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Radiological Assessment of Artisanal Mining Sites in Michika Local Government Area, Adamawa State

Yusuf E. Y[1], Maitera O. N[2], Moddibo U. U[3], Buba One M[4]
[1]Joseph Sarwuan Tarka University Makurdi, Nigeria; [2,3]Moddibo Adama University Yola, Nigeria; [4]Borno State University, Nigeria
emmanuelyila@gmail.com

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Abstract

The proliferation of artisanal mining activities in Michika Local Government Area (LGA) of Adamawa State, Nigeria, has raised serious environmental and radiological safety concerns due to the presence of naturally occurring radioactive materials (NORMs), particularly uranium-238 (U-238) and thorium-232 (Th-232). This study assesses the radiological hazards associated with these activities by analyzing soil samples collected from ten artisanal mining sites using gamma-ray spectrometry. The results revealed that the mean activity concentrations of U-238 and Th-232 were 1187.85 Bq/kg and 1052.20 Bq/kg, respectively substantially exceeding the global average values of 33 Bq/kg and 45 Bq/kg recommended by UNSCEAR (2000). Potassium-40 (K-40) was below detectable levels, likely due to the geochemical composition dominated by minerals such as monazite, zircon, and phosphate-rich rocks. The mean absorbed dose rate was 1184.32 nGy/h, significantly higher than the global average of 57 nGy/h, while the estimated mean annual effective dose equivalent (AEDE) was 1.45 mSv/year, surpassing the 1 mSv/year public exposure limit. The mean radium equivalent activity (Ra_eq) reached 2692.50 Bq/kg, far above the recommended safety limit of 370 Bq/kg. Additionally,

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the calculated excess lifetime cancer risk (ELCR) averaged 0.005084, markedly higher than the acceptable threshold of 0.00029. Other radiological indices, including the Representative Level Index (RLI), Internal Hazard Index (H_in), and External Hazard Index (H_ex) also recorded values exceeding international safety standards, particularly at sites like Sina Mala and Garta. These findings underscore the urgent need for regulatory enforcement, radiological monitoring, and the adoption of sustainable and safe mining practices to mitigate health risks for both miners and local communities.

Keywords: Michika; NORMs; Radiological Indices; UNSCEAR; Environmental Contamination; Health Risk

INTRODUCTION

Michika Local Government Area, located in northern Adamawa State, Nigeria, has emerged as a significant site for artisanal and small-scale mining (ASM) activities. The area, which borders the Republic of Cameroon and serves as the fourth largest town in Adamawa State, has witnessed increased mining operations targeting various mineral resources. These activities, while providing economic opportunities for local communities, have raised concerns about potential radiological hazards associated with the extraction and processing of minerals containing naturally occurring radioactive materials.

The geological composition of the Michika region, characterized by crystalline basement rocks and sedimentary formations, presents conditions conducive to the concentration of radioactive elements such as uranium-238, thorium-232, and their decay products. Understanding the radiological implications of mining activities in this area is crucial for protecting public health and ensuring sustainable mining practices (Maitera *et al.,* 2010).

Michika LGA is situated within the crystalline basement complex of northeastern Nigeria, an area known for its diverse mineral deposits. The geological formations in the region include granites, gneisses, and schists that may contain elevated levels of naturally occurring radioactive elements. Recent enforcement actions have identified various mining activities in the area, including the extraction of fluorides and other minerals (Ezekiel *et al.,* 2021).

The artisanal mining sector in Michika, like many other regions in Nigeria, operates with limited regulatory oversight and often lacks proper safety protocols. Miners typically employ rudimentary extraction methods, including surface mining, shallow pit excavation, and basic processing techniques that may inadvertently concentrate radioactive materials (Abba *et al.,* 2018).

The primary radiological concern in artisanal mining sites stems from the presence of NORMs, particularly. Uranium Series (U-238): This decay chain produces various radioactive progeny, including radium-226, radon-222, and lead-210 (IAEA, 2012). These elements can be concentrated during mining and processing activities, creating potential exposure pathways for workers and communities. The thorium decay chain produces radium-228, thoron-220, and other radioactive isotopes that contribute to overall radiation exposure in mining environments (Felix *et al.,* 2015).

Potassium-40 (K-40), A naturally occurring radioactive isotope of potassium that is commonly found in minerals and contributes to background radiation levels (Abdulkarim and Umar, 2013).

Mining activities in Michika LGA create multiple pathways for radiological exposure: Dust generated during excavation, crushing, and processing activities can contain radioactive particles. Workers and nearby residents may inhale these particles, leading to internal radiation exposure. Direct exposure to gamma radiation emitted by radioactive materials in ore, tailings, and processing equipment poses risks to individuals working in close proximity to these sources. Direct contact with radioactive materials during handling and processing can contribute to radiation exposure, particularly for workers without adequate protective equipment (Ibe *et al.,* 2020).

Mining activities can lead to the redistribution and concentration of radioactive materials in soil and sediment. Studies conducted in similar geological settings have shown that activity concentrations may vary significantly depending on the type of mining operation and the geological characteristics of the area. The presence of elevated radioactivity in soil can affect agricultural productivity and pose long-term environmental risks (Abubakar *et al.,* 2020).

Workers in artisanal mining operations face the highest risk of radiological exposure due to their direct contact with potentially radioactive materials and prolonged presence in mining environments. The lack of proper protective equipment and safety protocols in many artisanal operations exacerbates these risks (Abba *et al.,* 2018).

