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## Research Article

**Keywords:** Radioactivity, Mineral, Soil, Percentage contribution, Mining area.

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# Assessment of Solid Mineral to Soil Radioactivity Contamination Index in selected Mining Sites and their Radiological Risk Indices to the Public

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## Abstract

This study examined the radioactivity levels of soil samples within selected solid mining sites in Nigeria using high purity germanium (HpGe) detector. Sixty soil samples in all were collected from the ten solid mineral mining sites investigated and six samples were collected as control samples from non-mining environment for analyses. The results of the activity concentration values obtained for <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th are 100.22 Bq kg<sup>-1</sup>, 33.15 Bq kg<sup>-1</sup> and 77.31 Bq kg<sup>-1</sup> respectively. The <sup>226</sup>Ra and <sup>40</sup>K activities were found to be within the United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) acceptable permissible limit, but the <sup>232</sup>Th mean value was above the permissible limit of 30 Bq kg<sup>-1</sup> for the public. In comparison, <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th soil samples mean activity concentrations were higher than the control soil samples values by 48.6%, 43.7% and 62.3% respectively. The results of estimated radiation hazard indices indicate average values of 150.72 Bq kg<sup>-1</sup>, 68.40ηGyh<sup>-1</sup>, 83.65μSvy<sup>-1</sup> and 454.70μSvy<sup>-1</sup> for the Radium Equivalent (Ra<sub>eq</sub>), Absorbed Dose Rate (D), Dose Equivalent (AEDE) and Annual Gonadal Equivalent Dose (AGED) respectively. The mean values for External Hazard Indices (Hex, Hin), Representative Gamma index (I<sub>γ</sub>) and Excess Life Cancer Risk (ELCR) were 0.41, 0.50, 1.06 and 0.29 x10<sup>-3</sup> respectively. The statistical analysis shows positive skewness.

**Keywords:** Radioactivity, Mineral, Soil, Percentage contribution, Mining area.

## 1.0 Introduction

Assessment of background radioactivity level plays a significant role in the protection of man from excessive radiation exposure (Abodunrin *et al.*, 2017). Natural background radiation levels are likely to vary with human activities and natural processes, it may also change with locations due to different mineralogical, deformational and climatic factors responsible for the syngenetic processes for mineral formation. Although natural background radiation level is time dependent, it does not depend on any constant level, because it is terrestrial and cosmic induced (Ahmed *et al.*, 2020). Radioactivity levels are evaluated as part of national and international survey at different areas and countries of the world, for radiation protection (Mane *et al.* 2014; Ugbede, 2020).

1 Naturally occurring radionuclide materials (Norms) are inherent in many geologic materials  
2 and consequently encountered during geologically related activities. Since radioactive  
3 materials are prevalent in many minerals and soil formation and in the water that meets them,  
4 extraction and processing of these mineral resources that emanate from these sources exposes  
5 and raises the concentration of naturally occurring radionuclide in the environment (*Avwiri, et*  
6 *al., 2012*). Exposure to high radiation level causes a wide range of health problems such as  
7 cancer of the lung, bone and skin, kidney ailments and blood infections (*Kessaratikoon, et al.,*  
8 *2013; UNSCEAR, 2016*). Other problems associated with high exposure to ionizing radiations  
9 to health include; alteration in the structure and functions of the cells and organs, deterministic  
10 effect, stochastic effects, irritations, sensitization, embryonic effects, etc. The knowledge of  
11 radionuclide distribution in the environment is therefore of immense benefits in assessing the  
12 effects of radiation exposure, thus, monitoring of radioactive materials are of primary  
13 importance to man and for the protection of the environmental (*Avwiri et al., 2012; Emelue et*  
14 *al., 2014; Dolchinkov and Nichev, 2017*).

