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# Assessment of Natural Radioactivity and Health Hazards in soils from some selected Solid Mineral Mining Sites in Edo-North, Nigeria

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## Abstract

This paper presents an assessment of natural radioactivity in soil of some selected solid mineral mining sites in Edo-North Nigeria using gamma spectroscopy [NaI(TI)]. The measured activity concentrations of radionuclides for all the sites ranged from (0 – 3137.18±162.21) $Bqkg^{-1}$ with mean value of 961.5±55.245 $Bqkg^{-1}$ for $^{40}K$, $^{232}Th$ in the range of (3.7±0.23 – 21.63±1.30) $Bqkg^{-1}$ with a mean value of 12.9±0.79 $Bqkg^{-1}$ and $^{238}U$ in the range of (0.68±0.10 – 197.3±19.21) $Bqkg^{-1}$ with mean value of 28.2±3.25 $Bqkg^{-1}$. Similarly, comparing the mean activity concentration of radionuclides of all soil samples with UNSCEAR, (2000) standards, it was observed that the obtained average results of $^{40}K$ were above the recommended standard values of 400 $Bqkg^{-1}$. While that of $^{232}Th$ and $^{238}U$ were below the recommended standard value of 30 $Bqkg^{-1}$and 33 $Bqkg^{-1}$. The variation in the specific activity concentration of radionuclides in the soils sample follows the order $^{232}Th < ^{238}U < ^{40}K$. However, the estimated radiological hazard and activity utilization indices are lower than the world permissible values in most of the solid mineral mining environment and higher than standard in some others (Vandom-Uruoke, Cinoma-Okpilla, Bua-Okpilla, Ayetoro-pitting and Pettra-Ogben). Therefore, utilization of the studied soil may not cause any immediate health hazard to man but prolonged exposure might pose health challenges.

***Keywords***: Assessment, Mining pits, Background, Exposure, lifetime cancer risk.

## 1. Introduction

The race to finding an alternative source of income that is not only sustainable but ecologically benign is stronger than ever. Similarly, the exploration, exploitation and processing/transformation of solid

minerals also induce a paradigm shift in the radioisotope equilibrium of the ecosystem through the occurrence of Technologically Enhanced Radioactive Materials (TENORM). Abdu Hamoud *et. al.*, (2020), demonstrated the assessment of potential radiological risks due to natural gamma radiations in some selected rock samples in Aurangabad-India using gamma-ray spectrometry, he alluded that the mean activity concentrations of the $^{226}$Ra, $^{232}$Th, and $^{40}$K were 6.883, 10.841 and 128.616 Bq/kg, which is lower than the global average values of 35, 30, and 400 Bq/kg, indicating that the rocks of the study area are radiologically safe and may be used for construction without causing any threat to human health. Usikalu M. R. *et. al*., (2018) investigated the activity concentration of $^{238}$U, $^{40}$K and $^{232}$Th in soil samples from cement factory and environs using the NaI(TI) detector, in three zones in Ogun State, Nigeria and stated, that the activity concentrations obtained for the three zones are in the order 238U < 232Th < 40K respectively. The radiological parameters estimated from the activity measured were all within the recommended permissive limit except for the annual gonadal doses from the cement factory and its environs, which are higher than the global standard by the factors of 1.03 and 1.07 respectively.

Ibrahim (1999) reported that the radioactivity concentrations for Th and 40 K in the red clay brick samples from Malaysia were 241, 51 and 7541 Bq kg-1, respectively, whereas for the concrete samples were 51, 23 and 832 Bq kg-1, respectively. For granitic aggregate sources, Zakaria et al. (1993) reported that the average concentrations of $^{238}$U, $^{232}$Th and $^{40}$K in granite samples from The Main Range Granite in Peninsular Malaysia were 314, 221 and 1315 Bq kg-1, respectively. These values are higher than the world's average concentration values (33, 45 and 420 Bq kg-1) of $^{238}$U, $^{232}$Th and $^{40}$K in soil (UNSCEAR, 2000). Manigandan and Natrajan, (2014) studied the activity concentrations of natural radionuclides in Soils of Rainforest Sites in Western Ghats and reported that the obtained results for natural radionuclides calculated radiological parameters in the forest soils were within the range specified by UNSCEAR (2000) report for virgin soils except $^{232}$Th.

This study aimed at delineating the natural radioisotopes ($^{40}$K, $^{232}$Th and $^{238}$U) concentrations in soil samples collected from solid mineral mining pits across the six(6) LGA of Edo-North, using gamma-ray spectrometry technique with Sodium iodide [NaI(TI)] Detector and to evaluate its radiological hazards indices as it affect occupational and public health across the area.

## 2. Materials and Methods

### 2.1 Study Area

The study area is located at the northern part of Edo State, which falls within the north – east of Benin City, the State's Capital and it is the North Senatorial District of Edo State, Nigeria. Geographically, the study area lies approximately within the following coordinate intervals: Latitude (6°50'00''N - 7°31'30''N) and Longitude (6°31'10''E - 6°49'40''E). Structurally, the study area, Edo-North is made up of Six (6) Local Government Areas with administrative headquaters, viz: Akoko-Edo(Igara), Etsako-

East(Agenegbode), Etsako-Central(Fugar), Etsako-West(Auchi), Owan-East(Afuze) and Owan-West(Sabongida-Ora). Out of all the six LGAs five are involved in solid mineral mining business in commercial scale. These are Akoko-Edo, Etsako-East, Owan-West, Owan-East and Etsako-West LGAs are involved in quarry business in Edo-North (Figure 1).