Communities surrounding mining sites may experience increased radiological exposure through various pathways, including inhalation of dust, consumption of contaminated water and food, and external radiation from mining waste and stockpiles (Abubakar *et al.,* 2020).

MATERIALS AND METHODS

Sample Location and Site Description

Soil was collected from the Michika local government area of Adamawa state Nigeria. The coordinates of Michika are 10°37'N, 13°23'E, respectively. Adamawa state is a settlement located in North east of Nigeria. The area falls within the Basement Complex of the Northeastern Nigeria and covers an aerial extent of about 188.5 km. It lies within latitudes 100 32'N to 100 14'N and longitudes 130 19' E to 130 25'E.

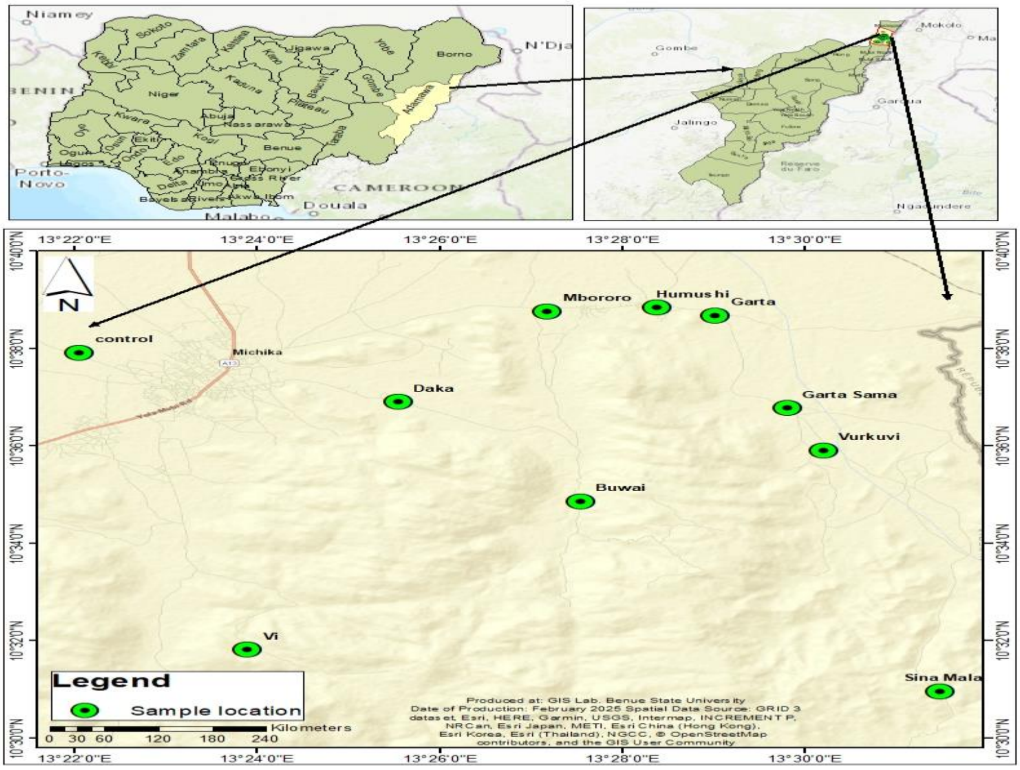

Figure 1: Map of Adamawa state showing study area

Sample collection and Preparation

Method reported by Venkatesh *et al.*, (2016) was adopted for this research. 2.0 kg of the samples was randomly collected by digging, from ten (10) different pits and locations each of the Michika mineral mining sites (Garta, Garta Sama, Vi, Vurkuvi, Buwai, Humushi, Sina Mala, Daka, Mbororo, and Control) Adamawa state. The sampling points was spaced at about two meters (2m) apart for possible variations in their constituents. At each location, there are three (3) sampling points, given a total of 30 points. The control location was directly collected from (1km) away from the mining area.

Initially filled into polyethylene bags separately from respective points in equal measures sealed and labeled for easy of identification and transported to chemistry department, Moddibo Adama University Yola, Nigeria, for laboratory analysis. In the laboratory, the soil samples were put in an oven at a temperature of 105°C to allow for drying overnight in order to remove any available moisture. After drying, the samples were crushed and sieved with a mesh having holes each of diameter of 2 mm in order to remove organic materials, stones and lumps. Thereafter, 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 *et al.,* (2000). The 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 put up approximately 300g of the soil sample. The sealed samples were kept for a minimum period of 30 days so as to allow for 226Ra and its short-lived progenies to reach secular radioactive equilibrium before gamma counting (Okeyode and Akanni (2009).

Gamma-ray spectrometry analysis

The gamma-ray spectrometry analysis was conducted at the National Institute of radiation protection and research, University of Ibadan Campus, Nigeria. Each sample was counted for a total of 36 000 seconds. The detector employed for the radioactivity measurements was a 76 mm × 76 mm NaI(Tl) detector crystal (802 Series, Canberra Inc.) coupled to a Canberra series 10 Plus multichannel analyzer (MCA) of model no: 1104 via a preamplifier. The system had an adequate lead shield that reduced the background radiation by 95%. The energy resolution of the NaI(Tl) detector was 8% at 0.662 MeV (137Cs).