15 Most mineral deposits are associated with radionuclide like uranium, thorium and its'  
16 progenies. Primary uranium ore minerals when weathered, oxidized or decompose and form  
17 secondary uranium minerals which on interaction with groundwater drift and contaminate the  
18 soil, water and aquatic bodies, even some distance away from the original source (*Aliyu et al.,*  
19 *2015*). They are also found in conglomerates, shale, limestone, sediment and hydrocarbon  
20 (*Xhixha et al., 2015*). Because minerals are found in within a host rock, there is the tendency  
21 that the immediate soil when weathered these minerals are found content an appreciable  
22 amount of radionuclides found in these minerals due to radioactivity transfer. Soil radioactivity  
23 concentration is one of the main determinants of the natural occurring radiation (*Agbalagba et*  
24 *al., 2012; Ugbede, 2020*). Measurement of the radioactivity level of some rock samples,  
25 potential sources rocks of hydrocarbons have been conducted in different parts of the world  
26 (*Silo et al., 2013; Guidotti et al., 2015*). They reported that the radioactivity concentrations of  
27 the radionuclides from the eastern region were generally low compared to that of the other  
28 regions, but Th-232 was identified as the major contributor of the dose that can be received  
29 from the environment.

30 When minerals are disintegrated through either natural or anthropogenic processes,  
31 radionuclides are liberated into the soil by rain infiltration and percolation processes (*Taskin et*  
32 *al., 2009*). It has been established from previous studies that some of these soil and minerals  
33 such as monazite, pyrochlore and xenotime, which are obtained as byproducts of tin mining

1 are radioactive, (*Eroglu and Kabadayi 2013, Ekeocha, 2016; Kritsananuwet et al., 2015;*  
2 *Omotehinse and Ako, 2019*). Exposure to radiations emitted by some of these radioactive  
3 minerals is a major source of health hazards (*Charro et al., 2013; Todorovic 2015*). However,  
4 some of these mining sites had persons do business and living in hunts around them, which  
5 overtime have developed into hamlets and villages where elevated level of radiation has been  
6 recorded. Literatures abound on research works that have been undertaken to precisely quantify  
7 the amount of radioactivity levels in different soil and solid minerals found in Nigeria in recent  
8 time (*Avwiri et al., 2010; Sadiq and Agba, 2011; Agbalagba et al., 2012; Ademola and Onyema,*  
9 *2014; Azionu et al., 2019; Babatunde et al., 2019;*) and some countries of the world for  
10 radiation protection (*Ragheb, 2007; Belivermis, 2012; Charro et al., 2013; Kovacs et al., 2013;*  
11 *Santawamaitre et al., 2014; Guidotti et al., 2015; Milenkovic et al., 2015; Todorovic et al.,*  
12 *2015; Kavitha et al., 2016*). In the Northern and Western Nigeria, a sizeable number of research  
13 work have been conducted in this regard (*Ademola and Obed, 2012; Innocent et al., 2013;*  
14 *Ademola et al., 2014*), while little or nothing has been done in the eastern region of the country  
15 with rich solid mineral present. It is worth mentioning that investigation on the level of dosage  
16 and excess level of radiation in the risk of cancer in this area has been reported in previous  
17 studies (*Wahsha et al., 2016; Ugbede and Echeweozo 2017; Ugbede, 2020; Ugbede and*  
18 *Osahon, 2021*). This has necessitated the focus of this research work on the Eastern region of  
19 Nigeria. Moreso, most of these studies focused on radioactivity concentration in solid mineral  
20 with little or no attention given to the measurement of radioactivity levels in the soil where the  
21 minerals are found and which the public make greater contact with for farming, building and  
22 other domestic uses.

23 The government of Nigeria in recent time are making deliberate efforts to revamp mining  
24 activities in these long abandoned mineral resources mining sites to boost the internally  
25 generated revenues (IGR) of these States and for regional developed and integration, though  
26 according to the Nigerian Mining Act (2007), all mineral resources regardless of where they  
27 are occurring it is under the control of the Federal Government. But the growing concern of  
28 the radiation safety and health status of those living and working within these mineral mining  
29 environments are always not put into consideration in the planning and implementation of  
30 mining companies and government. This lend credence to this research work, because results  
31 obtained will serve as baseline data in these study areas and data obtained shall be sources of  
32 reference for future radiological impact evaluation studies, serving as data base which may be  
33 incorporated to Nigeria Nuclear Regulatory Agency (NNRA) resources for National Planning.

