

Assessment of Environmental Safety and Related Radiological Exposure in Zircon and Monazite Sands in Hong, Adamawa State, North-Eastern Nigeria

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Abstract

This paper presents the results of the activity concentration of radionuclides from raw zircon and monazite sands and the survey conducted to examine the environmental impact of zircon mining in Hong. Twelve (12) Zircon and Monazite samples were collected each and analyzed using Gamma Ray Spectroscopy. The activity concentration of Radium, Thorium and Potassium from raw zircon sample ranges from 15.83 to 53.87 Bq/kg, 10.69 to 63.40 Bq/kg and 144.95 to 671.38 Bq/kg respectively with average values of 29.19, 32.92, and 396.02 Bqm⁻³. The absorbed dose rates, annual effective doses, range from 24.97 to 91.86, with an average value of 50.56 nGy/h, 0.03 to 0.11, with an average value of 0.06 mSv/y. R_{aeq} , $I\gamma$ range 53.56 to 196.23 with a mean value of 107.56 Bq/kg, 0.20 to 0.72, 0.40 as the average. The hazard indices (external and internal) range from 0.15 to 0.53, 0.19 to 0.68 with an average value of 0.30, 0.38 respectively. The global averages for absorbed dose and AEDE are 59 nGy/h, 0.5 mSv/y respectively. The recommended limit for geogenic R_{aeq} is 370 Bq/kg. Gamma index greater than 1 indicates a potential radiation hazard. The removal of vegetation and topsoil for mining activities has disrupted local ecosystems and contaminated the surface water which is the source of drinking water the communities relied on. The study highlighted the need for sustainable mining practices, robust regulatory frameworks, and community engagement to mitigate these impacts. Recommendations are provided to enhance environmental protection, workers' safety, and public health.

Keywords: Activity concentration; Gamma spectroscopy; Monazite, Naturally Occurring Radionuclide Material; Zircon

1. Introduction

All living things are continuously exposed to ionizing radiation from naturally occurring radioactive materials (NORM), technically enhanced naturally occurring radioactive materials (TENORM), man-made radionuclides, or nuclear accidents. Zircon is a valuable mineral used in various industries, including ceramics, electronics, and nuclear energy industry. Elemental zirconium is not found in nature instead, zirconium bonds with sodium, calcium, iron, silicon, titanium, thorium and oxygen to form several zirconium-bearing minerals. The most common zirconium ores are baddeleyite (ZrO₂) and zircon (ZrSiO₄) (Righi et al., 2005). Zircon often contains trace amounts of radioactive elements such as uranium and thorium. The concentration of radioactivity in zircon lies typically within the ranges 0.5-1Bqg⁻¹ and 1-5 Bqg⁻¹ for ²³²Th and ²³⁸U, respectively (NRPB, 1993).

Environment, health, and safety (EHS) are a growing concern worldwide associated with mineral sand mining. The industry lacks far the minimum international EHS standards. Nigeria is a mineral rich country with over sixty percent

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(60 %) illegal mineral production. Zircon extraction often involves open-pit mining, which leads to deforestation, and loss of biodiversity (Eze et al., 2019). Deforestation significantly contributes to soil erosion, as the protective cover provides by vegetation is removed, leaving the soil exposed to the elements (Smith et al., 2020). The roots of trees and plants help to bind the soil together, preventing it from being washed away by rain or blown away by wind. When vegetation is removed, the soil becomes more vulnerable to erosion, leading to the loss of topsoil, which is rich in organic matter and essential nutrients. Soil erosion can have severe consequences, including reduced soil fertility, sedimentation of waterways, and increasing flood risk.

The Improper disposal of mining tailing can lead to contamination of soil and water, increasing the risk of radiation exposure for local populations (Okonkwo et al., 2022). Dust and particulate matter generated during mining and processing operations degrade air quality, posing risks to both workers and nearby communities (Ogunbajo et al., 2021). Prolonged exposure to airborne silica particles can cause respiratory diseases such as silicosis and lung cancer).

Mining remains to-date, one of the most hazardous and challenging employment sector, despite the considerable efforts in many countries to implement and maintain occupational and health safety (Smith et al, 2020). The toll of fatalities, injuries and occupational diseases remains high amongst the world's mine workers. Much preventive work, in terms of health and safety, is still required. Above accidents, many of the adverse health effects associated with mining and the extractive industries are caused by the inhalation of airborne pollutants which are not controlled at source (Elgstrand, et al., 2017).

In Hong, Adamawa State, zircon mining has become a key economic activity, providing employment and contributing to local development. The extraction and processing of zircon are associated with significant environmental, health, and safety risks. These risks include land degradation, water contamination, radiation exposure, and occupational hazards, which can have long-term consequences for ecosystems and human health.

