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# Analysis of Radiological Hazard Indices from Mining Sites in Adamawa State, Nigeria

**Samson Dauda Yusuf [a*], Soja Reuben Joseph [b] and Ibrahim Umar [a]**

*[a] Department of Physics, Faculty of Natural and Applied Sciences, Nasarawa State University, Keffi, Nigeria.*
*[b] Nigerian Nuclear Regulatory Authority (NNRA), Abuja, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by authors SDY, SRJ and IU. The first draft of the manuscript was written by author SRJ, reviewed and redrafted by authors SDY and SRJ. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** To analyse the radiological hazard indices from mining sites in Adamawa State, Nigeria.
**Study Design:** Experimental study design using Gamma ray spectroscopy with a well calibrated Sodium Iodide (NaI) detector.
**Place and Duration of Study:** Adamawa State, Nigeria and Department of Physics, Nasarawa State University Keffi, Nigeria, and Centre for Energy Research and Training (CERT) Laboratory, Ahmadu Bello University Zaria, Nigeria between November 2019 and August 2020.
**Methodology:** Fifteen composite samples of soil from four mining sites collected using the systematic sampling techniques were analysed for activity concentrations of Ra-226, Th-232 and K-40 and Gamma Absorbed Dose Rate, Radium Equivalent Activity, External Hazard Index, Annual Effective Dose Rate and Excessive Life Cancer Risk were calculated.
**Results:** Mean activity concentrations Ra-226 (107.60Bq/kg), Th-232 (84.89Bq/kg), and K-40 (475.34Bq/kg) were all above the world average values 35Bq/kg, 30Bq/kg and 400Bq/kg recommended by UNSCEAR. Mean Gamma Absorbed Dose Rate, Radium Equivalent Activity, Annual Effective Dose Rate, External Hazard Index, and Excessive Life Cancer Risk were

**Corresponding author: E-mail: samsonyusufu@yahoo.com;*

120.31nGy/h, 265.469Bq/kg, 0.148mSv/y, 0.401, and 0.369 respectively, against recommended values 59nGy/h, 370Bq/kg, 1mSv/y, 0.45, and 0.29 according to UNSCER, NEA-OECD and ICRP.
**Conclusion:** High values of Activity Concentrations, Gamma Absorbed Dose, and Excessive Life Cancer Risk poses significant threat to the host community, especially around the 3 mining sites SA, SB and SC.
Therefore, safety distance from mining areas is recommended by the competent Authority responsible for radiation protection matters in Nigeria. General awareness to enlighten the public about the possible dangers of undue radiation exposure and the risk of residing close to mining vicinity is required, for adequate protection of the host community.

*Keywords: Radiation exposure; absorbed dose rate; radium equivalent activity; external hazard index; effective dose rate; life cancer risk; public dose limit.*

## 1. INTRODUCTION

Human environment is characterized mainly by both natural and artificial radionuclides that continuously decay, thus causing significant radiation exposure hazards. Naturally occurring radionuclides can be found in the air we inhale, the food we consume, and the water we drink, causing public health problems. Earth's natural radioactive elements (primarily Uranium, Thorium, Radium and Potassium) and cosmic radiation constantly immerse us in a field of natural radiation. The natural radionuclides, Th-232 and U-238 including their decay products and non-series K-40 are distributed by the geological and geochemical processes in the soils that originated from the earth crust [1]. Natural hazards are primarily caused by primitive radioactive elements that are found in practically all geological elements in the ecological environment and thus are extensively dispersed. These transuranic elements are referred to as 'NORMs'. The radioactive elements U-238 and Th-232, as well as K-40, make up the vast bulk of NORMs which are earth radioactive materials that reach the body through the food chain, primarily through consumption. These radioactive materials are taken up by plants via plant roots and aggregate in the consumable sections. The accumulating radioactive elements in such plants provide an internal radiation exposure to people when they are prepared and eaten [2].

Th-232, Ra-226, and their by-products, as well as K-40, are the most dangerous natural radioactive isotopes. The alpha decay of Uranium and Thorium is the most common. While Potassium emits 89% beta decay and 11% gamma decay, both of which are difficult to detect. Many of their daughter products, on the other hand, are powerful gamma emitter. Gamma rays penetrate deeper than alpha and beta rays and are frequently employed to define the earthly elements of the environmental form of radiation. As a result, the gamma radiation releases from radioactive progeny isotopes Th-232 and U-238 are utilized to assess their quantities [3]. Mining activities can results to environmental pollution due to its harmful nature to human and environment even at low concentration which also facilitates Because most mineral co-exist with NORMs, the discharge of radioactive elements from the ores to the surroundings is a concern [4]. Exposure pathway of radionuclides to humans can be as a result of either ingestion through eating, inhalation through radio-particle dust contaminated air or absorption/contamination through the skin. NORMS are the most important sources of both externally and internally radiation exposure to low levels, and they can be found with in air that we inhale, the food that we eat, as well as the water we drink, causing health challenges. Ionizing radiation exposure causes health concerns after a few years. Radon (Rn-222), a breakdown product of U-238 often present in earth materials, is the most significant source of exposure to radiation [5].

In the case of Adamawa State in Nigeria, uncontrolled mining activities have been going on for more than 50 years. However, despite these illegal mining activities, no much studies have been carried out in the literature on the radiological hazards as a result of mining activities within the study area. Therefore, the objective of this study is to analyse the radiological hazard indices from mining sites in Adamawa State. The analysis covers only three Local Government Areas namely Fufore, Demsa and Song in Adamawa State and four mining sites were selected at different locations. In these four locations, the radiological hazard indices from activity concentration of soil samples were analysed.