## 1 **2.0 Materials and Methods**

### 2 **2.1 Location of Study Area**

3 Mineral resources abound in different part of Nigeria, proper harnessing of the resources based  
4 on the host rocks as presented in the Figure 1, hence giving rise to the different types of mineral  
5 deposits as shown in Figure 2. To conform to international best practices is the greatest  
6 challenge of the industry (see Figure 2). This study was conducted in five Eastern Geopolitical  
7 Zone (Made up of Abia, Anambra, Ebonyi, Enugu and Imo States). The region lies between  
8 longitudes 7° 6" E and 7° 54" E and latitudes 5° 56" N and 6° 52" N. It encompasses an area of  
9 about 7161km<sup>2</sup> with elevation ranging from 32.0m to 590.2m above mean sea level (*Osimobi*  
10 *et al.*, 2018). The region has two main landforms viz; a high relief central zone with undulating  
11 hills and ridges and lowland area. The high relief zone is geologically associated with the  
12 syncline composed of Ajali Sandstone and Nsukka Formation, while the eastern lowland zone  
13 is associated with rocks of Asu River group, Eze Aku Shale group, Awgu/Ndeabor Shale group,  
14 Asata/Nkporo Shale group and parts of Mamu Formation (*Osimobi et al.*, 2018).

15

### 16 **2.2 Sample Collection and Preparation Techniques**

17 Soil samples were collected from coal and silica mining sites in Ewe in arochukwu in Abia  
18 State, glass-sand mine in Mbara-Ozu sand sites in Ihiala in Anambra State, limestone and iron-  
19 stone mine in Akpuoach and Ishiagu sites in Ebonyi State. Soil samples were also collected  
20 from bitumen, coal and gypsum mine Ezeagu, Udi and Aninri sites in Enugu State, and clay  
21 and kaolin mine Isu and Okigwe sites in Imo State. A total of forty-eight soil samples were  
22 collected in all, and one control sample each from a non-mineral mining location from the five  
23 states. The soil samples were collected at depths of 0 to 10 cm (which represents the soil  
24 permeability to particle settlement depth variation), within the different mineral mine sites in  
25 black paper bags (to prevent interaction with sunlight to avoid breaking down of the  
26 radionuclides present). The soil samples collected were spread on stainless still sheets at  
27 ambient temperature for seven days to dry in a controlled environment to prevent local dust  
28 contamination. Samples were further dried in an oven at regulated temperature of 60°C to attain  
29 a constant weight.

30 The dried samples were then grounded using mortar and pestle to pulverize form and then  
31 filtered using 100-mesh sieve. At each interval of pulverization, the pestle and mortar were  
32 clean using methylated spirited to avoid crossed contamination. The dried homogeneously  
33 pulverized samples with dry-weight of 250 g were filled in air tight cylindrical plastic container

1 (Marinelli beaker) that is of the detector geometry, and stored for a period of 28 days before  
2 counting to allow for secular equilibrium to be attained between  $^{226}\text{Ra}$  and its short lived  $^{222}\text{Rn}$   
3 progeny (Zarie and Al Mugren, 2010; Avwiri et al., 2012; Ononugb et al., 2017; Wang, et al.,  
4 2017; Ugbede, 2020).

5  
6

### 7 **2.3 Radioactivity Analysis of Samples**

8 The soil samples analysis for the natural radionuclide concentration were carried out using a  
9 computerized  $\gamma$ -ray spectrometry system with high purity germanium (HpGe) detector. The  
10 relative efficiency of the detector system was 39% and resolution of 1.8 keV at 1.33 MeV of  
11 Co-60. The spectrometer was attached to conventional electronics connected to a multichannel  
12 analyzer (MCA) card installed in a laptop computer. MAESTRO-32 software program was  
13 deployed to accumulate and analyze the data of the natural radionuclides present in the samples.  
14 The detector is located inside a cylindrical lead shield of 5 cm x 24 cm x 60 cm geometry. The  
15 metal (lead) shield was lined with different coatings of copper, cadmium and Plexiglas, of  
16 thickness 3 mm each. A counting time of 10 hours was adopted from the system calibration  
17 result for the acquire samples spectral data.