The radionuclides (238U and 232Th) activity concentrations were determined using the gamma energy of their progenies that was noticed during the decay series as 1.760 MeV for 226Ra (238U) and 2.615 MeV for 232Th. The activity concentration of 40K was determined using only its gamma energy of 1.460 MeV. The activity concentrations of radionuclides in the samples were

estimated using equation (1-7)

Activity concentrations of 238U, 232Th and 40K

$$C\,(BqKg^{-1}) \;= \frac{C_n}{\varepsilon p_\gamma M_s^t} \tag{1}$$

where C is the radionuclide activity concentration of soil samples given in Bqkg−1, C_n represents the count rate under the corresponding peak, ε is the detector's efficiency at the specific gamma-ray energy, Pγ is the absolute transition probability of the specific gamma-ray, Ms is the soil sample mass in kg, and t is the counting time in seconds.

Representative level index (RLI)

Representative level index is the level of gamma radioactivity associated with different concentrations of some specific radioactive elements which can be measured using the following formula;

$$\mathrm{RLI} = \frac{1}{150}\mathrm{Cu} + \frac{1}{100}\ \mathrm{CTh} + \frac{1}{1500}\mathrm{Ck} \tag{2}$$

where CU; CTh and CK are the activity concentrations of ^{231}U, ^{232}Th, and ^{40}K in Bqkg^{1} respectively. The maximum limit for RLI is 1 ((Alfred *et al.,* 2013).

Activity utilization index (AUI)

The dose rates in air from different combinations of ^{238}U, 232Th, and ^{40}K (Bq kg^{1}) in soil samples and (AUI) is calculated from the following relation ((Alfred *et al.,* 2013).

$$\mathrm{AUI} = \frac{CU}{50}\mathrm{fu} + \frac{cth}{50}\ \mathrm{ft} + \frac{ck}{500}\mathrm{fk} \tag{3}$$

where, CU, CTh hand CK are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in Bqkg^{l} in soil samples, respectively, and U (0.462), Th (0.604) and K (0.042) are the respective fractional contributions from the actual activities of ^{238}U, ^{232}Th, and ^{40}K to the total dose rate in air (Chen *et al.*, 2014).

Radium equivalent radioactivity (Ra)

The radium equivalent activity (Raequ) is the sum of the activity of ^{238}U, ^{232}Th, and ^{40}K based on the assumption that 10 Bq/Kg of ^{238}U, 7 Bq/Kg of ^{232}Th, and ^{130} Bq/Kg of ^{40}K produced the same, $\gamma -$ray dose rates. The equivalent radioactivity is computed from the suggested Equation (Chen *et al.,* 2014).

$$\text{Raequ (Bq/Kg)} = \text{CRa} + 1.43\ \text{CTh} + 0.077\ \text{CK} \tag{4}$$

where CRa, CTh, and Ck are the activity concentration of ^{238}U (^{226}Ra), ^{232}Th, and ^{40}K in Bq/Kg, respectively. To keep the external dose <1.5mGy/h (UNSCEAR, 2000), the highest value of Raeq must be <370 Bq/Kg.

Absorbed dose rate (D)

The absorbed dose of radiation is the energy imparted per unit mass of the irradiated material. The measured activity concentrations of ^{238}U, ^{232}Th, and ^{40}K are converted into doses by applying the conversion factors 0.462, 0.604 and 0.0417 for uranium, thorium and potassium, respectively (UNSCEAR, 2000). The total absorbed dose rate (D) in nGy/h is calculated using the following formula suggested by (Chen *et al.,* 2014)

$$D\frac{1}{4} = 462CU + 604CTh + 0417CK = h \tag{5}$$

where, CU, CTh and CK are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in $Bqkg^{1}$ (UNSCEAR, 2000).

Hazard indices (Hex and Hin)

The gamma ray radiation hazards due to the specified radioactive elements in soil samples are assessed by calculating the following two hazard indices using the below given relations (Alfred *et al.,* 2013).

$$HEX = Cu\frac{cu}{370Bq/kg} + \frac{cth}{259Bq/kg} + \frac{Ck}{4810Bq/kg} \tag{6}$$

Where, CU, CTh and CK are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in $Bqkg^{-1}$. The internal hazard index (Hin) is used to control the internal exposure to radon and its short life products which are also dangerous to the respiratory organs (Alfred *et al.,* 2013).

Annual effective dose equivalent (AEDE

The conversion coefficient from absorbed dose in air to effective dose received by adults is 0.7 Sv/Gy and the occupancy factor for indoor and out-door is 0.8 and 0.2, respectively, i.e., the fraction of time spent indoors and outdoors is 0.8 and 0.2, respectively. The annual effective dose equivalent (AEDE) in indoor and outdoor air is determined as follows (UNSCEAR, 2000):

$$\text{AEDE (indoors)} = 45.041\ \text{nGy/h} \times 8760\text{h} \times 0.8 \times 0.7\ \text{Sv/Gy} = 0.221\ \text{mSv/y},$$

$$\text{AEDE (outdoors)} = 45.041\ \text{nGy/h} \times 8760\text{h} \times 0.2 \times 0.7\ \text{Sv/Gy} = 0.055\ \text{mSv/y} \quad (7)$$

RESULTS AND DISCUSSION

Activity concentration of uranium and thorium in soil sample

The activity concentration in the soil sample from ten (10) locations as shown in figure 2 indicate that mean activity concentration for uranium (U-238) in the soil samples is 1187.85 Bq/kg, and for thorium (Th-232) is 1052.20 Bq/kg, the activity concentration of (K-40) was beyond detection limits across all the samples, this may be due to the samples containing high level of minerals like Monazite, zircon and phosphate rick rocks.