## 2. MATERIALS AND METHODS

### 2.1 Materials

The Sodium Iodide (NaI) detector, Global Positioning System (GPS), Ziplock Polyethylene, Shovel and Cutlasses, Disposable Gloves, and Face Mask.

### 2.2 Methods

#### 2.2.1 Study area

Adamawa State is situated in the North Eastern part of Nigeria and has a land mass of 39,742.12sq km which covers about 4.4% of the land mass of Nigeria, lies between latitudes $8^0$N and $11^0$N, longitude $11.5^0$E and $13.5^0$E. Fig. 1 show the geographical map of Adamawa State obtained using google search.

#### 2.2.2 Sampling technique

A total of Fifteen (15) samples of soil were collected from the four selected quarry mining sites at 500m apart using the systematic sampling techniques. Composite samples were collect with a shovel at a depth of about 10 cm and placed in a sealed labeled polythene

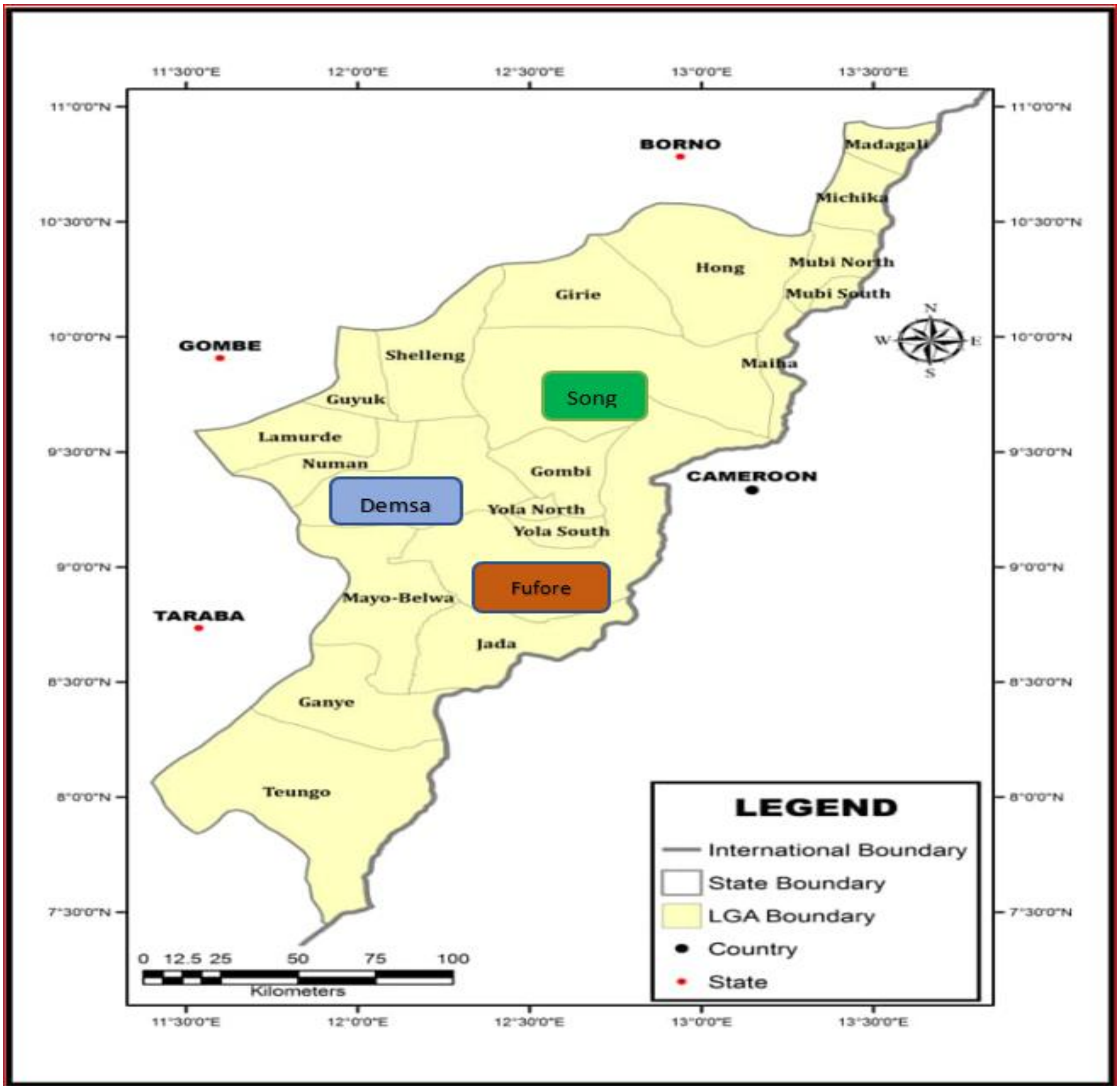


**Fig. 1. Map of Adamawa State showing Boundaries point [6]**

**Table 1. Sample coordinates and identification codes**

| Mining Locations | Soil Sample ID | Sampling coordinates | |
|---|---|---|---|
| | | Latitude | Longitude |
| Raycon Fufore | S - A1 | $09^0$ 08' 36" | $12^0$ 19' 09" |
| Raycon Fufore | S - A2 | $09^0$ 08' 29" | $12^0$ 19' 19" |
| Raycon Fufore | S - A3 | $09^0$ 08' 23" | $12^0$ 19' 04" |
| Raycon Fufore | S - A4 | $09^0$ 08' 39" | $12^0$ 19' 14" |
| NRC Demsa | S - B1 | $09^0$ 21' 48" | $12^0$ 11' 32" |
| NRC Demsa | S - B2 | $09^0$ 21' 42" | $12^0$ 11' 28" |
| NRC Demsa | S - B3 | $09^0$ 21' 36" | $12^0$ 11' 22" |
| NRC Demsa | S - B4 | $09^0$ 21' 53" | $12^0$ 11' 19" |
| Ministry Demsa | S - C1 | $09^0$ 21' 55" | $12^0$ 11' 23" |
| Ministry Demsa | S - C2 | $09^0$ 21' 51" | $12^0$ 11' 20" |
| Ministry Demsa | S - C3 | $09^0$ 21' 45" | $12^0$ 11' 17" |
| Ministry Demsa | S - C4 | $09^0$ 21' 59" | $12^0$ 11' 13" |
| AG Vision Song | S - D1 | $09^0$ 56' 15" | $12_0$ 37' 46" |
| AG Vision Song | S - D2 | $09^0$ 56' 19" | $12^0$ 37' 39" |
| AG Vision Song | S - D3 | $09^0$ 56' 11" | $12^0$ 37' 44" |