However, there are few studies from the area (Alexander, et al. 2018; Amadi, et al. 2019; & Dangari, et al. 2025) that investigated the groundwater quality and physiochemical parameters. Prior to this work, there was no data on the naturally occurring radionuclide material from the mineral sand of the study area. This study was set to examine the Environmental, Health, and Safety implications of zircon mining in the region, focusing on land degradation, and radiological health risks associated with naturally occurring radionuclide materials from zircon and monazite sands of the study area, and proposes strategies to address these challenges.

2. Materials Method

2.1. Geology of the Study Area

Hong Local Government Area is situated in the North-Eastern part of Adamawa State, Nigeria. It lies between latitude 10.38°N and longitude 12.35°E. It shares boundary with Gombi in the south, Mubi North and Mubi South in the west and Michika to the North. Hong Local Government area has land mass of about 2419 square kilometers and a total population of 195580 people (NPC, 2011). The topography of Hong local government is a picture of mountain land transverse by the river, and valley of Hawul and Kuliyi. It has its headquarters in Hong Town is the largest settlement and is classified by Ilesanmi (1999) as a third-order core urban settlement in Adamawa state. Hong LGA consists of seven (7) districts namely, Hong, Dugwaba, Pella, Kulinyi, Hildi, Gaya, and Uba districts.

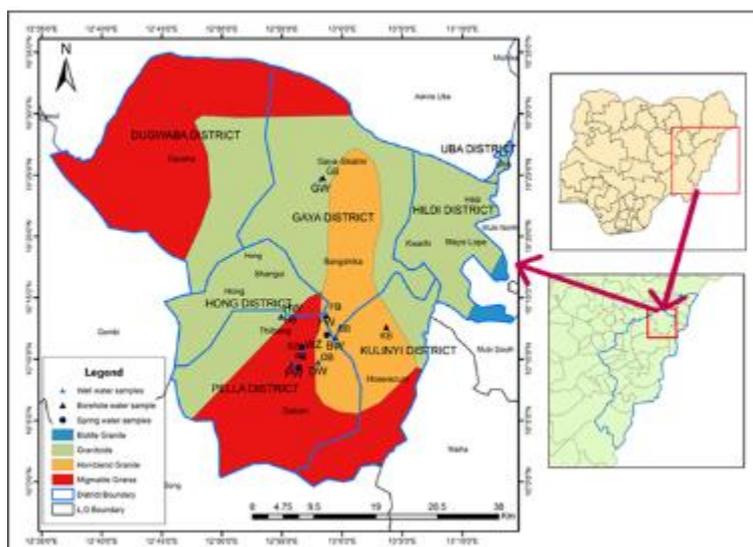


Figure 1 Map of Adamawa Showing the study area

2.2. Soil Sampling

A total of twelve (12) mineral sand samples from 12 different mining sites across the villages of the district were collected, taken to the separation plant where they were separated into various constituents i.e. monazite, zircon, iron, tin and sand. The soil samples were then transported to Health Physics and Radiation Biophysics Laboratory of the Centre for Energy Research and Training (CERT) Ahmadu Bello University Zaria, Nigeria for Gamma Spectroscopy.

Table 1 The Coordinates and Elevation of the Sampling Points from the Study Area

Location	Latitude	Longitude	Elevation (m)
Kwanan Kuka	10°14'02.1"	13°00'00.6"	558
Ziga Yerima	10°13'23.1"	13°01'50.7"	593
Kwakwa	10°11'37.7"	13°02'38.2"	556
Dilwacira	10°13'16.7"	13°05'05.1"	557
Fadama Reke	10°13'52.2"	12°59'12.6"	584
Kwajiga	10°16'47.7"	12°58'09.1"	557
Dogon Daji	10°16'05.4"	12°58'48.2"	583
Mijili	10°20'41.2"	12°58'48.5"	570
Mutuku	10°18'10.2"	12°57'42.8"	536
Balkari	10°04'43.5"	13°03'04.9"	507
Dagza	10°08'07.2"	13°00'59.1"	536
Mbakwa	10°06'16.5"	12°58'53.9"	503

2.3. Sample Preparation for Gamma ray spectroscopy

For Gamma ray spectroscopy, 300 g of the zircon and monazite samples were air-dried for three days in the lab to eliminate the remaining moisture, the samples were further dried at 105 °C in a temperature-controlled furnace for 24 hours. For homogeneity, the samples were then mashed using mortar and piston and then sieved through a 20-millimeter mesh screen. The samples were packed into 500 ml Marinelli containers sealed with candle wax and a masking tape and left in a storage area for 30 days to attain secular equilibrium. Their net weight was measured, and each sample was counted for 8 h.