The values obtained are significantly higher than the worldwide average values reported by UNSCEAR (2000), (33 Bq/kg for U-238 and 45 Bq/kg for Th-232). Exceptionally high activity concentrations were observed in Sina Mala, Garta, and Garta Sama.

Comparative studies show lower concentrations. In Keffi, Nasarawa State, Khamis *et al.,* (2022) reported average U-238 and Th-232 levels of 76.5 and 61.3 Bq/kg, respectively. Abubakar *et al.,* (2022) in Bauchi found U-238 and Th-232 concentrations ranging from 35 to 94 Bq/kg. Ajayi *et al.,* (2021) in Ondo State documented average concentrations of 41.7 Bq/kg for U-238 and 54.2 Bq/kg for Th-232, while Agbalagba *et al.,* (2019) reported values of 67.5 and 72.8 Bq/kg respectively in oil-contaminated soils of Delta State.

Compared to these studies, the current results indicate alarmingly high concentrations of uranium and thorium in several sample locations. These levels present potential risks for both environmental contamination and human exposure.

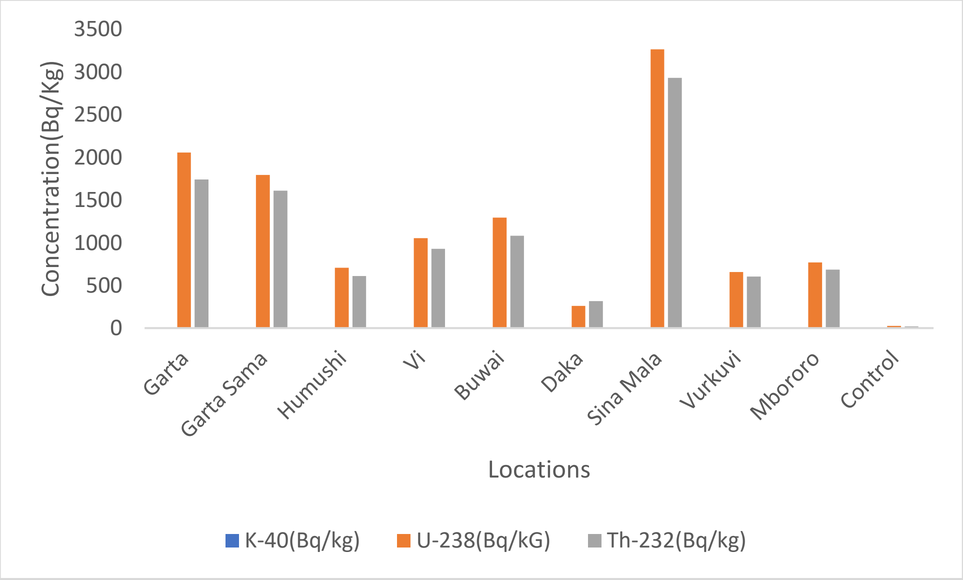

Figure 2: Activity concentration of Uranium and Thorium in soil Sample

Absorbed dose rate(D)

From figure 3. The mean absorbed dose rate from the samples is approximately 1,184.32 nGy/h. This value is significantly higher than the global average of 57 nGy/h as reported by UNSCEAR (2000). The high dose rates observed in samples such as Sina Mala (3,279.05 nGy/h) and Garta (2,000.65 nGy/h) suggest the presence of elevated natural radioactivity, likely due to geological, artisan mining activities or anthropogenic influences.

In comparison, a study in Keffi, Nasarawa State reported absorbed dose rates as high as 4,410 nGy/h, particularly in rock cutting zones, indicating occupational exposure (Khamis *et al.,* 2022). A study in Auyo, Jigawa State found much lower values, averaging 66.8 nGy/h, consistent with global background levels (Musa *et al.,* 2021). Another study conducted in Ijero Ekiti, Southwestern Nigeria, showed dose rates of 89.7 nGy/h in mining areas and 72.2 nGy/h in residential zones (Ademola *et al.,* 2020).

The values obtained in this study, therefore, indicate a notable radiological concern, particularly for areas with dose rates exceeding 1,000 nGy/h.