bag to avoid cross contamination during transportation. Open air drying at room temperature for seven days was adapted to remove moisture, while stony samples were grinded into powdery form using mortar and pestle and sieved with a wire mesh with holes of thickness 0.5 mm to obtain homogeneity of sample size. About 400g mass were kept in polythene bags for 28 days to attain secular equilibrium between Ra-226 and Th-232 and their progeny before taking to the laboratory for analysis. Attainning secular equilibrium is important since the NORM radionuclides considered in this study has extremely long half-lives. The sample points for each quarry mining sites alongside their coordinates and sample identification codes are presented in Table 1.

### 2.2.3 Measurement of Activity Concentration (AC)

The samples were analyzed to determine the radioactivity concentration levels of Ra-226, Th-232, and K-40 using Gamma ray spectroscopy with a well calibrated NaI (Tl) detector at the Centre for Energy Research and Training (CERT) Laboratory, Ahmadu Bello University Zaria.

### 2.2.4 Measurement of gamma absorbed Dose rate (D)

The gamma absorbed dose rate (D) was determined from the activity concentrations by applying the conversion factors of 0.462, 0.604 and 0.0417 for Ra-226, Th-232 and K-40 respectively as expressed by UNSCEAR [7] as:

$$\mathrm{D}\ (\mathrm{nGy}.hr^{-1}) = 0.462\mathrm{A}_{\mathrm{Ra}} + 0.604\mathrm{A}_{\mathrm{Th}} + 0.0417\mathrm{A}_{\mathrm{K}} \quad (1)$$

where, $A_{Ra}$, $A_{Th}$ and $A_K$ are the specific activities of Ra-226, Th-232 and K-40 in $Bqkg^{-1}$ respectively.

### 2.2.5 Measurement of Radium equivalent activity ($Ra_{eq}$)

The Radium equivalent activity ($Ra_{eq}$) was determined using the weighted sum activity concentrations of Ra-226, Th-232 and K-40 as expressed by Chowdhury et al. [8] as:

$$Ra_{eq}(Bq.kg^{-1}) = A_{Ra} + 1.43\mathrm{A}_{Th} + 0.077\mathrm{A}_{K} \quad (2)$$

### 2.2.6 Measurement of external Hazard Index ($HI_{ex}$)

The external hazard index ($HI_{ex}$) was evaluated to limit the activity concentrations of Ra-226, Th-232 and K-40 to ensure that a permissible dose rate of less than 1mSv/y as expressed by UNSCEAR [9] as:

$$\mathrm{H}_{\mathrm{Iex}} = \frac{\mathrm{A}_{\mathrm{Ra}}}{370} + \frac{\mathrm{A}_{\mathrm{Th}}}{259} + \frac{\mathrm{A}_{\mathrm{K}}}{4810} \leq 1 \quad (3)$$

### 2.2.7 Measurement of Annual Effective Dose Rate (AEDR)

The annual effective dose rate (AEDR) was evaluated using the absorbed dose rate (D) obtained and a conversion factor value of 0.7Sv/Gy of absorbed dose in air to effective dose an adult receives as expressed by UNSCEAR [10] as:

$$AEDR(mSv.y^{-1}) = D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} \quad (4)$$

#### 2.2.8 Measurement of Excessive Life Cancer Risk (ELCR)

The excessive life cancer risk (ELCR) was determined by taking the product of the determined AEDR with life duration (LD) (70 years and 50 years for children and adult), and low dose background radiation Risk Factor (RF) of 5% for public exposure measured to yield stochastic consequence as expressed in Clarke [11] as:

$$ELCR = AEDR \times RF \times LD \quad (5)$$

## 3. RESULTS AND DISCUSSION

### 3.1 Activity Concentration

Table 2 shows the radioactivity concentration levels result of Ra-226, Th-232, and K-40 as obtained using Sodium Iodide (NaI) detector.

For Ra-226, Table 2 shows that the highest mean activity concentration value of Ra-226 amongst the individual mining sites occurred at site SC (115.58Bq/kg) followed by site SB (113.75Bq/kg), while the least was at site SD (65.43Bq/kg). However, the overall mean activity concentration value of Ra-226 for the four (4) mining sites is 107.60Bq/kg.

For Th-232, Table 2 shows that the highest mean activity concentration value of Th-232 amongst the individual mining sites occurred at site SB (97.04Bq/kg), followed by site SA (85.21Bq/kg), while the least was at site SD (57.08Bq/kg). The overall mean activity concentration value of Th-232 for the four (4) mining sites is 84.89Bq/kg.

For K-40, Table 2 shows that the highest mean activity concentration value of K-40 amongst the individual mining sites occurred at site SA (859.72Bq/kg), followed by site SB (397.38Bq/kg), while the least was at site SD (246.02Bq/kg). The overall mean activity concentration value of K-40 for the four (4) mining sites is 475.34Bq/kg.