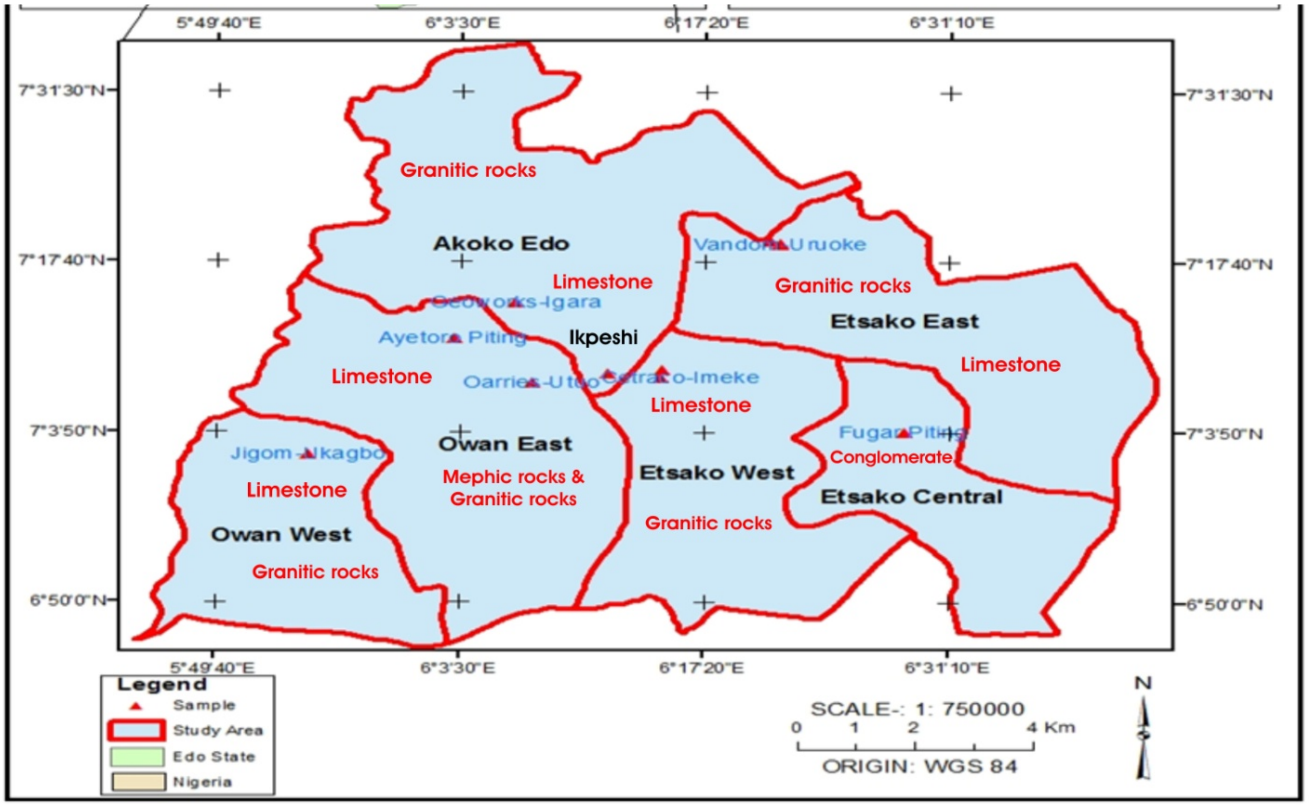


**Fig.1: Base Map of the study area, Edo North.**

## 2.2 Methods

### Sample Collection and Preparation

Two soil samples each were collected from the twelve mining pits investigated. The samples were collected using standard methods. At the point of sampling, the sampled soil were seal in a transparent polythene bag and labeled accordingly to avoid cross contamination before trans porting to the radiological laboratory (National Institute of Radiation Protection and Research centre (NIRPR), University of Ibadan) for instrumental analysis using gamma spectroscopy instrument. Before the instrumental analysis, the soil samples were air-dried at room temperature for two (2) week, then oven dried at a temperature of about 110 $^{o}$C to remove its moisture content and reduce the sample to a constant weight. The dried samples were then milled and sieved using a 2mm mesh screen to obtain a fine texture of soil samples. The sieved, smooth and dried soil samples were then sealed for a period of four weeks in merinelli bottle for secular

equilibrium. The soil samples were subjected to gamma spectroscopic counting to determine the radionuclide concentrations in the samples.

### 2.3. Sample analysis

The samples were analyzed at National Institute of Radiation Protection and Research Centre (NIRPR), University of Ibadan. Gamma Ray Spectrometry using a thallium activated 3"x3" Sodium iodide [NaI(TI)] detector connected to ORTEC 456 amplifier. The detector, enclosed in a 100mm thick lead shield, was connected to a computer program SAMPO 90 window that matched gamma energies to a library of possible isotopes. Since the accuracy of the quantitative measurements is depended on the calibration of the spectrometry system and adequate energy. Background measurement and efficiency calibration of the system was made possible using Cs -137 and Co-60 standard sources from IAEA, Vienna. Spectrum were accumulated for background for 29000s at 900volts to produce strong peaks at gamma emitting energies of 1460 keV for $^{40}K$; 609 keV of $^{214}Bi$ and 911 keV of $^{228}Ac$, which were used to estimate the concentration of $^{238}U$ and $^{232}Th$, respectively. The energy resolution of the detector using Cs -137 and Co-60 standards is 39.5% and 22.2% respectively while the activity of the standards at the time of calibration is 25.37 KBq for Cs -137 and 4.84 KBq for Co- 60. The background spectra, measured under the same conditions for both the standard and sample measurements, were used to correct the calculated sample activities concentration in accordance with Arogunjo *et al*., 2005. The activity concentration (C) in Bq/kg of the radionuclides in the samples was calculated after subtracting decay correction using the expression:

$$Cs = NEy \,/\, \varepsilon E\gamma \times Mv \times tc \times P\gamma \quad (Bq/kg) \qquad (1)$$