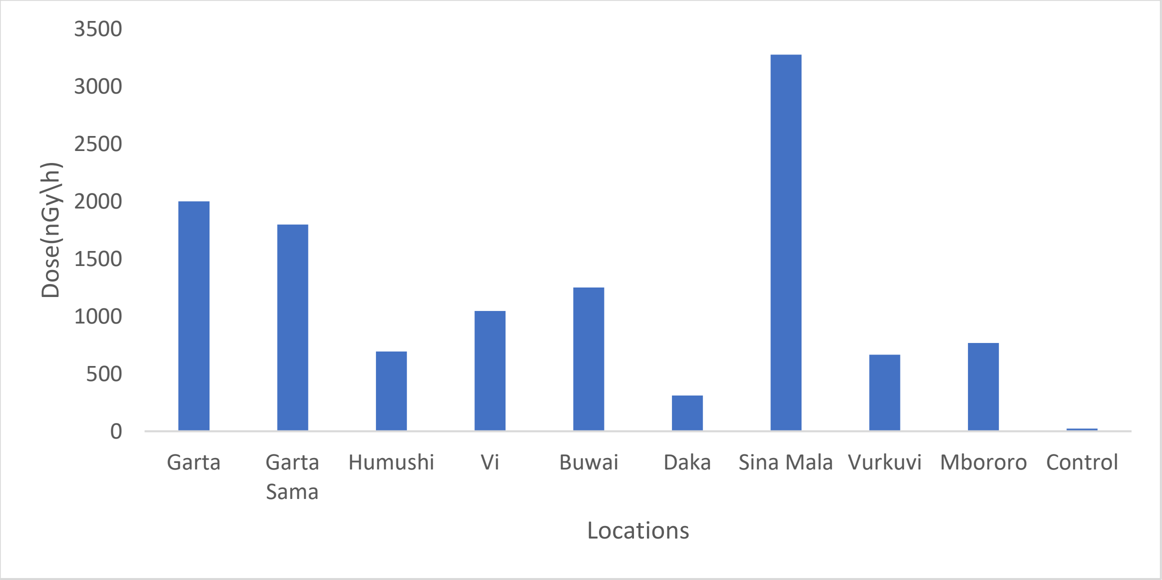

Figure 3: Absorbed Dose Rate of the soil sample

Annual Effective Dose Equivalent (AEDE)

The mean value of AEDE is approximately 1.45 mSv/year. According to UNSCEAR (2000), the recommended public exposure limit is 1 mSv/year from all sources excluding natural background and medical exposure. In this study as shown in figure 4, several locations exceed this threshold, especially Sina Mala (4.02 mSv/year), Garta (2.45 mSv/year), and Garta Sama (2.21 mSv/year) and maybe due to geological and mining activities.

A study in Keffi, Nasarawa State by Khamis *et al.,* (2022) reported AEDE values as high as 5.38 mSv/year due to intense uranium activity in borehole environments. Meanwhile, Musa *et al.,* (2021) in Auyo, Jigawa State reported AEDE of 0.082 mSv/year, well below the threshold. Ademola *et al.,* (2020) reported values of 0.110 mSv/year in residential zones and 0.137 mSv/year in mining zones of Ijero Ekiti.

Thus, the elevated AEDE values in the current study suggest potential radiological health risks, particularly in mining site like Sina Mala.

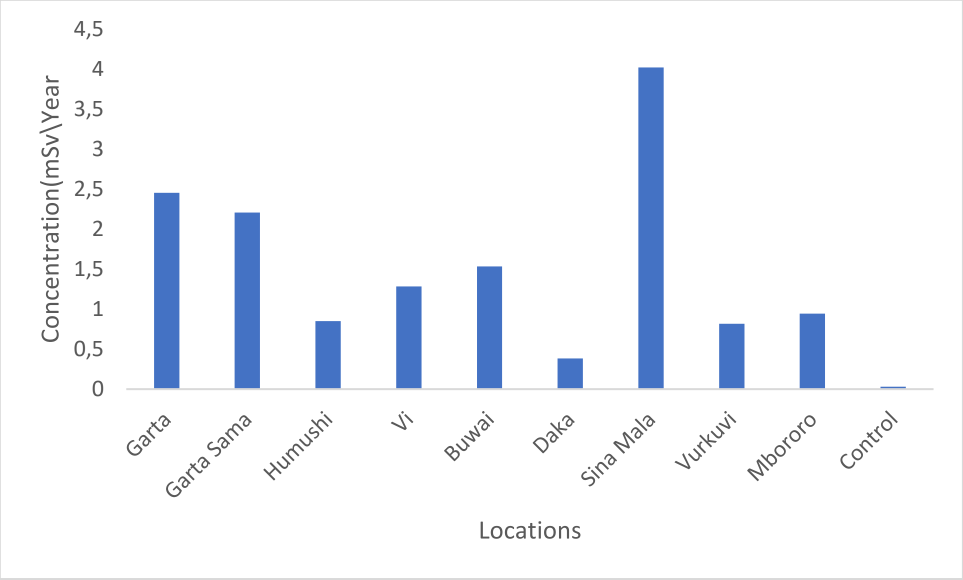

Figure 4: Annual Effective Dose Equivalent of the soil sample

Radium Equivalent Activities of the soil sample

The mean Radium Equivalent Activity (Ra_eq) across all samples is approximately 2692.50 Bq/kg. This value is far above the maximum recommended value of 370 Bq/kg set by UNSCEAR (2000), indicating a potential gamma radiation hazard in most of the study locations. Particularly elevated values were observed in Sina Mala (7,457 Bq/kg), Garta (4,544 Bq/kg), and Garta Sama (4,092 Bq/kg) as shown in figure 5.

Khamis *et al.,* (2022) reported Ra_eq values up to 5,652 Bq/kg in borehole environments of Keffi, Nasarawa State, a level similarly indicative of significant radiological hazards. Musa *et al.,* (2021) in Auyo, Jigawa State reported much lower Ra_eq values averaging 143 Bq/kg, within the safe limit. Ademola *et al.,* (2020) found average Ra_eq values of 237 Bq/kg in mining zones and 192 Bq/kg in residential zones in Ijero Ekiti.

Therefore, the current findings highlight a serious radiological concern, particularly in areas such as Sina Mala and Garta.