From Table 2 the activity concentrations of Ra-226, Th-232, and K-40 show variations across the individual mining sites with values of Ra-226 and Th-232 all above the median values throughout the world 35Bq/kg and 30Bq/kg according to UNSCEAR [10]. However, the values of K-40 was below the median value throughout the world 400Bq/kg according to UNSCEAR [10] in each of the mining sites, except for mining site SA where this value was very higher as a result, the overall mean value become higher than the recommended value. This implies that the host community are more exposed to Ra-226 and Th-232 as against K-40. The mean activity concentration for Ra-226, Th-232 and K-40 for the individual mining sites is shown in Fig. 2.

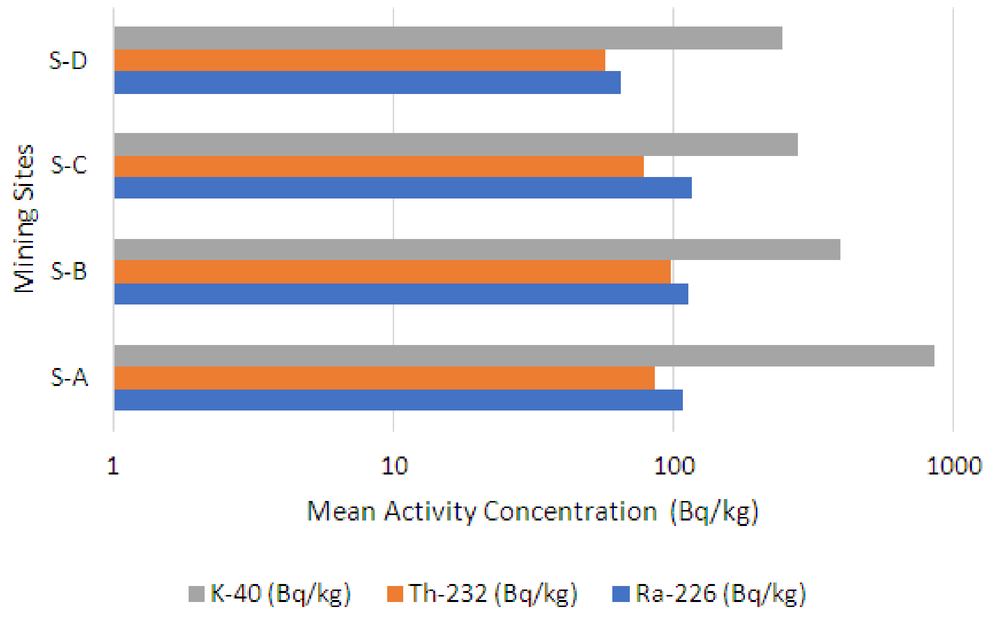


**Fig. 2. Mean activity concentration of the individual mining sites**

**Table 2. Activity Concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K in soil samples**

| Soil Sample ID | Mean Sample Per Location | Ra-226 (Bq/Kg) | Mean Per Location | Th-232 (Bq/Kg) | Mean Per Location | K-40 (Bq/Kg) | Mean Per Location |
|---|---|---|---|---|---|---|---|
| S - A1 | SA | 88.29 | 108.72 | 78.72 | 85.21 | 1080.28 | 859.72 |
| S - A2 | | 120.29 | | 92.67 | | 1074.7 | |
| S - A3 | | 104.59 | | 92.79 | | 941.28 | |
| S - A4 | | 121.72 | | 76.67 | | 342.61 | |
| S - B1 | SB | 99.83 | 113.75 | 73.02 | 97.04 | 368.83 | 397.38 |
| S - B2 | | 114.29 | | 157.24 | | 251.34 | |
| S - B3 | | 95.92 | | 76.59 | | 441.98 | |
| S - B4 | | 144.97 | | 81.31 | | 527.35 | |
| S - C1 | SC | 104.91 | 115.58 | 110.64 | 78.99 | 295.05 | 279.43 |
| S - C2 | | 124.4 | | 92.4 | | 352.96 | |
| S - C3 | | 110.38 | | 52.92 | | 261.69 | |
| S - C4 | | 122.64 | | 60 | | 208.01 | |
| S - D1 | SD | 89.37 | 65.43 | 82.49 | 57.08 | 174.07 | 246.02 |
| S - D2 | | 75.54 | | 64.09 | | 45.67 | |
| S - D3 | | 96.8 | | 81.74 | | 764.32 | |
| Max | | 144.97 | | 157.24 | | 1080.28 | |
| Min | | 75.54 | | 52.92 | | 45.67 | |
| Mean | | 107.6 | | 84.89 | | 475.34 | |

**Table 3. Calculated radiological hazard indices**

| Sample ID | D (nGy/h) | $Ra_{eq}$ (Bq/kg) | HIex | AEDR (mSv/y) | ELCR |
|---|---|---|---|---|---|
| S-A1 | 133.385 | 284.041 | 0.490 | 0.164 | 0.409 |
| S-A2 | 156.362 | 335.560 | 0.558 | 0.192 | 0.479 |
| S-A3 | 143.617 | 309.758 | 0.509 | 0.176 | 0.440 |
| S-A4 | 116.830 | 257.739 | 0.378 | 0.143 | 0.358 |
| S-B1 | 105.606 | 232.649 | 0.347 | 0.130 | 0.324 |
| S-B2 | 158.256 | 358.496 | 0.498 | 0.194 | 0.485 |
| S-B3 | 109.006 | 239.476 | 0.363 | 0.134 | 0.334 |
| S-B4 | 138.079 | 301.849 | 0.456 | 0.169 | 0.423 |
| S-C1 | 127.599 | 285.844 | 0.408 | 0.156 | 0.391 |
| S-C2 | 128.001 | 283.710 | 0.413 | 0.157 | 0.392 |
| S-C3 | 93.872 | 206.206 | 0.302 | 0.115 | 0.288 |
| S-C4 | 101.574 | 224.457 | 0.320 | 0.125 | 0.311 |
| S-D1 | 98.372 | 220.734 | 0.309 | 0.121 | 0.302 |
| S-D2 | 75.514 | 170.705 | 0.230 | 0.093 | 0.232 |
| S-D3 | 125.965 | 272.541 | 0.441 | 0.154 | 0.386 |
| Max. | 158.256 | 358.496 | 0.558 | 0.194 | 0.485 |
| Min. | 75.5143 | 170.705 | 0.230 | 0.093 | 0.232 |
| Average | 120.341 | 265.469 | 0.401 | 0.148 | 0.369 |
| Median | 125.97 | 272.50 | 0.4080 | 0.154 | 0.386 |
| Range | 82.74 | 187.79 | 0.328 | 0.101 | 0.253 |
| World Average | 59nGy/h | 370Bq/kg | 0.45 | 1mSv/y | 0.29 |