Where $C_S$= Sample concentration, NEy= net peak area of a peak at energy, $\varepsilon$Ey= Efficiency of the detector for a $\gamma$-energy of interest, Mv=Sample volume, tc= total counting time, $P\gamma$=Emission probability of radionuclide of interest.

### 2.4. Radiation Hazard Indices Calculation:

#### 2.4.1. Radium equivalent activity index ($Ra_{eq}$)

The radium equivalent (Raeq) was calculated using Equation (2) and it allows a single index or number to describe the gamma output from different mixtures of uranium, thorium, and $^{40}K$ in soil samples from different communities (Mahur *et al*., 2008). It is mathematically defined by (UNSCEAR, 2000):

$$Raeq = A_{Ra} + 1.43A_{Th} + 0.077A_K \qquad (2)$$

Where $A_{Ra}$, $A_{Th}$ and $A_K$ are the activity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ (Bq/kg), respectively

### 2.4.2. Representative level index ($I_{yr}$):

The representative level index, $I\gamma r$ is used to estimate the level of gamma radioactivity hazard associated with different concentrations of some radionuclide in specific investigated samples is known as the representative level index (UNSCEAR, 2000), which is given as

$$I_{yr} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (3)$$

Where $A_{Ra}$, $A_{Th}$ and $A_k$ are the concentrations of for $^{238}U$, $^{232}Th$ and $^{40}K$ respectively.

### 2.4.3. External hazard index ($H_{ex}$)

The external hazard index Hex, is used to estimate the level of radiological risk of the samples to the immediate environment. The value of Hex must be less than (unity) one (Ham lat *et al*., 2001). The value of Hex was calculated using the formula below:

$$Hex = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (4)$$

Where $A_{Ra}$, $A_{Th}$, $A_K$, are the average activity concentrations of $^{226}Ra$, $^{232}Th$ and $^{40}K$, respectively in Bq/kg as earlier defined.

### 2.4.4. Internal hazard index ($H_{in}$)

In addition to external hazard index, radon and its short- lived products are also hazardous to the respiratory organs. The internal exposure to radon and its daughter progenies is quantified by the internal hazard index Hin, which is given by the equation below (UNSCEAR, 2000).

$$Hin = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \quad (5)$$

Where $A_{Ra}$, $A_{Th}$, $A_K$, are the average activity concentrations of $^{226}Ra$, $^{232}Th$ and $^{40}K$, respectively in Bq/kg has earlier defined.

### 2.4.5. Absorbed doss rate (D):

The contribution of natural radionuclides to the abs orbed dose rate in air (D) depends on the natural specific activity concentration of $^{238}U$, $^{232}Th$ and $^{40}K$. The greatest part of the gamma radiation comes from terrestrial radionuclides. There is a direct connection between terrestrial gamma radiation and radionuclide concentrations (Kurnaza *et al*., 2007). If a radionuclide activity is known then its expos ure dos e rate in air at 1m above the ground can be calculated using the formula (UNSCEAR, 2000):

$$D = 0.462Au + 0.621\ A_{Th} + 0.0417A_k \quad (6)$$

Where D is the dose rate in $nGyh^{-1}$ and Au, $A_{Th}$ and $A_k$ are the concentrations of uranium, thorium and potassium, respectively. UNSCEAR, (2000) has given the dose conversion factors for converting the activity concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ into doses ($nGy.h^{-1}$ per $Bql^{-1}$) as 0.462, 0.621 and 0.0417, respectively.

**2.4.6. Annuall effective dose rate (outdoor):**

The annual effective dose ($mSvyr^{-1}$) was calculated using the formulas below (UNSCEAR, 2000). The annual effective dose equivalent was determined using the equation

$$\text{AED (Outdoor) } (mSvy^{-1}) = \text{Absorbed dose } (nGyh^{-1}) \times 8760\ h \times 0.7\ Sv/Gy \times 0.2$$

$$= \text{Absorbed dose } (nGyh^{-1}) \times 1.2264 \times 10^{-3} \quad (7)$$

where D is effective dose rate, (UNSCEAR, 2000) has recommended 0.7 Sv/Gy as the conversion coefficient from absorbed dose in air to effective dose and 0.2(5/24) as the value for the outdoor occupancy factor

**2.4.7. The Annual effective dose rate (indoor):**

The Annual effective dose rate (indoor) was calculated using the equation below

Effective dose ($mSvyr^{-1}$) = D ($\eta Ghyr^{-1}$) × $8760hyr^{-1} \times 0.7 \times$ (103mSv/109) ηGy $\times 0.8 \times 10^{-6}$…… (8)

The United Nation Scientific Committee on the effect of Atomic Radiation (UNSCEAR, 2000) has recommended 0.7 Sv/Gy as the conversion coefficient from absorbed dose in air to effective dose and 0.8(19/24) as the value for the indoor occupancy factor.