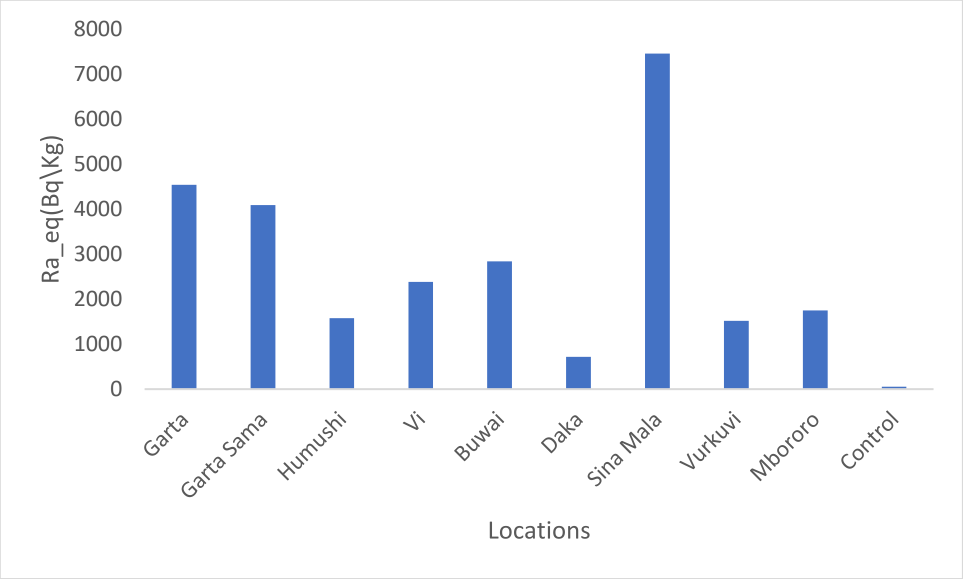

Figure 5: Radium Equivalent Activities of the soil sample

Excess Lifetime Cancer Risk of the soil sample

Excess Lifetime Cancer Risk (ELCR) estimates the probability of developing cancer over a lifetime due to exposure to ionizing radiation. The mean ELCR across all samples is approximately 0.005084, which is significantly higher than the global average acceptable risk level of 0.00029 recommended by UNSCEAR (2000) for the general public. The highest values were recorded in Sina Mala (0.014075), Garta (0.008588), and Garta Sama (0.007723) as seen in figure 6, suggesting these communities face a relatively elevated lifetime cancer risk from natural radiation sources.

A similar study conducted by Khamis *et al.,* (2022) in Keffi, Nasarawa State reported ELCR values reaching 0.0188, linked to high uranium levels in borehole environments. Musa *et al.,* (2021), studying soil samples in Auyo, Jigawa State, reported an average ELCR of 0.00029, closely aligned with global safety standards. In Ijero Ekiti, Ademola *et al.,* (2020) observed ELCRs of 0.00037 in mining areas and 0.00031 in residential areas.

The findings in this report suggest that populations in certain areas, particularly Sina Mala and Garta, are exposed to radiation levels that pose long-term cancer risks.

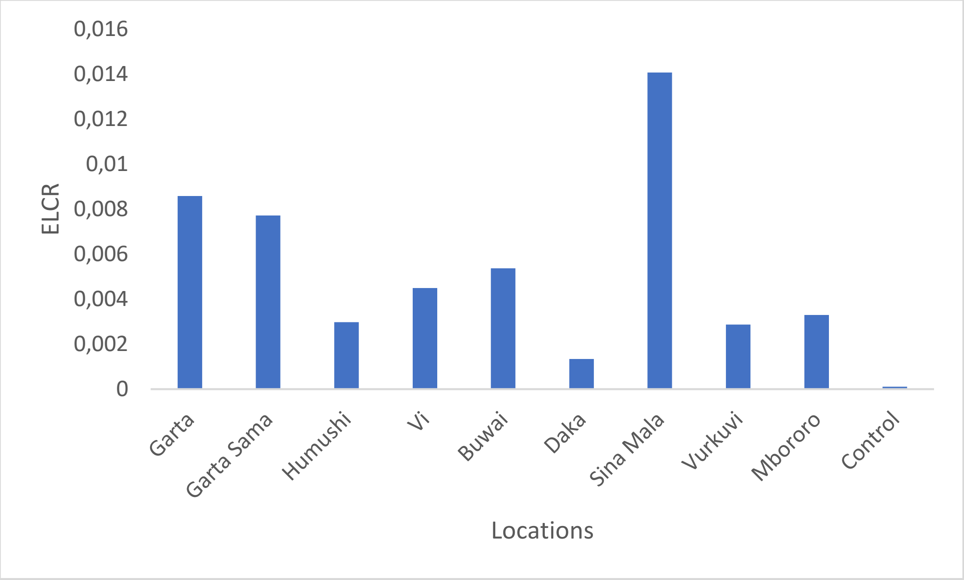

Figure 6: Excess Lifetime Cancer Risks of the soil sample

Representative level Index (RLI)

The mean value for Representative Level Index (Iγr) for the samples is approximately 18.441, which far exceeds the international benchmark of 1, indicating a significantly elevated gamma radiation hazard in many locations. The highest values were observed in Sina Mala (51.081), Garta (31.103), and Garta Sama (28.027) as shown in figure 7, all suggesting very high radiological risks. This index is particularly useful for evaluating building materials and soil.

