the mean value of excess alpha radiation (I_α) calculated using equation 11 ranged from 0.1344 $Bq.Kg^{-1}$(ZB3) to 0.4305 $Bq.Kg^{-1}$ (ZB1), as shown in table 9. All these values for I_α is below the maximum permissible value of I_α=1 which corresponds to 200 $Bq.Kg^{-1}$

Table 9: Excess alpha radiation I_α (Bqkg-1) for the Soil Samples investigated.

Soil Sample ID	I_α
ZB1	0.4305
ZB2	0.1941
ZB3	0.1344
ZB4	0.2729
ZB5	0.1750
ZB6	0.2231
ZB7	0.2654

RECOMMENDED DOSE LIMIT EXPOSURE TO NATURAL RADIATION SOURCES.

The table 10. Below gives an average worldwide exposure to natural radiation sources for occupational persons and member of the public..

Table 10: Recommended Dose Limits for Natural radiation Sources

Application	Dose Limit	
	Occupational Exposed Person	**Member of the Public**
Effective Dose	20 mSv per year average over 5 consecutive calendar years	1 mSv in a year
Equivalent dose to :	150 mSv in a year	15 mSv in a year
Lens of the eye		
Skin	500 mSv in a year	50 mSv in a year
Hands and Feet	500 mSv in a year	No limit specified

Note. With the further provision that the effective dose should not exceed 50 mSv in a single year (provided the 100 mSv (max) dose average over 5 years is maintained. Hence the recommended tissue weighing factors is listed in Radiation Safety guidelines to determine whole body dose and tissue relationship.

Source: HRD-WHS-GUI-144.6

DISCUSSION OF THE RESULTS

The results shows mean activity concentrations ^{40}K ^{226}, Ra and ^{232}Th is 197.2449 $Bq.Kg^{-1}$; 48.4357 $Bq.Kg^{-1}$ and 40.6581 respectively. The total mean for the absorbed dose rate of all the 7 soil samples analysed is 46.0830 $\eta Gy.h^{-1}$ and also the annual effective dose in the study areas ranged from 0.0342 - 0.0893 $mSvy^{-1}$ (i.e 34 – 89 $\mu Sv.y^{-1}$), which had an mean annual effective dose of 0.0646 $mSv.y^{-1}$ (ie 65$\mu Sv.y^{-1}$). These results shows that the radiation exposure level for members of the public in the study areas is lower than the recommended limit value of 1 $mSv.y^{-1}$ (UNSCEAR, 2000). Furthermore, the mean external hazard index (H_{ext}) is 0.1694 $Bqkg^{-1}$ (ZB3) to 0.4269 $Bqkg^{-1}$ (ZB7), while its maximum allowed value is (H_{ext} = 1) which corresponds to upper limit of Ra_{eq} (370 $BqKg^{-1}$) in order to limit the external gamma radiation dose from the soil materials to 1.5 mGy y^{-1}. The accepted index value should be equal to or less than unity ($H_{ext} \leq$ = 1). Therefore, it can be deduce said that no radiological hazard is conceptualize to dwellers in the study areas and the miners working on those mining sites. The entire environment is within the permissible dose limit for the workers of the mining sites and also for the agriculture and construction buildings. Therefore, the mining site is safe of radiological hazards.

CONCLUSION

From the study, the exposure level for the members of general public is still within the recommended value of 1 $mSv.y^{-1}$ (IAEA, 1999) &UNSCEAR (2000; No.224 NY):), this is an indication that the mining activities in the study areas do not appear to have any impact on the radiation burden of the environment. This comfortable safety level of the target study area derived from this analysis agrees with when compared with the world wide exposure. It can therefore be said that no radiological hazard is envisaged to dwellers of study areas

and the miners working on those sites. The entire environment is within the permissible dose limit for the workers of the mining sites and also for the agriculture and construction buildings. Therefore, the mining site is safe in terms of radiological hazards.

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COMPETING INTEREST

There is no competing interest whatsoever that could have influenced the results of this study in any manner.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

This study was carried out in collaboration amongst all the authors. Author IKS, BM and AM collected and prepared the field samples, participated in the laboratory procedures, performed the statistical analysis and wrote the draft of the manuscript. Author IKS and BM also designed the study and contributed to the statistical analysis and supervised the analyses of the study. All authors read and approved the final manuscript.

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