**2.4.8: Annual Gonadal Equivalent Dose (AGED)**

The Annual Gonadal Equivalent Dose (AGED)is a measure of the activity concentration in reproductive organs (such as testis or an ovary) from exposed of gross alpha and beta due to intake of a particular level of radiation from the water sampled. The annual gonadal equivalent dose (AGED) for members of the public can be calculated using the equation below (UNSCEAR, 2000).

$$\text{AGED} = \frac{AEDE}{RadiationWeighingFactor\ (We) \times TissuesWeighingFactor\ (Wt)} \quad (9)$$

Where $W_e$ for $\alpha$ – activity is equal to 20, $W_e$ for $\beta$ – activity is equal to 1

$W_t$ for Gonads is equal to 0.20

Gonad dose can be calculated from the radionuclide activity concentration using

$$\text{AGED} = 3.09CRa + 8760 \text{ x } 0.7 \text{ Sv/Gy x } 0.25 \text{ x } 10^{-9} \quad (10)$$

**2.4.9: Cancer Risks and Hereditary Effects**

The cancer and hereditary risk due to low dose without any threshold dose known as stochastic effect were estimated using the ICRP cancer risk model (ICRP, 2012). Radiation risk to population result

from exposure to low dose radiation are normally known as chronic risk of somatic or hereditary damage of human tissues, thus much emphasis is always placed on the reduction of these radiological risks to natural radiation. The nominal lifetime risk coefficient of fatal cancer recommended in the 2007 recommendations of the ICRP for members of the public is $5.5 \times 10^{-2}$ $Sv^{-1}$. For hereditary effects, the detriment adjusted nominal risk coefficient for the whole population as stated in ICRP for stochastic effects after exposure at low dose rates is estimated at $0.2 \times 10^{-2}$ $Sv^{-1}$.

The risk to population was then estimated using the recommended risk coefficient in ICRP report and assumed 70 years lifetime of continuous exposure of population to low level radiation. According to the ICRP methodology:

Cancer Risk = Total annual Effective Dose (Sv) x cancer risk factor (11)

Hereditary Effects = Total annual Effective Dose (Sv) x hereditary effect factor (12)

## 3. Results and Discussions

The activity concentration of $^{40}K$, $^{238}U$ and $^{232}Th$ in soil from mining sites are presented in Table 2.

**Table 2: Mean Specific activity concentration of $^{40}$ K, $^{238}$U and $^{232}$Th (Bq/kg) Results in Soil Samples.**



| S/N | Sample Code | Location | K-40 (Bq/Kg) | U-238 (Bq/Kg) | Th-232 (Bq/Kg) | Raeq (**Bq/kg**) |
|---|---|---|---|---|---|---|
| 1 | CO-$S_1$ | Okpilla | 260.23±14.22 | 70.05±7.51 | 13.65±0.83 | 109.6072 |
| 2 | CO-$S_C$ | Etsako-East | 260.86±14.17 | 197.3±19.21 | 11.75±0.72 | 234.1887 |
| 3 | VU- $S_1$ | Uruoke | 2081.09±108.29 | 13.55±1.76 | 20.78±1.25 | 203.5093 |
| 4 | VU- $S_C$ | Etsako West | 2004.96±104.16 | 18.63±2.36 | 12.14±0.74 | 190.3721 |
| 5 | GI- $S_1$ | Igara | 534.13±28.32 | 0.68±0.10 | 3.7±0.23 | 47.09901 |
| 6 | GI- $S_C$ | Akoko-Edo | 216.34±11.52 | 17.83±2.29 | 13.43±0.81 | 53.69308 |
| 7 | AP- $S_1$ | Ayetoro | 1749.12±90.87 | 4.63±0.61 | 18.24±1.09 | 165.3954 |
| 8 | AP- $S_C$ | Owan-East | 1772.95±92.00 | 18.53±2.32 | 15.7±0.95 | 177.4982 |
| 9 | FI- $S_1$ | Ikpeshi | 129.3±6.88 | 7.98±1.10 | 12.1±0.73 | 35.2391 |
| 10 | FI- Sc | Akoko-Edo | 259.1±13.81 | 18.5±2.55 | 14.41±0.87 | 59.057 |
| 11 | CI- $S_1$ | Imeke | 643.49±34.04 | 4.78±0.71 | 9.4±0.57 | 67.77073 |
| 12 | CI- $S_C$ | Etsako-West | 524.47±27.62 | 22.98±2.70 | 16.02±0.96 | 86.27279 |
| 13 | FP- $S_1$ | Fugar | BDL | 9.08±1.30 | 3.32±0.20 | 13.8276 |
| 14 | FP- $S_C$ | Etsako-Central | BDL | 20.25±2.65 | 8.96±0.54 | 33.0628 |
| 15 | JU- $S_1$ | Ukagbo | 721.12±37.98 | 30.88±3.78 | 9.69±0.59 | 100.2629 |
| 16 | JU- Sc | Owan-West | 817.81±42.95 | 24.23±3.03 | 21.63±1.30 | 118.1323 |
| 17 | BO- $S_1$ | Ogbo-Okpilla | 764.89±40.04 | 28.85±3.61 | 17.66±1.06 | 113.0003 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 18 | BO- $S_C$ | Etsako-East | 1097.98±57.37 | 16.5±2.04 | 9.99±0.10 | 115.3302 |
| 19 | OU- SC | Utuo | 542.91±28.97 | 23.50±3.55 | 19.07±1.16 | 92.57417 |
| 20 | OU- $S_C$ | Owan-East | 755.73±40.07 | 8.00±1.13 | 15.16±0.92 | 87.87001 |
| 21 | PIO- $S_1$ | Ihieube-Ogben | 3137.18±162.21 | 11.75±1.51 | 12.63±0.76 | 271.3738 |
| 22 | PIO- $S_C$ | Owan-East | 2883.72±149.31 | 52.08±5.80 | 17.69±1.07 | 299.4231 |
| | | **Mean** | **961.5±55.24** | **28.2±3.25** | **12.9±0.79** | **121.6** |
| UNSCEAR, (2000)STANDARD | | | 400 | 35 | 30 | 370 |