*StDev = Standard deviation*

**Table 4. Mining Site specific analysis of radiological hazard indices**

| Mining Site | Parameters | D (nGy/h) | $Ra_{eq}$ (Bq/kg) | HI(ex) | AEDR (mSv/y) | ELCR |
|---|---|---|---|---|---|---|
| SA | Max | 156.361650 | 335.56000 | 0.557595519 | 0.191761928 | 0.479404819 |
| | Min | 116.830157 | 257.73907 | 0.377696658 | 0.143280505 | 0.358201261 |
| | Mean | 137.548365 | 296.77463 | 0.483458670 | 0.168689315 | 0.421723286 |
| | Median | 138.50 | 296.9 | 0.4995 | 0.1700 | 0.4692 |
| | Range | 39.53 | 77.82 | 0.1800 | 0.0490 | 0.1210 |
| SB | Max | 158.255818 | 358.49638 | 0.497884769 | 0.194084935 | 0.485212338 |
| | Min | 105.605751 | 232.64851 | 0.346807461 | 0.129514893 | 0.323787233 |
| | Mean | 127.736353 | 283.11758 | 0.416037643 | 0.156655863 | 0.391639657 |
| | Median | 123.5 | 270.7 | 0.4095 | 0.1515 | 0.3785 |
| | Range | 52.7 | 125.8 | 0.1510 | 0.0640 | 0.1610 |
| SC | Max | 128.000832 | 285.84405 | 0.412599677 | 0.156980220 | 0.392450551 |
| | Min | 93.871713 | 206.20573 | 0.301567568 | 0.115124269 | 0.287810672 |
| | Mean | 112.761202 | 250.05412 | 0.360563381 | 0.138290338 | 0.345725845 |
| | Median | 114.59 | 254.1 | 0.3640 | 0.1405 | 0.3510 |
| | Range | 34.13 | 79.6 | 0.1110 | 0.0420 | 0.1040 |
| SD | Max | 125.964704 | 272.54084 | 0.441083468 | 0.154483113 | 0.386207782 |
| | Min | 75.514279 | 170.70529 | 0.230261069 | 0.092610712 | 0.231526779 |
| | Mean | 99.950201 | 221.32674 | 0.327021085 | 0.122578926 | 0.306447315 |
| | Median | 98.4 | 220.7 | 0.3090 | 0.1210 | 0.3020 |
| | Range | 50.5 | 101.8 | 0.2110 | 0.0610 | 0.1540 |

### 3.2 Analysis of Radiological Hazard Indices

Table 3 shows the result of the gamma absorbed dose rate (D), Radium equivalent activity ($Ra_{eq}$), external hazard indices ($HI_{ex}$), annual effective dose rate, and excessive life cancer risk calculated from the activity concentration of Ra-226, Th-232 and K-40 in soil samples presented in Table 2 using equations 1 to 5 respectively.

The values of Gamma Absorbed Dose Rate (D) ranges from 75.514nGy/h to 158.256nGy/h, with a mean value of 120.341nGy/h (median value of 125.97nGy/h and range of 82.74nGy/h) above the population weighted average of outdoor absorbed dose rate in air from terrestrial gamma radiation throughout the world 59nGy/h according to UNSCEAR [10]. Radium Equivalent Activity ranges from 170.705Bq/kg to 358.496Bq/kg with a mean value of 265.469Bq/kg (median value of 272.50 Bq/kg and range of 187.79Bq/kg) below the recommended value 370Bq/kg according to NEA-OECD.

External Hazard Index value ranges from 0.230 to 0.558 with mean value of 0.401 (median value of 0.4080 and range of 0.328)which is below the recommended value of 0.45, Annual Effective Dose Rate (AEDR) ranges from 0.093mSv/y to 0.194mSv/y with mean value of 0.148mSv/y (median value of 0.154 mSv/y and range of 0.101 mSv/y) which is below the recommended public dose limit of 1mSv/y as recommended by ICRP and Excessive Life Cancer Risk value ranges from 0.232 to 0.485 with mean value of 0.369 (median value of 0.386 and range of 0.253) which is above the recommended value of 0.29.

### 3.3 Mining Site Specific Analysis of Radiological Hazard Indices

Table 4 shows the mining sites specific analysis of radiological hazard indices from activity concentration of Ra-226, Th-232 and K-40 in soil samples.

For the gamma absorbed dose, Table 4 shows that the highest value amongst the mining sites occurred at site SB (158.256nGy/h) followed by site SA (156.362nGy/h), while the least was at site SD (125.965nGy/h). However, the highest mean and median values occurred at site SA (137.548nGy/h and 138.50nGy/h) followed by site SB (127.736nGy/h and 123.5nGy/h), and the least was at site SD (99.950nGy/h and 98.4nGy/h).