18 The high resolution of the HpGe detector made it possible to identify many  $\gamma$ -rays of the  
19 analyzed samples. The radioactivity levels of the uranium series were obtained using  $\gamma$ -ray  
20 emissions of  $^{214}\text{Pb}$  at 351.9 keV (35.9%) and  $^{214}\text{Bi}$  at 609.3 keV (44.9%), for the  $^{232}\text{Th}$ -series,  
21 the emissions of  $^{228}\text{Ac}$  at 911 keV (26.6%),  $^{212}\text{Pb}$  at 238.6 keV (43.2%) and  $^{208}\text{Tl}$  at 583 keV  
22 (30.2%) and were used as the radionuclide emission probabilities of  $\gamma_p$ . The  $^{40}\text{K}$  activity levels  
23 was acquired straight from its emission line of 1460.8 keV (10.7%). The background spectra  
24 measured were used to correct the computed sample activities concentration in accordance with  
25 standard procedures (Zarie and Al Mugren, 2010, Avwiri et al., 2012 and Ononugbo et al.,  
26 2017).

27 The radioactivity content ( $A_c$ ) in  $\text{Bq kg}^{-1}$  of the radionuclides were computed after decay  
28 correction was made using the expression (Adamu et al., 2013).

$$29 \quad A_c = \frac{N_p}{\varepsilon_{ff} \times M_s \times T_c \times \gamma_p} \text{ Bqkg}^{-1} \quad (1)$$

30 Where;  $A_c$  is the sample activity concentration,  $N_p$  is the net peak area of a peak at energy,  $\varepsilon_f$  is  
31 the efficiency of the detector for a  $\gamma$ -energy of interest,  $M_s$  is the sample mass,  $T_c$  is the total  
32 counting time and  $\gamma_p$  is the emission probability of radionuclide of interest.

## 1 **2.4. Radiological Hazard Indices**

### 2 **2.4.1 Radium Equivalent Activity ( $Ra_{eq}$ )**

3  
4 The radium equivalent ( $Ra_{eq}$ ) activity is the measured number of activities of the natural  
5 radionuclides (Radium, Thorium, Potassium) and is established on the proven fact that 1 Bq  
6  $kg^{-1}$  of  $^{226}Ra$ , 0.7 Bq  $kg^{-1}$  of  $^{232}Th$ , and 13 Bq  $kg^{-1}$  of  $^{40}K$  generate equal radiation dose rates  
7 (*Osimobi et al., 2018*). Radium equivalent ( $Ra_{eq}$ ) equates the specific activity levels of the  
8 sample contained in the three natural radioactivity ( $^{40}K$ ,  $^{226}Ra$  and  $^{232}Th$ ) by a sole amount and  
9 account for the radiological risk (*Agbalagba et al., 2012*). The index is very useful in regulating  
10 safe allowable standards and is estimated using the expression (*Kavitha et al., 2016*):

$$11 \quad Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_k \quad (2)$$

12 where  $Ra_{eq}$  ( $Bq\ kg^{-1}$ ) is the radium equivalent,  $C_{Ra}$ ,  $C_{Th}$  and  $C_k$  are the activity levels ( $Bq\ kg^{-1}$ )  
13 of  $^{226}Ra$ ,  $^{232}Th$ , and  $^{40}K$  respectively. Every material or environment whose  $Ra_{eq}$  values  
14 exceed 370  $Bq\ kg^{-1}$  is strongly advised to be avoided (*Wang et al., 2017*).

### 15 **2.4.2 Absorbed Dose Rate ( $D_R$ )**

16 The outdoor ( $D_R$ ) is the gamma emission in air which represents an even dispersal of  $^{40}K$ ,  $^{226}Ra$   
17 and  $^{232}Th$ . The outdoor ( $D_R$ ) value is computed using the guidelines given by *UNSCEAR* and  
18 is expressed as (*Ashraf et al., 2010; UNSCEAR 2010*):

$$19 \quad D_R = 0.462C_{Ra} + 0.621C_{Th} + 0.0417C_K \quad (3)$$

20 where  $D_R$  ( $\eta Gy\ h^{-1}$ ) is the outdoor dose rate,  $C_k$ ,  $C_{Ra}$ ,  $C_{Th}$ , are the activity content levels in  
21 ( $Bq\ kg^{-1}$ ) for  $^{40}K$ ,  $^{226}Ra$  and  $^{232}Th$ , respectively.