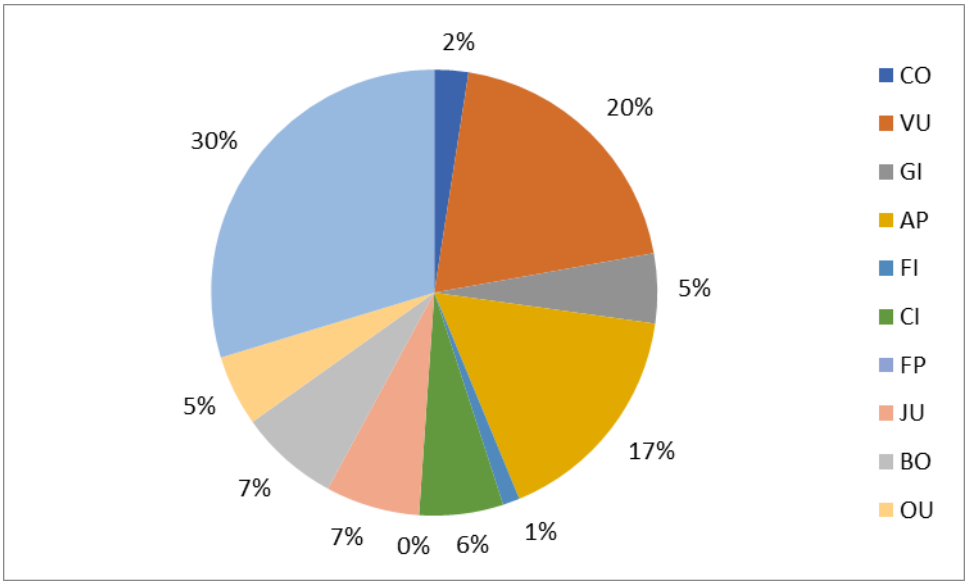


**Fig 2: Percentage Contributions of $^{40}K$ to the overall concentrations at the Different Mining Locations.**

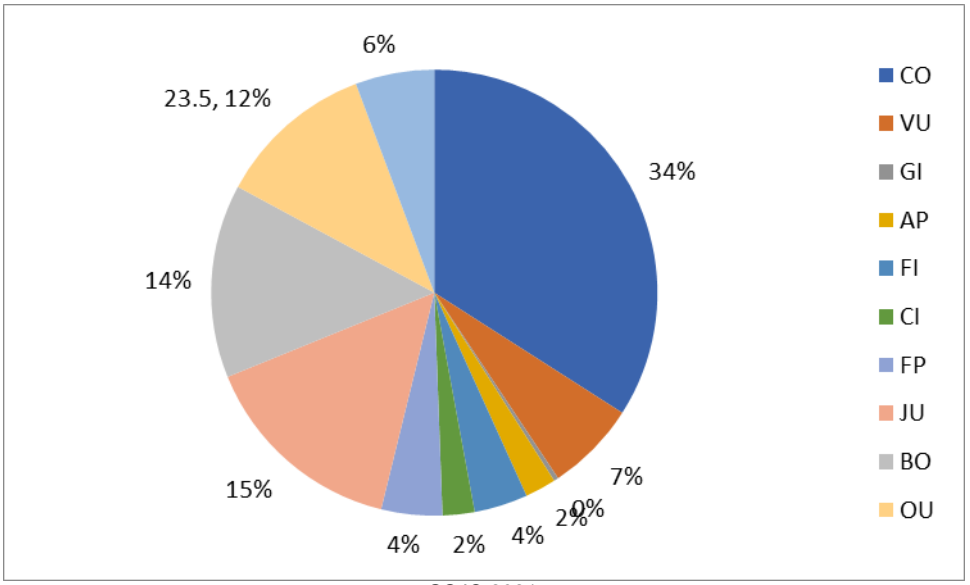

**Fig 3: Percentage Contributions of $^{238}U$ to the overall concentrations at the Different Mining Locations**

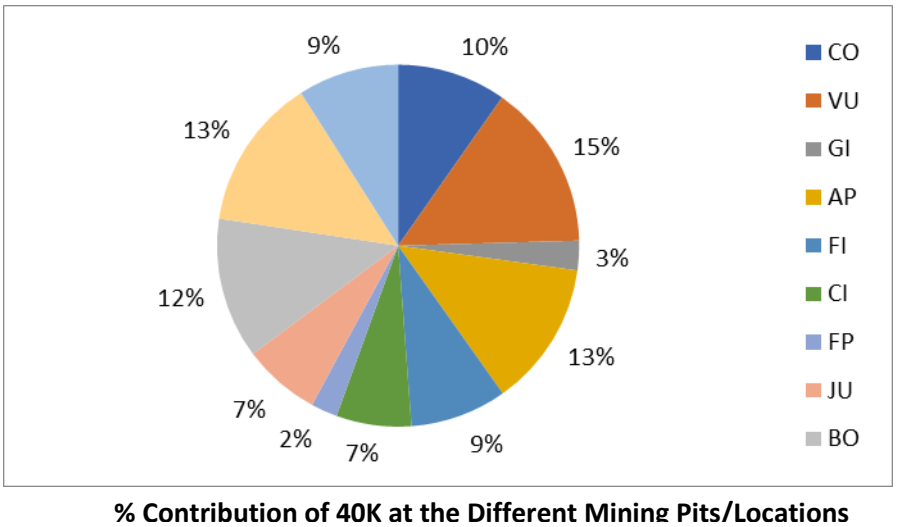


**Fig 4: Percentage Contributions of $^{232}Th$ to the overall concentrations at the Different Mining Locations.**

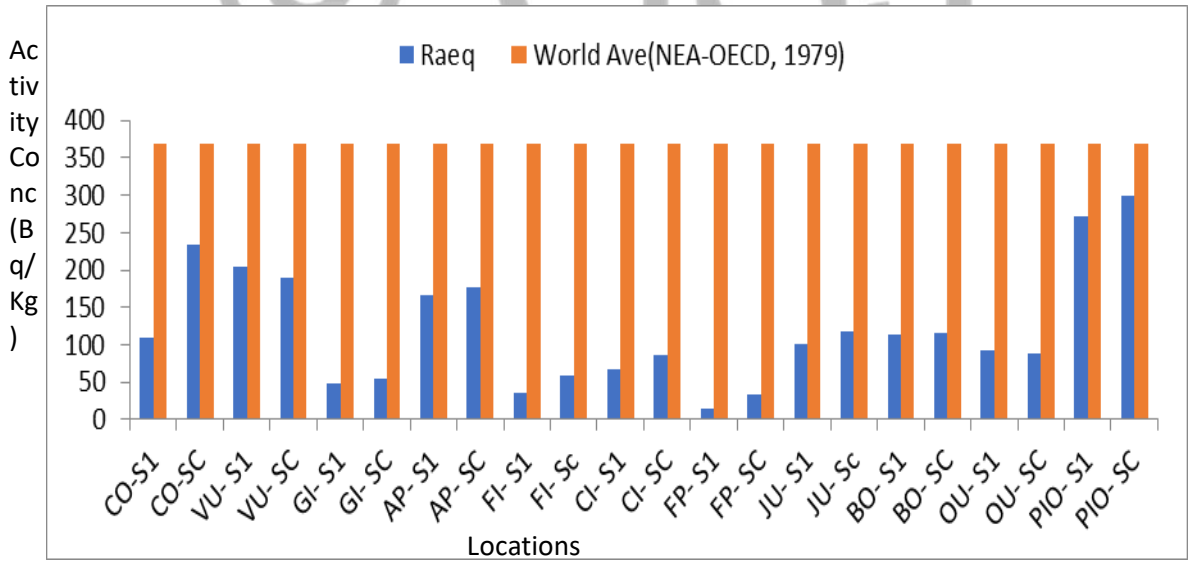


**Fig 5: Comparison of activity concentration of Raeq in soil samples with NEA-OECD, 1979 Standard across the study area.**

**Table 3: Radiological Hazard and Level Indices calculated in soil samples from the study area.**

| S/N | Sample Code | Hazard Indices | | Level Indices | | AEDE | Activity Utilization index | ELCR | AGDE |
|---|---|---|---|---|---|---|---|---|---|
| | | $(H_{ext})^a$ | $H_{in}$ | Iext-γ | Iint-α | ($\mu Svy^{-1}$) | I | x $10^{-3}$ | ($mSvy^{-1}$) |
| 1 | CO-$S_1$ | 0.296 | 0.776 | 0.388 | 0.350 | 0.06 | 0.472 | 0.15 | 355.2 |
| 2 | CO-$S_C$ | 0.632 | 1.607 | 0.803 | 0.986 | 0.13 | 0.661 | 0.32 | 740.6 |
| 3 | VU- $S_1$ | 0.549 | 1.686 | 0.843 | 0.068 | 0.13 | 2.049 | 0.33 | 782.1 |
| 4 | VU- $S_C$ | 0.514 | 1.582 | 0.791 | 0.093 | 0.12 | 1.908 | 0.31 | 737.8 |
| 5 | GI- $S_1$ | 0.127 | 0.398 | 0.199 | 0.003 | 0.03 | 0.506 | 0.08 | 185.2 |
| 6 | GI- $S_C$ | 0.145 | 0.397 | 0.199 | 0.089 | 0.03 | 0.348 | 0.08 | 179.2 |