2.4 Gamma ray spectroscopy Analysis

The γ -ray spectrometer set used in this work consisted of a coaxial high purity Germanium (HPGe) detector (EG&G ORTEC® *p*-type, model GEM-70-S), with 60% relative efficiency with respect to 7.62×7.62 cm NaI (Tl) crystal at an operating voltage of 4000 V. The detector peak to Compton ratio was 78:1, and the measured energy resolution for ^{60}Co at γ -ray line energy 1332 keV at a source to detector top distance of 25 cm was 1.85 keV (in terms of full width at half maximum, FWHM). The validation of the full energy peak efficiency (FEPE) for optimizing the measurement of ^{40}K , ^{238}U , and ^{232}Th in a geological matrix was achieved using standard calibration process. The method allows direct conversion of a net count rate of a γ -ray peak of a given energy, E , from a specific radionuclide to the activity of that radionuclide. It also eliminates needs for corrections, and it is well suited for measurement of limited number of radionuclides (ANSI). IAEA standard reference material (RGset), also used in (Ibeannu, 1999) was used for the measurement validation (Iqbal; Kreiger, 1981). The sources were positioned at the same geometry as in FEPE determination. The spectra were acquired for times ranging from 21 600 to 28 800 s and were analyzed using Gamma Vision®-32 software (EG&G ORTEC, v.6). The efficiency ε as a function of γ -radiation energy E was approximated by polynomials of degree 6 in the logarithmic scale

$$\ln\varepsilon(E) = \sum_{i=0}^N (a_i \ln E) \quad 1$$

where a_i are the correction factors, and N is the degree of the polynomial.

2.5 Radiation Hazard Parameters

2.5.1 Radium Equivalent activity (R_{aeq})

Radium equivalent activity gives a single index, which expresses the gamma yield from various mixture of ^{226}Ra , ^{232}Th and ^{40}K in the sample considering the associated radiation hazards. It is defined as follows

$$Ra(\text{BqKg}^{-1}) = C_U + 1.43C_{Th} + 0.077C_K \quad 2$$

where C_U , C_{Th} , and C_K , are the specific activities of ^{238}U , ^{232}Th , and ^{40}K , respectively. The maximum R_{aeq} value is expected to be below 370 Bq kg^{-1} so that the dose of external gamma radiation remains under 1.5 mSv y^{-1} (Beretka & Mathew, 1985; UNSCEAR,2000; Amrani & Tahtat,2001).

2.5.2 Absorbed dose rate (D)

To quantify the radiation exposure from the soil-based primordial radionuclides, the absorbed dose rate is used. This represents the amount of energy absorbed per unit mass of the exposed material, typically measured in (nGy h^{-1}) . The specific activities of ^{226}U , ^{232}Th , and ^{40}K were used to calculate the absorbed dose rate according to Eq. (3)(UNSCEAR, 2000)

$$D(\text{nGyy}^{-1}) = 0.461C_U + 0.623C_{Th} + 0.041C_K \quad 3$$

where C_U , C_{Th} , and C_K are the specific activities of ^{238}U , ^{232}Th , and ^{40}K , respectively.

2.5.3 Annual effective dose equivalent (AEDE)

The annual effective dose equivalent (AEDE) was calculated via the recommendations and data provided by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000). This approach considers a conversion coefficient from the absorbed dose in air to the effective dose of 0.7 SvGy^{-1} , and the outdoor occupancy factor of 0.2. Equation. (4)

$$AED(\text{mSvy}^{-1}) = D(\text{nGyy}^{-1}) \times 8760\text{h} \times 0.2 \times 0.7\text{SvGy}^{-1} \times 10^{-6} \quad 4$$

2.5.4 Gamma Index (I_γ)

Gamma Index represents the total radiological hazard due to presence of ^{226}Ra , ^{232}Th and ^{40}K in the soil. This index is given by European Commission 1999. It was calculated using equation (5) (EC 1999).

$$I_\gamma = \frac{C_U}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000} \quad 5$$

Where I_γ , is gamma index and C_U , C_{Th} , and C_K are the activity of ^{226}Ra , ^{232}Th and ^{40}K respectively.

2.6 Hazard Indices

The internal and external radiation exposure linked to gamma radiation from soil-based natural radionuclides, the External Hazard Index (H_{ex}) and the internal hazard index (H_{in}). These indices provide an assessment of the radionuclide’s potential radiological threats. Given by equation (6) and (7). (Asaduzzaman, 2016).