22 *UNSCEAR (2010)* reported that the global permissible limit value of absorbed dose for the  
23 public should be 59  $nGy\ h^{-1}$ .

### 24 **2.4.3 Annual Gonadal Equivalent Dose (AGED)**

25 Protecting the vital organs outer layers is of key importance to the radiation community  
26 (*UNSCEAR 2000; 2010*). The AGED is estimated using equation 4:

$$27 \quad \mathbf{AGED} = \mathbf{3.09C_{Ra}} + \mathbf{4.18C_{Th}} + \mathbf{0.314C_k} \quad (4)$$

28 where AGED is the Annual Gonadal Equivalent Dose ( $mSv\ y^{-1}$ ), and  $C_{Ra}$ ,  $C_{Th}$ , and  $C_k$  ( $Bq\ kg^{-1}$ )  
29 are the radioactivity levels of  $^{226}Ra$ ,  $^{232}Th$ , and  $^{40}K$ , respectively.

### 1 2.4.3 Hazard Index (External $H_{ex}$ )

2 The hazard index ( $H_{ex}$ ) was a derivative of the  $Ra_{eq}$  calculation with the assumption that the  
3 maximum permissible value agrees with the  $370 \text{ Bq kg}^{-1}$  upper limit of  $Ra_{eq}$  value, with its  
4 equivalent radiation dose value limited to  $1.0 \text{ mSv y}^{-1}$ . The ( $H_{ex}$ ) index is computed applying  
5 the expression (Wang et al., 2016):

$$6 H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_k/4810 \quad (5)$$

7 where  $H_{ex}$  is the external hazard index ( $\text{Bq kg}^{-1}$ ), and  $C_k$ ,  $C_{Ra}$  and  $C_{Th}$  are the  
8 radioactivity levels in ( $\text{Bq kg}^{-1}$ ) for  $^{40}\text{K}$ ,  $^{226}\text{R}$  and  $^{232}\text{Th}$  respectively.

### 9 2.4.5 Internal Hazard Index ( $H_{in}$ )

10 The internal index ( $H_{in}$ ) is estimated as (Kavitha et al., 2016):

$$11 H_{in} = C_{Ra}/185 + C_{Th}/259 + C_k/4810 \quad (6)$$

12 where  $H_{in}$  is the internal hazard index ( $\text{Bq kg}^{-1}$ ), and  $C_k$ ,  $C_{Ra}$ ,  $C_{Th}$  are radioactivity levels  
13 in ( $\text{Bq kg}^{-1}$ ) for  $^{40}\text{K}$ ,  $^{226}\text{R}$  and  $^{232}\text{Th}$ , respectively.  $H_{in} \leq 1$  implies negligible radiation risk.  
14 Internal exposure to radon is very hazardous and can result to lung diseases like asthma and  
15 lung cancer.

### 16 2.4.6 Representative Gamma ( $I_\gamma$ )

17 The representative gamma was formulated to estimate the  $\gamma$ -radiation risk linked to a specific  
18 natural radionuclide samples being investigated. It is an analytical tool for categorizing samples  
19 that might cause radiological implications if deployed for construction (Agbalagba et al 2012).  
20 Values of  $I_\gamma \leq 1$  correspond to  $1.0 \text{ mSv}$ , while  $I_\gamma \leq 0.5$  is within an annual effective dose of  
21  $0.3 \text{ mSv}$  (Wang et al 2017).

22 The  $I_\gamma$  is expressed as (Ashraf et al., 2010):

$$23 I_\gamma = C_{Ra}/150 + C_{Th}/100 + C_K/1500 \quad (7)$$

24 where  $I_\gamma$  is the representative gamma index ( $\text{Bq kg}^{-1}$ ), and  $C_k$ ,  $C_{Ra}$ ,  $C_{Th}$  are the  
25 radioactivity content values ( $\text{Bq kg}^{-1}$ ) for  $^{226}\text{R}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  respectively.