| 7 | AP- $S_1$ | 0.446 | 1.379 | 0.689 | 0.023 | 0.11 | 1.719 | 0.27 | 639.8 |
| 8 | AP- $S_C$ | 0.479 | 1.462 | 0.731 | 0.092 | 0.11 | 1.738 | 0.28 | 679.6 |
| 9 | FI- $S_1$ | 0.095 | 0.260 | 0.130 | 0.039 | 0.02 | 0.242 | 0.05 | 115.8 |
| 10 | FI- Sc | 0.159 | 0.440 | 0.220 | 0.092 | 0.03 | 0.396 | 0.08 | 198.8 |
| 11 | CI- $S_1$ | 0.183 | 0.554 | 0.277 | 0.024 | 0.04 | 0.663 | 0.11 | 256.1 |
| 12 | CI- $S_C$ | 0.233 | 0.663 | 0.332 | 0.115 | 0.05 | 0.652 | 0.13 | 302.7 |
| 13 | FP- $S_1$ | 0.037 | 0.093 | 0.047 | 0.045 | 0.01 | 0.046 | 0.02 | 41.9 |
| 14 | FP- $S_C$ | 0.089 | 0.224 | 0.112 | 0.101 | 0.02 | 0.119 | 0.04 | 100.0 |
| 15 | JU- $S_1$ | 0.271 | 0.783 | 0.392 | 0.154 | 0.06 | 0.776 | 0.15 | 362.4 |
| 16 | JU- Sc | 0.319 | 0.923 | 0.462 | 0.121 | 0.07 | 0.965 | 0.18 | 422.1 |
| 17 | BO- $S_1$ | 0.305 | 0.879 | 0.439 | 0.144 | 0.07 | 0.888 | 0.17 | 403.1 |
| 18 | BO- $S_C$ | 0.311 | 0.941 | 0.471 | 0.083 | 0.07 | 1.087 | 0.18 | 437.5 |
| 19 | OU- SC | 0.250 | 0.709 | 0.355 | 0.118 | 0.06 | 0.698 | 0.14 | 322.8 |
| 20 | OU- $S_C$ | 0.237 | 0.709 | 0.354 | 0.040 | 0.06 | 0.822 | 0.14 | 325.4 |
| 21 | PIO- $S_1$ | 0.732 | 2.296 | 1.148 | 0.059 | 0.18 | 2.895 | 0.45 | 1074.2 |
| 22 | PIO- $S_C$ | 0.809 | 2.446 | 1.223 | 0.260 | 0.19 | 2.787 | 0.48 | 1140.4 |
| | **Mean** | **0.328** | **0.964** | **0.478** | **0.141** | **0.08** | **1.019** | **0.19** | **445.6** |