2.6.1 External Hazard Index (H_{ex}).

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \tag{6}$$

2.6.2 Internal hazard index (H_{in})

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \tag{7}$$

where C_U , C_{Th} , and C_K are the specific activities of ^{238}U , ^{232}Th , and ^{40}K , respectively

2.7 Environmental Impact Assessment

The assessment was conducted using a mixed-methods approach, integrating both qualitative and quantitative research methodologies to ensure a comprehensive understanding of the environmental impacts of mineral sand mining. The combination of field studies and surveys was conducted to gather firsthand information on the perceptions of the affected communities on mining activities, environmental degradation. Stratified sampling was applied to segment respondents into distinct groups; such that community members and mining workers are all sampled. Random sampling was integrated to minimize selection bias and ensure that the sample accurately represents the broader population affected by mining. This hybrid sampling approach enhances the generalization of the findings. One hundred and fifty-six (156) people were interviewed

3. Results and Discussion

The activity concentration of ^{226}Ra , ^{232}Th , and ^{40}K was measured from twelve zircon and monazite sand samples each from locations across the study area Table 1. The activity concentration of Ra-226 from raw zircon sample ranges from 15.83 to 53.87 Bq/kg, with average values of 29.19, activity concentration of Th-232 ranges from 10.69 to 63.40 Bq/kg with average values of 32.92, and that of K-40 ranged from 144.95 to 671.38 Bq/kg with average values of 396.02 Bqm⁻³ respectively. For Monazite samples, the activity concentration of Ra-226 ranges from 14.38 to 156.73, with an average value of 57.54, for Th-232, ranges from 39.68 to 391.70 with an average value of 155.56, and 28.43 to 3356.93 Bq/Kg with an average value of 651.11Bq/Kg for K-40 respectively as presented in Tables 2 and 3.

Table 2 Measured Activity Concentration of ^{226}Ra , ^{232}Th , and ^{40}K in Monazite samples.

Sample ID	Ra-226 (Bq/Kg)	Th-232 (Bq/Kg)	K-40 (Bq/Kg)
M1	20.16±1.04	48.80±2.28	104.04±2.94
M2	19.58±2.55	39.68±2.05	92.69±2.95
M3	45.71±1.61	222.85±1.61	357.88±5.05
M4	103.33±3.56	202.00±3.13	389.99±3.74
M5	25.49±1.16	49.94±2.39	87.09±3.27
M6	38.01±2.84	49.60±2.54	78.07±3.27
M7	78.12±7.81	238.76±8.49	289.64±8.25
M8	82.86±1.55	391.70±1.80	668.02±9.08
M9	14.38±3.60	53.08±1.75	161.63±8.96
M10	156.73±5.96	359.83±5.06	3356.93±9.34
M11	33.84±3.36	44.98±4.25	115.76±3.54

M12	16.18±1.64	45.22±3.89	28.43±3.53
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Table 3 Measured Activity Concentration of ²²⁶Ra, ²³²Th, and ⁴⁰K in Zircon Samples

Sample ID	Ra-226 (Bq/Kg)	Th-232 (Bq/Kg)	K-40 (Bq/Kg)
Z1	37.09±1.74	30.56±1.94	506.69±6.84
Z2	30.01±3.36	46.07±2.05	479.16±6.53
Z3	53.87±1.73	63.40±3.59	671.3841±4.93
Z4	53.41±1.62	58.38±2.74	522.71±3.58
Z5	25.25±1.74	26.26±2.28	144.95±2.80
Z6	27.34±3.13	37.47±2.76	414.75±3.89
Z7	17.03±1.39	15.87±1.25	435.61±3.73
Z8	18.88±1.64	21.20±0.97	275.46±6.63
Z9	15.83±0.48	17.46±0.76	165.65±3.10
Z10	22.84±2.32	41.96±2.17	539.81±5.91
Z11	18.04±1.96	10.69±1.72	293.76±3.40
Z12	19.32±0.99	17.47±1.17	278.03±4.34

The mean activity concentration of Ra-226 and K-40 from Zircon sample are within the global average set by the UNSCEAR. Th-232 average values marginally exceeding the global average threshold established by (UNSCEAR 2000; IAEA). However, some samples Z1, Z3, and Z4 made up 25% of the total sample showed a concentration exceeding the global average value of 35 BqKg⁻¹ for Ra-226, and Z1, Z2, Z3, Z4, Z6, Z7, and Z10 made up 58% of the sample showed a K-40 concentration higher than the global average of 400 BqKg⁻¹. Z2, Z3, Z4, Z6, and Z10 made up approximately 42% of the samples exhibit a Th-232 concentration above the global mean value of 30 BqKg⁻¹. For Monazite, the average activity of Ra-226 from M3, M4, M6, M7, and M8 make up 50% of the sample has concentration above the global average of 35 BqKg⁻¹, only two samples M8, and M10 had K-40 concentration above the global average value of 410 BqKg⁻¹. However, all the samples showed a Th-232 concentration above the global average of 30 Bq/kg, this is because Monazite sands are rich in thorium which potentially enhances the activity of the natural radionuclide in the soil.