For the Radium Equivalent Activity ($Ra_{eq}$), Table 4 shows that the highest value amongst the mining sites occurred at site SB (358.496Bq/kg), followed by site SA (335.560Bq/kg), while the least was at site SD (272.541Bq/kg). The highest mean and median values occurred at site SA (296.775Bq/kg and 296.9 Bq/kg) followed by site SB (283.118Bq/kg and 270.7 Bq/kg), and the least was at site SD (221.327Bq/kg and 220.7 Bq/kg).

For the External Hazard Index (HIex), Table 4 shows that the highest value amongst the mining sites occurred at site SA (0.5576), followed by site SB (0.4979), while the least was at site SC (0.4126). The highest mean and median values occurred at site SA (0.4835 and 0.4995) followed by site SB (0.4160 and 0.4095), and the least was at site SD (0.3270 and 0.3090).

For the Annual Effective Dose Rate (AEDR), Table 4 shows that the highest value amongst the mining sites occurred at site SB (0.1941mSv/y), followed by site SA (0.1918mSv/y), while the least was at site SD (0.1545mSv/y). The highest mean and median values occurred at site SA (0.1687mSv/y and 0.1700mSv/y) followed by site SB (0.1567mSv/y and 0.1515mSv/y), and the least was at site SD (0.1226mSv/y and 0.1210mSv/y).

Finally, for the Excessive Life Cancer Risk (ELCR), Table 4 shows that the highest value amongst the mining sites occurred at site SB (0.4852), followed by site SA (0.4794), while the least was at site SD (0.3862). The highest mean and median values occurred at site SA (0.4217 and 0.4692) followed by site SB (0.3916 and 0.3785), and the least was at site SD (0.3064 and 0.3020).

From Table 4 the calculated radiological hazard parameters shows some variations across the four (4) selected mining sites with high values of Gamma Absorbed Dose Rate (D) in each of the mining sites above the population weighted average of outdoor absorbed dose rate in air from terrestrial gamma radiation throughout the world 59nGy/h according to UNSCEAR [10]. However, the values of Radium Equivalent Activity (Raeq) were below the recommended value 370Bq/kg according to NEA-OECD in each of the mining sites. Similarly, External Hazard Index (HIex) were all below the recommended value of 0.45 in all the mining sites except for mining site SA that was above the recommended value, Annual Effective Dose Rate (AEDR) were all below the recommended value of 1mSv/y, while Excessive Life Cancer Risk (ELCR) were above the recommended value of 0.29 as recommended by ICRP in each of the mining sites. This implies that even though they are highly exposed to gamma radiation, the impact of gamma radiation can occur throughout a body as they are however less ionising than alpha particles. This effect may carry stochastic health risk as the probability of cancer induction is high with increased exposure. However, high exposures can cause direct acute effects in this case through immediate damage of cells.

This also implies that, the contribution of high dose rates of Gamma Absorbed Dose Rate (D), External Hazard Index (HIex), and Excessive Life Cancer Risk in this study were mainly from mining sites SA and SB, as compared to those at SC and SD. The calculated radiation hazard indices for the individual mining sites are presented in Figs. 3 and 4.