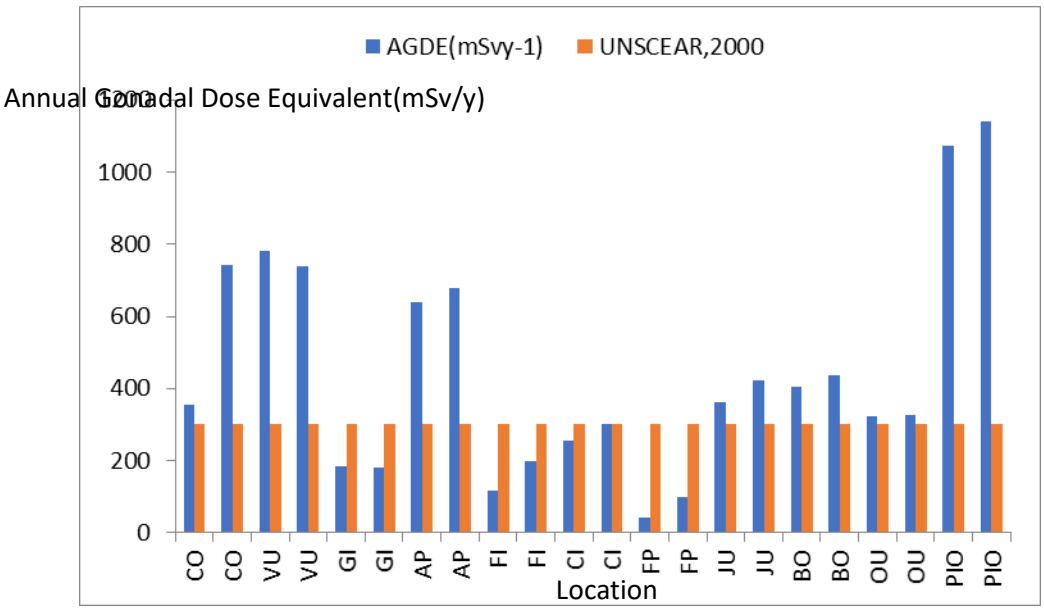


**Fig 6: Comparison of Annual Gonadal Dose Equivalent in Soils in the different Mining Pits/Communities with UNSCEAR World Standard.**

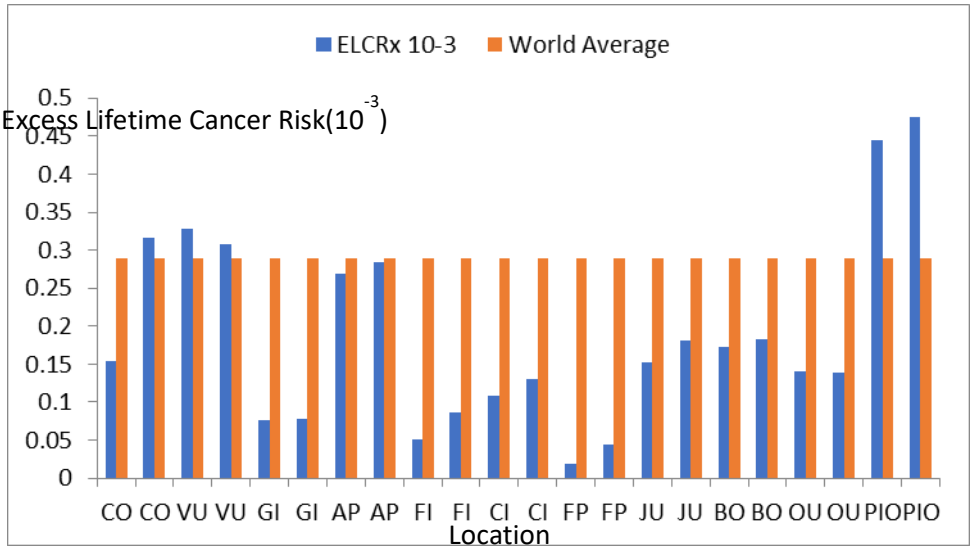


**Fig 7: Comparison of Excess Life Cancer Risk of Soils in the different Mining Pits/Communities with UNSCEAR World Standard.**