3.1 Radiological Hazard Indices

The radiation hazards associated with natural radionuclides in mineral sand samples collected from mining sites across the study area were evaluated by calculating several hazard indices, which include the radium equivalent, absorbed dose rate, annual effective dose, both external and internal hazard indices, representative or gamma index.

Table 4 The radium equivalent (Raeq) absorbed dose rate(D) in nGy/h, annual effective dose equivalent (AEDE) in mSvy⁻¹, the external and internal hazard indices, and the representative level index (I_γ) as calculated from the Monazite Samples

Sample ID	Raeq (Bq/Kg)	D (nGy/y)	AEDE (mSv/y)	H _{ex}	H _{in}	I _γ
M1	97.96	43.96	0.05	0.26	0.32	0.35
M2	83.46	37.55	0.05	0.23	0.28	0.29
M3	391.95	174.59	0.21	1.06	1.18	1.39
M4	422.23	189.48	0.23	1.14	1.42	1.48
M5	103.62	46.44	0.06	0.28	0.35	0.36
M6	114.95	51.62	0.06	0.31	0.41	0.40

M7	441.85	196.64	0.24	1.19	1.40	1.55
M8	694.42	309.61	0.38	1.88	2.10	2.46
M9	102.73	46.33	0.06	0.28	0.32	0.37
M10	929.77	434.06	0.53	2.51	2.93	3.44
M11	107.07	48.37	0.06	0.29	0.38	0.38
M12	83.04	36.80	0.05	0.22	0.27	0.29
Ave.	327.56	149.02	0.18	0.88	1.04	1.18

The calculated average value of the radium equivalent activity was 327.56 Bqkg⁻¹ in the monazite samples and 107.56 Bq/Kg for zircon, which are lower than the average global recommended value of 370 Bqkg⁻¹ and some results from other countries. According to UNSCEAR (2000), the recommended safe limit for the radium equivalent, absorbed dose rate is 57 nGy/h. It can be observed from Table 4 that seven out of the 12 monazite samples fall within this limit, except for Sample M3, M4, M7, M8, and M10 which exceeds the global average. However, the absorbed dose rate from Zircon sand showed the same trend with seven out 12 sample below the global average and Z1, Z2, Z3, Z4, and Z10 exceeding 57nGy/y Table 5. The average absorbed dose rate across all samples is 149.02 nGy/h, from monazite and 50.56nGy/y from zircon samples respectively. The value from zircon sample remains below the UNSCEAR (2000) recommended limit. This suggests that radiation exposure from this soil does not present significant health risk. In the other hand, values from monazite sample remain far above the UNSCEAR (2000) recommended limit. This suggests that radiation exposure from these mineral sands will potentially present a significant health risk.

The average annual effective dose equivalent presented in table 4 and 5 are 0.18 (mSv/y) for monazite and 0.06 (mSv/y) for zircon. These values are well below the world average of 0.46 (mSv/y) by UNSCEAR 2000 and therefore within safe limits. The safe limit for internal hazard index must be less than unity. From Table 4 and 5 all the zircon samples have H_{in} and H_{ex} less than 1 and therefore pose no significant internal radiation hazard to the community, farmers and mine workers of the study area. However, five monazite samples show a H_{in} and H_{ex} value above the recommended level with the marginal average across all samples 0.88, and 1.04 which is slightly greater than unity. The gamma or representative index (I_γ) average value for zircon and monazite samples are 0.40, and 1.18 the RI from zircon sample is lower than the global average of 1 set by UNSCEAR while is higher in monazite. As a result, the community, farmers, and mine workers should avoid spending too much time along site to reduce the exposure from radionuclides across the study area.

Table 5 The radium equivalent (R_{aeq}) absorbed dose rate (D) in nGy/h, annual effective dose equivalent (AEDE) in mSvy-1, the external and internal hazard indices, and the representative level index (I_γ) as calculated from the Zircon Samples

Sample ID	R _{aeq} (Bq/Kg)	D (nGy/y)	AEDE (mSv/y)	H _{ex}	H _{in}	I _γ
Z1	119.81	56.91	0.07	0.32	0.42	0.45
Z2	132.77	62.18	0.08	0.36	0.44	0.49
Z3	196.22	91.86	0.11	0.53	0.68	0.72
Z4	177.14	82.42	0.10	0.48	0.62	0.64
Z5	73.92	33.92	0.04	0.20	0.27	0.26
Z6	112.86	52.95	0.06	0.30	0.38	0.42
Z7	73.27	35.60	0.04	0.20	0.24	0.28
Z8	70.40	33.20	0.04	0.19	0.24	0.26
Z9	53.56	24.97	0.03	0.14	0.19	0.20
Z10	124.42	58.81	0.07	0.34	0.40	0.47
Z11	55.95	27.02	0.03	0.15	0.20	0.21

Z12	65.71	31.19	0.04	0.18	0.23	0.24
Aver.	107.56	50.56	0.06	0.29	0.37	0.40

The Pearson correlation analysis was performed using excel, the results are shown in Figure 2 and 3. The three primordial radionuclides in the soils are positively correlated (Pearson $r^2 = 0.60-0.78$), except for the correlation between Th-232 and K-40 in monazite soil, indicating shared lithologic controls and partial co-occurrence in the mineral matrix.