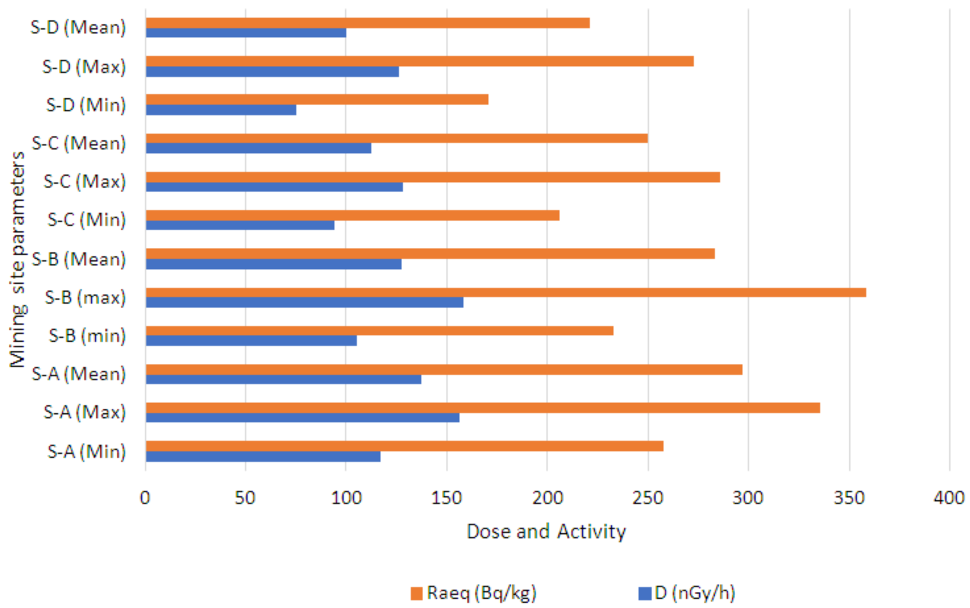


**Fig. 3. Gamma absorbed dose rate and radium equivalent activity**

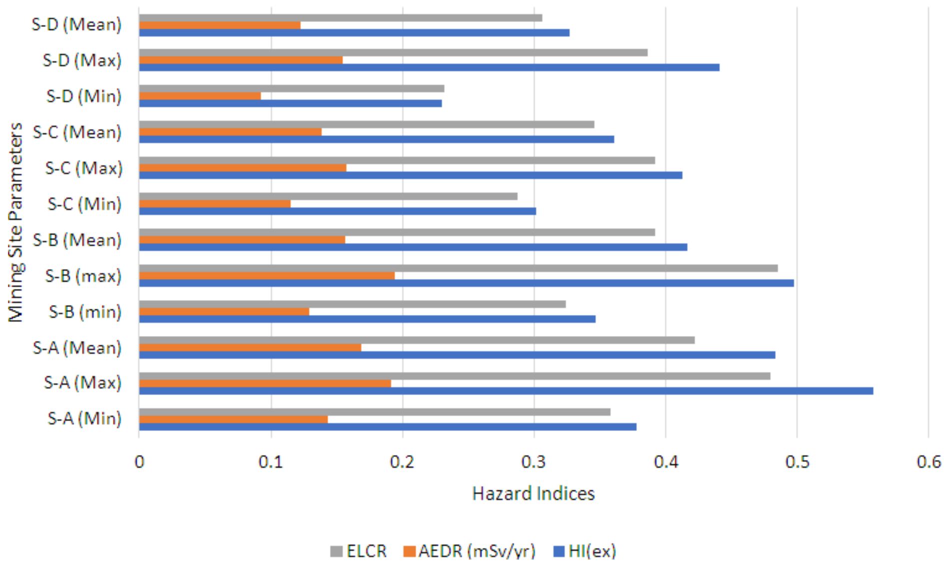


**Fig. 4. Excessive life cancer risk, annual effective dose rate and external hazard index**

**Table 5. Comparison of radiological hazard indices with previous studies and world standard**

| Country / Region | D (nGy/h) | Raeq (Bq/kg) | HI(ex) | AEDR (mSv/y) | ELCR | References |
|---|---|---|---|---|---|---|
| Nigeria (Adamawa) | 120.31±6.10 | 265.47±13.1 | 0.40±0.40 | 0.15±0.15 | 0.37±0.37 | Present Study |
| Nigeria (Anka) | 121.78 | 373.10 | 0.15 | 0.74 | - | Mbet et al. [12] |
| Nigeria (South West) | - | 191.34 | 0.04 | 0.52 | - | Ibikunle et al. [13] |
| Nigeria (Jos) | 146.79 – 291.69 | 322.49 – 642.26 | 0.68 – 1.34 | 1.00 – 2.08 | 0.24 | Solomon et al. [14] |
| Gabon (South East) | 1352.79 | 2928.75 | 10.96 | 7.92 | - | Mouandza et al. [15] |
| Nigeria (Benue) | 17.27 | - | 0.25 | - | - | Ode et al. [16] |
| Nigeria (FCT) | 197.45±29.06 | 331.50 – 529.91 | 0.38 | - | - | Shittu et al. [17] |
| Nigeria (Ogun) | 40.88 | - | 0.05 | - | - | Usikalu et al. [18] |
| Nigeria (Nasarawa) | - | 148.10 | 0.31 | - | - | Ibrahim et al. [3] |
| World Average | 60.00 | 370.00 | 0.45 | 1.00 | 0.29 | UNSCEAR [10] |

**Table 6. Comparison of activity concentrations of Ra-226, Th-232 and K-40 in soil samples with previous studies**

| Country / Region | Ra-226 (Bq/kg) | Th-232 (Bq/kg) | K-40 (Bq/kg) | References |
|---|---|---|---|---|
| Nigeria (Adamawa) | 107.59±11.20 | 84.86±6.23 | 475.34±12.30 | Present Study |
| Nigeria (Anka) | 41.60±11.06 | 151.15±21.09 | 380.34±116.41 | Mbet et al. [12] |
| Nigeria (South West) | 52.91 | 76.79 | 393.73 | Ibikunle et al. [13] |
| Nigeria (Osun) | - | 23.23±7.67 | 270.14±61.79 | Oluyide et al. [19] |
| Gabon (South East) | 2811.00±198.00 | 63.00±12.00 | 355.00±93.00 | Mouandza et al. [15] |
| Nigeria (Kogi) | 41.27±9.31 | 18.90±4.21 | 508.86±54.02 | Okeme et al. [2] |
| Egypt (Aswan) | 28.88±2.10 | 32.81±2.39 | 383.90±27.95 | Harb et al. [20] |
| Bangladesh (Chittagong) | 22.13±2.30 | 38.47±2.72 | 451.90±24.90 | Chakraborty et al. [21] |
| Nigeria (Nasarawa) | 32.52±4.65 | 56.23±2.30 | 403.96±9.63 | Ibrahim et al. [3] |
| World Average | 35.00 | 30.00 | 400.00 | UNSCEAR [10] |

### 3.4 Comparison of Radiological Hazard Indices with Previous Studies

Comparism of Radiological Hazards Indices with other studies and the median values throughout the world according to UNSCEAR [10] are presented in Table 5.

Comparison of radiological hazards indices (Gamma Absorbed dose rate (nGy/h), Radium Equivalent Activity (Bq/kg), Annual Effective Dose Rate (mSv/y), External Hazard Indices, and Excessive Life Cancer Risk respectively) from soil samples collected at different sampling points from the four selected mining locations considered in this study with published data from similar investigations in Nigeria, Gabon, and the median values throughout the world according to UNSCEAR [10] are presented in Table 4. Higher dose was determined by Mouandza [15] in Gabon, while lower dose was determined by Ode et al. [16] and Ibrahim et al. [3] in Nigeria.

Gamma Absorbed dose rate and Excessive Life Cancer Risk obtained in this study are higher than the world average whereas Radium Equivalent Activity, Annual Effective Dose Rate and External Hazard Indices are below the world average according to UNSCEAR [10].

### 3.5 Comparison of Activity Concentration with Previous Studies

The activity concentrations of Ra-226, Th-232 and K-40 in soil samples collected at different sampling points from the four selected mining locations considered in this study was compared with that of other regions/countries and world average and the result are presented in Table 6.