The mean activity concentration results of naturally occurring radionuclide of $^{40}K$, $^{232}Th$, and $^{238}U$ measured in solid mineral mining area of Edo-North Nigeria are shown in Table 2. The mean activity concentration of $^{40}K$ in soil samples have its lowest value as 0.00 $Bqkg^{-1}$ at Fugar-Pitting where conglomerates are mined and its highest value as 3137.18±162.21 $Bqkg^{-1}$ at Pettra-Quary-Ogben, with average value of 961.5 ± 55.24 $Bqkg^{-1}$. The mean activity concentrations of $^{238}U$ in soil samples have its lowest value as 0.68±0.10 $Bqkg^{-1}$ at Geoworks-Igara and its highest value as 197.3±19.21 $Bqkg^{-1}$ at Cinoma-Okpilla with average value of 28.2±3.25 $Bqkg^{-1}$. Lastly, the specific activity concentration of $^{232}Th$ in soil samples have its lowest value as 3.7±0.23 $Bqkg^{-1}$ at Geoworks Igara and its highest value as 21.63±1.30 $Bqkg^{-1}$ at Jogom-Ukagbo with average value of 12.9±0.79 $Bqkg^{-1}$. Comparing the obtained average results of soil samples of $^{40}K$, $^{232}Th$, and $^{238}U$ with UNSCEAR, 2000 standard, it was deduced that the obtained average results of $^{40}K$, towered above the recommended standard of 412.0 $Bqkg^{-1}$ while $^{232}Th$, and $^{238}U$ is lower than the recommended standard of 45 $Bqkg^{-1}$ and 33 $Bqkg^{-1}$. The anomalous high value of activity concentration may be attributed to the agricultural activity that is taking place across the study area, as NPK fertilizer being used in enriching the soils could be leached into the mining pits, which could account for the high value of $^{40}K$ being delineated in the study. The mean radium equivalent calculated from activity concentration of $^{40}K$, $^{232}Th$, and $^{238}U$ using equation 2 in soil samples is shown in Table 2.

Gamma index (Iγ) ranged from 0.047 to 1.223. All the samples of soil from different locations area are lower than the stipulated safe limit of ≤ 1 except locations PIO. The alpha index (Iα) ranged from 0.003 to 0.986. The values are also below the safe limit of unity as well. Fig. 9 shows the representation of the activity utilization index (I) of soil in all the mining pits investigated. Results shows that the activity utilization index (I) of most of the soil samples are less than unity except samples VU, AP and PIO where we infer spurious values of activity utilization Index. Locations JU and BO also have values tending towards unity, implying that the use of such soil as a building material will not pose any radiological risk in places where I ≤ 1 and vice-versa for places, such as VU, AP and PIO where I>1 respectively.

Results of the annual effective dose equivalent (AEDE) as calculated from equation-7 are presented in column 5 of Table 3. Obtained values ranged from 0.01 to 0.19 $\mu Svy^{-1}$ with most of the samples having values far lower than the safe limit of 0.48 $mSvy^{-1}$. The annual gonadal dose equivalent (AGDE) in soil samples ranged from 41.9 to 1074.2 $mSvy^{-1}$. The obtained AGDE in the samples are were found higher than the safe value of 300 $mSvy^{-1}$, except sample GI, FI, CI and FP where readings were found to be within safe-limit. The excess lifetime cancer risk calculated varied from $0.02 \times 10^{-3}$ to $0.48 \times 10^{-3}$. These values of ELCR were found lower than the safe limit of. $0.29 \times 10^{-3}$, excepting VU and PIO where we have elevated values. This means that in 100years time the mining site may still be safe for further use, except where other radiological indices shows otherwise.



## 4. Conclusion

Gamma Spectrometry using Sodium Iodide (Thallium) will continue to be popular for delineating the activity concentration of primordial isotopes $^{40}K$, $^{232}Th$, and $^{238}U$ present in soils/water underlying solid minerals mining environment such as Edo-North.

Findings shows that the deduced average activity concentrations and the estimated radiological hazard indices of the analyzed samples exhibited radiological parametric lows in comparison with the allowable standard limits, except at some of the pits such as Vandom-Uruoke, Bua-Okpilla, Ayetoro-Pitting, Petra-Ihieube-Ogben etc were results appears higher than the acceptable standard (Table 2&3, Figure 2-7). It may also be deduced that the radioactivity of the natural radionuclides follows the sequence $^{40}K < ^{238}U < ^{232}Th$, with K giving the lowest contribution to the different exposure pathways, despite its high activity concentrations across the various mining locations (average 961.5±55.245 $Bqkg^{-1}$). It may be observed also that mining pits with radiological parametric-high offers hot spot to radiation exposures to man and environment. Therefore, solid mineral mining operators should endeavour to integrate all available infrastructures in its mineral

exploitation business, so as to keep radiation exposure to man and environment as-low-as-reasonable-acceptable(ALARA), which is the hallmark of the Principle of Radiation Protection.

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