Study by Agbalagba *et al.,* (2022) in Delta State reported Iγr values between 1.2 and 4.5 in oil-impacted communities. Okoye *et al.,* (2021) in Enugu State observed Iγr values ranging from 0.9 to 3.7 in coal mining areas. A study by Oladele *et al.,* (2020) in Ondo State reported values up to 5.2 in mineralized zones. Additionally, Ibeanu et al. (2019) found average Iγr values of 2.8 in agricultural fields in Anambra State. The current study reveals much higher gamma radiation hazard levels, particularly in Sina Mala and Garta. This necessitates public awareness to mitigate long-term health risks.

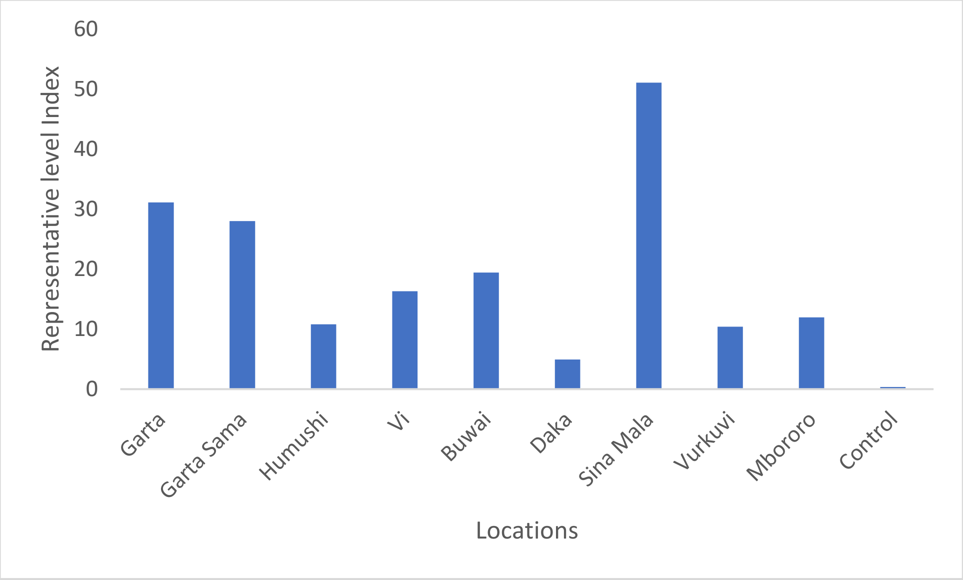

Figure 7: Representative level Index of the soil sample

Internal hazard index (Hin)

The average Internal Hazard Index (H_in) from the soil samples is 10.48, significantly above the safe limit of 1.0, indicating high internal radiation hazards in several locations as shown in figure 8. Extremely elevated H_in values were noted in Sina Mala (28.96), Garta (17.83), and Garta Sama (15.89), suggesting major health concerns regarding radon exposure and inhalation of radioactive dust.

Khamis *et al.,* (2022) recorded H_in values up to 11.7 in Keffi, Nasarawa State. Abubakar *et al.,* (2020) reported values around 4.2 in Bauchi. Ajayi *et al.,* (2021) observed average H_in values of 1.7 in Ondo State's mining zones, while Agbalagba *et al.,* (2019) reported average H_in values of 2.3 in oil-contaminated communities of Delta State.

Compared with these findings, the current study presents significantly higher internal hazard indices, particularly in Sina Mala and Garta.

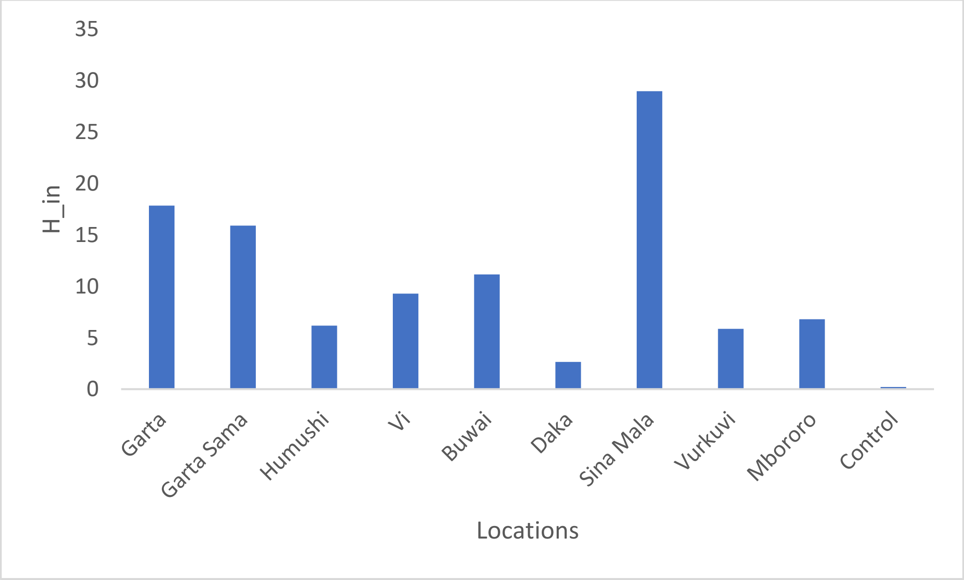

Figure 8: Internal Hazard Indices of the soil sample

External Hazard Indices (H_ex) of the soil sample

The average External Hazard Index (H_ex) for all samples is 3.8, significantly above the recommended safety threshold of 1.0. Extremely elevated H_ex values were found in Sina Mala (20.14), Garta (12.27), and Garta Sama (11.05) as seen in figure 9, indicating considerable gamma radiation exposure risks in these locations.