Comparison of the result of activity concentrations of Ra-226, Th-232 and K-40 in soil samples obtained at different sampling points from four selected mining locations in Adamawa State with published data from similar investigations in Nigeria, Gabon, Egypt, China, Pain, Japan and India and the median values throughout the world according to UNSCEAR [10] were presented. Higher activity concentration for Ra-226 was determined by Mouandza et al. [15] in Gabon, while that of Th-232 was determined by Mbet et al. [12] and that of K-40 was determined by Okeme et al. [2] in Nigeria respectively, while lower activity concentration was determined by Ibikunle et al. [13] and Oluyide et al. [19] in Nigeria and Harb et al. [20] in Aswan, Egypt.

The average activity concentration of Ra-226, Th-232 and K-40 obtained in this study is higher than that obtained in Nigeria by Mbet et al. [12], Ibikunle et al. [13] and Oluyide et al. [19] in Nigeria and Harb et al. [20] in Egypt. The average activity concentration of Ra-226, Th-232 and K-40 from this study are higher than the median values throughout the world according to UNSCEAR [10].

### 3.6 Discussion

Results from this study shows that the activity concentrations of Ra-226, Th-232 and K-40 in soil samples varied within the study area due to the differences in geological and topographical formation of the study area with mean all above the median values throughout the world according to UNSCEAR [10].

Comparison of the results of activity concentrations of Ra-226, Th-232 and K-40 in soil samples with published data from similar investigations in Nigeria, Gabon, Egypt, China, Pain, Japan and India and the median values throughout the world according to UNSCEAR [10] shows higher activity concentration for Ra-226 determined by Mouandza et al. [15], while that of Th-232 Mbet et al. [12] and K-40 by Okeme et al. [2] in Nigeria respectively, However, lower activity concentration was determined by Ibikunle et al. [13] and Oluyide et al. [19] in Nigeria and Harb et al. [20] in Egypt. The average activity concentration of Ra-226, Th-232 and K-40 obtained in this study is higher than that obtained in Nigeria by Mbet et al. [12] Ibikunle et al. [13] and Oluyide et al. [19] in Nigeria and Harb et al. [20] in Egypt. The average activity concentration of Ra-226, Th-232 and K-40 from this study are higher than the median values throughout the world according to UNSCEAR [10].

Analysis of radiological hazard indices varied within the study area from one mining site to the other. However, the average value have revealed significant information for good policy decision. The mean Gamma Absorbed Dose Rate was above the recommended value of 60.00, while Radium Equivalent Activity was below the recommended value 370.00. External Hazard Index was below the recommended value of 0.45, Annual effective dose rate was below the recommended public dose limit of 1mSv/y as recommended by ICRP, while Excessive Life Cancer Risk was above the recommended value of 0.29. Comparison of the results of radiological hazard indices with published data from similar investigations in Nigeria shows higher Gamma Absorbed Dose Rates reported by Mbet et al. [12] in Anka, Solomon et al. [14] in Jos and Shittu et al. [17] in FCT Abuja, while lower dose was recorded by Ode et al. [16] in Benue and Usikalu et al. [18] in Ogun. For the Radium Equivalent Activity, higher values were reported by Mbet et al. [12] in Anka, Solomon et al. [14] in Jos and Shittu et al. [17] in FCT Abuja, while lower values were reported by Ibikunle et al. [13] in the South West and Ibrahim et al. [3] in Nasarawa. In terms of External Hazard Index, higher values were reported by Solomon et al. [14] in Jos, while lower values were reported by Mbet et al. [12] in Anka, Ibikunle et al. [13] in the South West, Ode et al. [16] in Benue, Shittu et al. [17] in FCT Abuja, Usikalu et al. [18] in Ogun, and Ibrahim et al. [3] in Nasarawa. For Annual Effective Dose Rate, high value was reported by Solomon et al. [14] in Jos, while lower values were reported by Mbet et al. [12] in Anka and Ibikunle et al. [13] in the South West. Comparison of the result for Excessive Life Cancer Risk with published data from similar investigations in Nigeria, it appears that among the previous works reviewed in this study, only Solomon et al. [14] carried out this analysis, where he reported a lower value compared to this study. However, the analysis of radiological hazard indices for specific mining sites shows that gamma absorbed dose rate from all the mining areas were all higher than the population weighted average of outdoor absorbed dose rate in air from terrestrial gamma radiation throughout the world 59nGy/h according to UNSCEAR [10].

## 4. CONCLUSION

Evaluation of analyzed the radiological hazard indices from mining sites cannot be over emphasized due to the fact that, uncontrolled mining activities is one of the major courses of public exposure to radiation especially in Nigeria. This study analyzed the radiological hazard indices from mining sites in Adamawa State, Nigeria using Sodium Iodide (NaI) detector. Fifteen composite samples of soil from four mining sites were analyzed for activity concentrations of Ra-226, Th-232 and K-40. Gamma Absorbed Dose Rate, Radium Equivalent Activity, External Hazard Index, Annual Effective Dose Rate and Excessive Life Cancer Risk were calculated. High values of Activity Concentrations, Gamma Absorbed Dose Rate and Excessive Life Cancer Risk were observed especially in 3 mining sites, which poses significant threat to the host community. However, due to the high penetrating power of gamma, they are less ionizing but their impact can occur throughout a body. Gamma radiation is considered an external hazard with regards to radiation protection. Similar to all exposure to ionizing radiation, high exposures can cause direct acute effects through immediate damage of cells while low levels of exposure carry a stochastic health risk where the probability of cancer induction rises with increased exposure. This implies that all the mining sites has the tendency to pose significant risk to the host communities in the long run. Therefore, safety distances or setback from these mining areas, and general awareness for adequate protection of the host community is recommended.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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