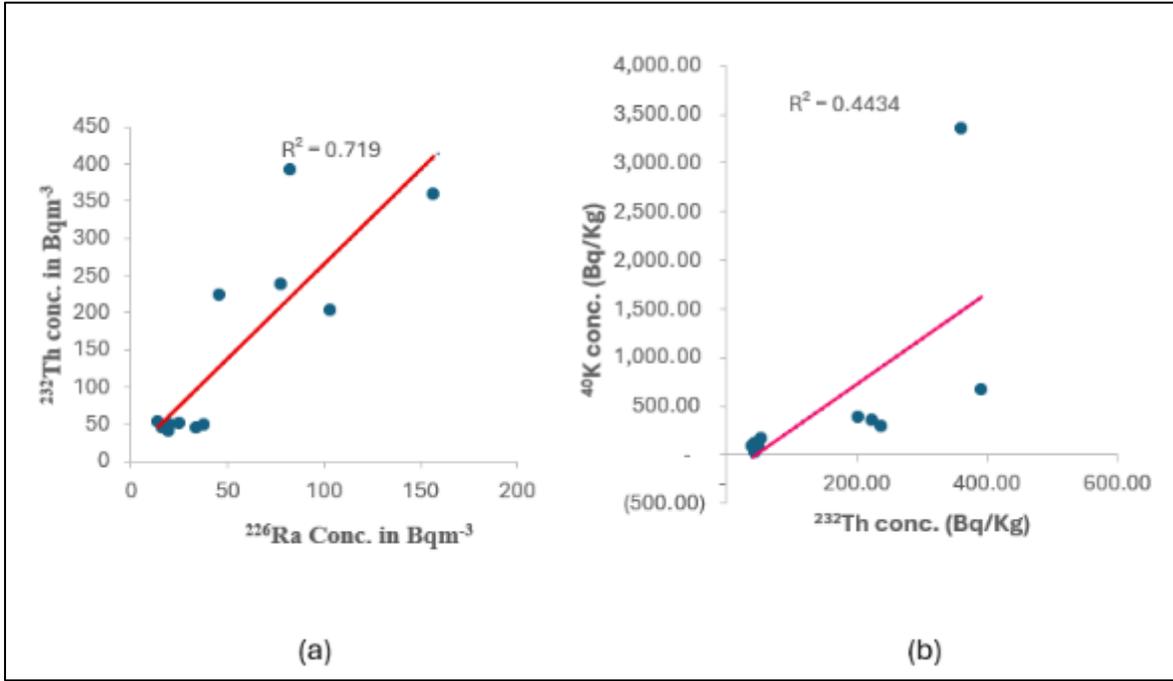


Figure 2 Correlation Between $^{226}\text{Radium}$ and $^{232}\text{Thorium}$ in Monazite sample