Khamis *et al.,* (2022) reported H_ex values up to 4.1 in Keffi, Nasarawa State. Abubakar *et al.,* (2022) observed H_ex values averaging around 2.8 in Bauchi. Ajayi *et al.,* (2021) found maximum H_ex levels of 1.5 in mineral-rich sites in Ondo State. Agbalagba *et al.,* (2019) reported average H_ex values of 2.1 in oil-impacted soils of Delta State.

Compared with these studies, the current value presents significantly higher external hazard indices, particularly in Sina Mala and Garta. These results suggest the presence of intense radiation sources, requiring immediate regulatory intervention, environmental control, and potential health risk management strategies.

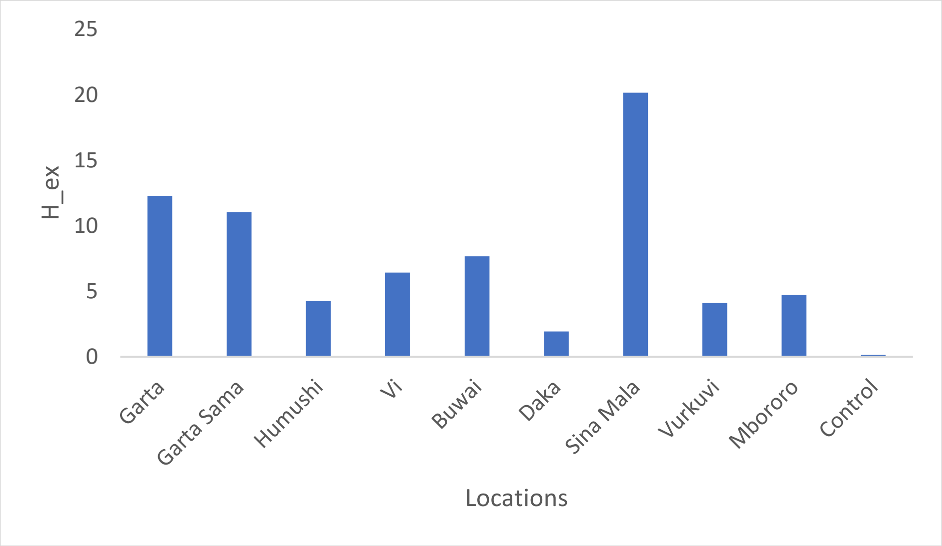

Figure 9: External Hazard Index (H_ex) of the soil sample

Activity utilization Index of the soil sample

The mean Activity Utilization Index (AUI) for the samples is 44.80, which is substantially higher than the threshold of 1.0. Extremely high AUI values were found in Sina Mala (123.93), Garta (75.91), and Garta Sama (68.01) as shown in figure 10, suggest that these soils should not be used in construction without radiological treatment or precaution.

Comparative studies have revealed lower levels of AUI. For example, Khamis *et al.,* (2022) in Keffi, Nasarawa State reported AUI values ranging between 1.5 and 4.3. Ajayi *et al.*, (2021) reported values between 2.2 and 5.1 in Ondo State, while Agbalagba *et al.,* (2019) found AUI levels between 1.1 and 6.0 in Delta State oil spill zones. Relative to these studies, the AUI values obtained in this study are significantly elevated. The extremely high levels of radiological activity in sites like Sina Mala pose severe environmental and public health concerns, and the soils from those mining sites should be strictly regulated against residential or commercial construction use.

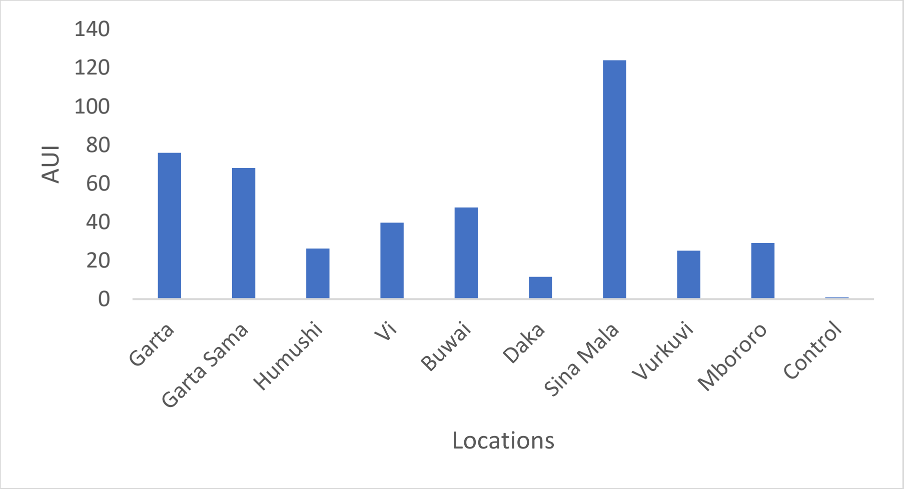

Figure 10: Activity Utilization Index of the soil sample

CONCLUSION

Based on available data and international standard, the region requires immediate attention to establish baseline radiological conditions, and to develop long-term monitoring and regulatory frameworks.

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