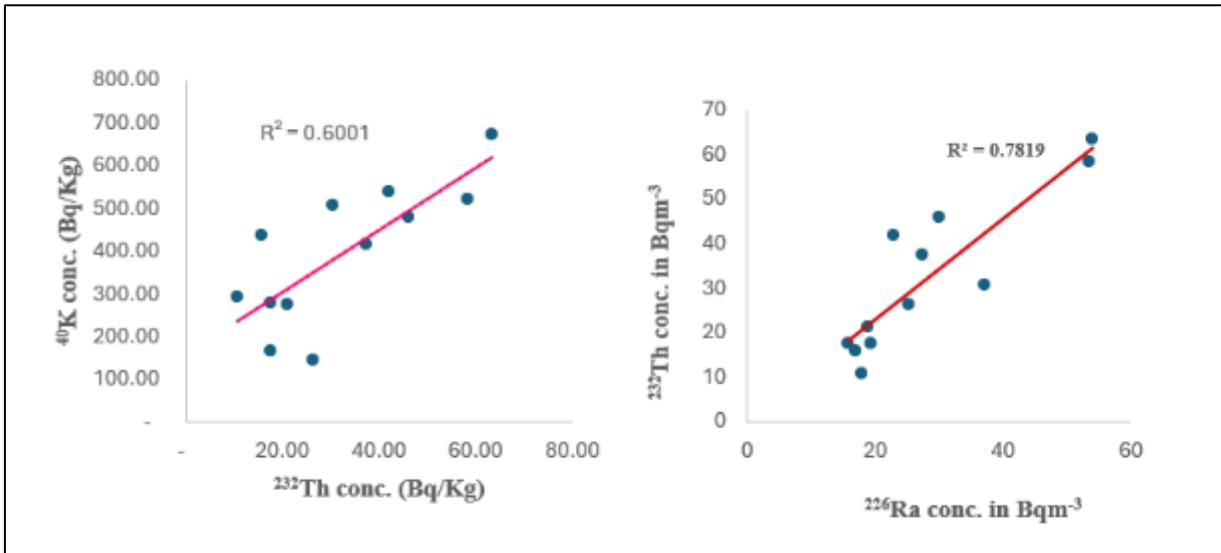


Figure 3 Correlation Between $^{226}\text{Radium}$ and $^{232}\text{Thorium}$ in Zircon sample

The correlation between the Activity Concentrations of radium-226 and thorium-232 from monazite samples. The correlation coefficient, $R^2 = 0.7190$. Figure 5 shows the correlation between the Mean Activity Concentrations of radium-226 and thorium-232: the correlation coefficient, $R^2 = 0.7819$. Both coefficients showed a linear relationship between radium-226 and thorium-232 in both monazite and zircon samples.

3.2 Environmental Impact

The removal of vegetation and topsoil for mining activities, reduced agricultural productivity, and threatened wildlife habitats. All these effects combined are observed in Hong. Land reclamation efforts are often inadequate, leaving behind barren landscapes that are prone to erosion and flooding as it is observed from the field figure 5.

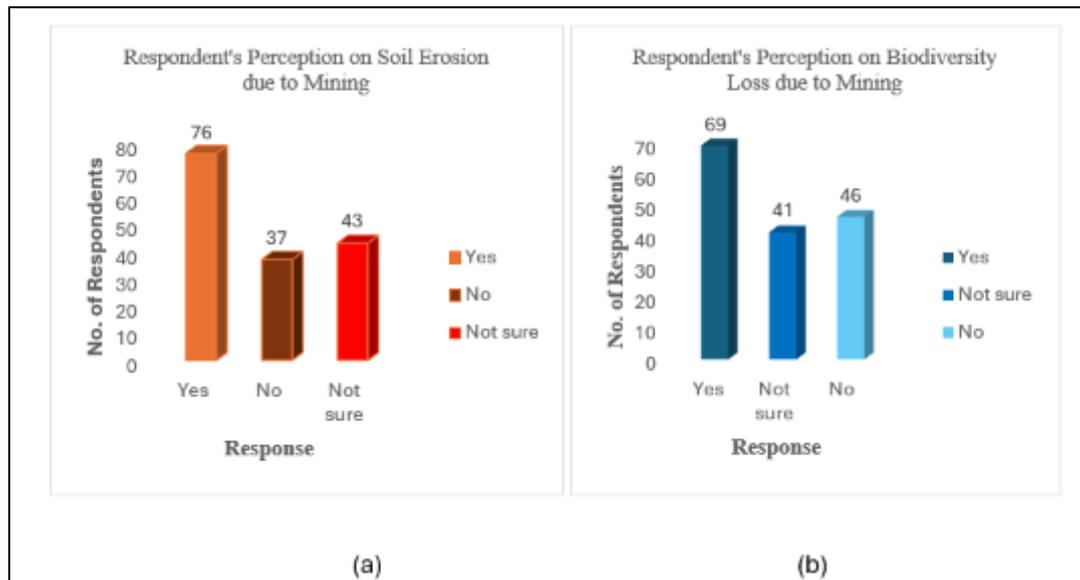


Figure 4 Respondent's Perception on Environmental impact of Mining

The analysis of environmental effects of mining focused on biodiversity loss, habitat destruction, and possible land restoration after mining. The study reveals significant negative impacts, as indicated by survey responses and field assessment plate 1 (a-c). The study reveals that unregulated mineral sand mining leads to riverbank erosion, habitat destruction, declining water quality, and the loss of agricultural land.

3.2.1 Erosion

Strip mining is a particular type of mining that is responsible for soil erosion all over the world. In Nigeria the excavation of sand for building purposes is the most common cause of soil erosion, as Ndinwa & Ohwona (2014) observed, that in the area underlain by sedimentary rocks such as Afowa, Ayoguri, Fugar and Apana, sand excavation has caused considerable damage to the land. Ako et al. (2014) also submitted that mining of sand and gravel in Luku area, Niger State, resulted in destruction of vegetation thereby destroying the natural habitats of some animals. Some very important plant species are also destroyed, and the soil is exposed to erosion. Similarly, this study also observed that the riverbanks along the mining sites are continuously expanding as operations expand, this impact grows geometrically at least five meters annually. Figure 4a shows that seventy-five percent (75%) of the respondents' perception of soil erosion due to mining in those areas support the fact that soil topsoil is been removed which results in soil erosion, thirty-seven percent (37%) of the respondents say no much effect observed and forty-three percent (43%) are not sure if there is any effect.

3.2.2 Biodiversity Loss

Sixty-nine percent (69%) of the respondents agreed to have observed a decline in plant and animal species near mining sites, forty-one (41%) not sure and forty-six (46%) say they did not observe any loss in biodiversity figure 4b. Loss of vegetation and habitat degradation have led to ecosystem imbalances and species displacement. Mineral Sand mining destroys habitats for terrestrial and aquatic species, making it hard for them to survive. Cutting down trees and top-soil vegetation removal eliminates food sources, nesting sites, and breeding grounds for birds, insects, and mammals. Sediment pollution from mining can harm fish and aquatic life, leading to reduced biodiversity. If biodiversity loss continues, the affected ecosystems may face long-term collapse, resulting in low agricultural productivity, loss of fisheries, and disruption of food chains.

3.2.3 Habitant Destruction

Sand mining has led to land degradation, soil erosion, and loss of vegetation cover. Many respondents believe mining operations have contributed to the destruction of ecosystems. Interpretation: Sand mining accelerates soil erosion and deforestation, leading to unstable land surfaces and an increased risk of landslides and flooding. Riverbank mining weakens natural barriers against floods, making surrounding areas more vulnerable to natural disasters. Local communities, especially those dependent on agriculture, fishing, and forest resources, are at risk due to declining ecosystem services. Implication: Without proper land reclamation and sustainable mining practices, habitat destruction will continue, causing irreversible environmental damage.



Figure 5 A photo from field during survey and sampling; (a) and (b) sites where trees are being cut for mining, (c) Eroding the Riverbank, and (d) processing plants

3.2.4 Land Reclamation

Reclamation in mining is the process of rehabilitating land disturbed by mining activities to a condition that is both environmentally stable and economically productive, often aiming to return the land to its pre-mining use or to a state that supports a beneficial post-mining land use (Mantey et al., 2024). Mining, while vital for obtaining the resources we need, inevitably disrupts the landscape. From open-pit mines to underground tunnels, the earth is moved, vegetation is cleared, and the soil structure is altered. Without proper reclamation, these disturbances can lead to significant environmental problems.

The perception of the respondents revealed that no land restoration is observed after mining as sixty-seven percent (67%) of respondents agreed while thirty-three percent (33%) agreed that land is been restored after mining and fifty-six percent (56%) are not sure if there is any restoration or its process ongoing.

4 Conclusion and Recommendation

Activity concentration of ^{226}Ra , ^{232}Th , and ^{40}K in soil samples collected from the zircon mines sites were assessed using gamma ray spectrometry (NaI)Ti. The mean activity concentration of Radium, Thorium and Potassium from raw zircon sample ranges from 15.83 to 53.87 Bq/kg, 10.69 to 63.40 Bq/kg and 144.95 to 671.38 Bq/kg respectively with average values of 29.19, 32.92, and 396.02 Bq/kg. The absorbed dose rates, annual effective doses, range from 24.97 to 91.86, with an average value of 50.56 nGy/h, 0.03 to 0.11, with an average value of 0.06 mSv/y. R_{eq} , I_{y} range 53.56 to 196.23 with a mean value of 107.56 Bq/kg, 0.20 to 0.72, 0.40 as the average. The hazard indices (external and internal) range from 0.15 to 0.53, 0.19 to 0.68 with an average value of 0.30, 0.38 respectively. The global averages for absorbed dose and AEDE are 59 nGy/h, 0.5 mSv/y respectively. The recommended limit for geogenic R_{eq} is 370 Bq/kg. Gamma index greater than 1 indicates a potential radiation hazard.

Zircon mining in Hong, Adamawa State, has significant environmental, health, and safety implications that must be addressed to ensure sustainable development. Mining activities need to be regulated at all levels, both small-scale and large-scale mining activities need to adopt sustainable mining practices, such as land reclamation, waste management, and water treatment. These can minimize the environmental impacts of zircon mining. Companies should also invest in technologies that reduce dust emissions and improve radiation shielding, especially in areas where large-scale mining takes place. The Nigerian government should enforce strict regulations to ensure that mining companies adhere to environmental and safety standards, regular inspections and monitoring are essential to prevent non-compliance. Engaging local communities in decision-making processes can help address their concerns and ensure that they benefit from mining activities. Companies should also provide compensation for land use and invest in community development projects. These claims were also made in studies such as (Adekola et al., 2018; Smith et al., 2020; Nwankwo et al., 2020). Further research is needed to assess the long-term effects of zircon mining and develop innovative solutions to these challenges.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no known competing financial or other interests that could have influenced this study.

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