### 26 2.4.7 Annual Effective Dose Equivalent (AEDE) Outdoor

27 The AEDE keeps control on the effects of radiation on reproductive organs. This hazard index  
28 received outdoor by an individual is given as (Avwiri et al., 2012; Ononugbo et al., 2017):

$$29 AEDE (Outdoor) = DR \times 8760 \times 0.7 \times 0.2 \times 10^{-3} \quad (8)$$

1 Where;

2  $AEDE$  (*Outdoor*) is given in  $\mu Sv y^{-1}$ ,  $DR$  in  $nGy h^{-1}$ , 0.7 is the dose conversion factor given  
3 in  $SvG y^{-1}$ , 8760 h is the in a year and  $0.2 \times 10^{-3}$  is the occupancy factor for outdoor.

#### 4 2.4.8 Excess Lifetime Cancer Risk (ELCR)

5 Excess lifetime cancer risk estimates the likelihood of contracting cancer over a lifetime at  
6 specific exposure rate. It is the estimated number of extra cancers probable in each population  
7 of persons on exposure to a radiation at a specific dose.

8 The ELCR is computed using the expression (*Taskin et al., 2009*):

$$9 \quad ELCR = AEDE \times DL \times RF \quad (9)$$

10 where  $ELCR$  has no units,  $AEDE$  is as defined in equation 8, the average Duration of Life (70  
11 years) is the  $DL$ , while  $RF$  is known to as the Risk Factor, i.e., lethal cancer risk per Sievert  
12 ( $Sv^{-1}$ ). ICRP recommend  $RF$  as 0.05 for stochastic effects for the public (*Taskin et al., 2009*).

13 In order to further understand our results, statistical analyses were performed using the SPSS  
14 software tool for mathematical/statistical data analysis. These include; Skewness, Kurtosis,  
15 mean, median, mode, standard deviation, minimum and maximum values.

16

### 17 2.5 Total Effective Dose

18 The total effective dose parameters depicting the occupational risk to oil and gas workers and  
19 the public' were estimated employing relevant conversion coefficients available in the  
20 literature (Table 3) using the equations (*Kola et al., 2016*):

21 External exposure ( $D_{ext}$ ) to gamma radiation from mine site and the exposed tailings, is  
22 calculated using the equation:

$$23 \quad D_{ext} = \sum A_i C_{ext} T_e \quad (10)$$

24 Internal exposure ( $D_{inh}$ ) from inhalation of solid mineral dust and contaminated air, is estimated  
25 using the expression

$$26 \quad D_{inh} = \sum A_i C_{inh} \eta_{inh} D_f T_e \quad (11)$$

27 Internal exposure ( $D_{ing}$ ) from any accidental ingestion of solid minerals, is estimated using the  
28 equation:

$$29 \quad D_{ing} \sum A_i C_{ing} \eta_{ing} T_e \quad (12)$$

30 where  $A_i$  is the specific activity of nuclide  $i$  in  $Bq kg^{-1}$ ,  $C_{ext}$ , is the effective dose coefficient  
31 for the nuclide in the contaminated surface measured in  $Sv h^{-1}/Bq g^{-1}$ ,  $C_{inh}$ , is the dose  
32 coefficient for inhalation of the nuclide measured in  $Sv Bq^{-1}$ ,  $\eta_{inh}$  is the breathing rate measured  
33 in  $m^3 h^{-1}$ , and  $D_f$  is the dust loading factor,  $C_{ing}$ , is the dose coefficient for ingestion of the

1 nuclide measured in Sv Bq<sup>-1</sup>;  $\eta_{\text{ing}}$  is the ingestion rate for adults, measured in kgh<sup>-1</sup> and  $T_e$  is  
2 the exposure duration in years (*ICRP, 1991, 1996*).

3

### 4 **3.0. Results and Discussion**

#### 5 **3.1 Results of Radioactivity Analysis**

6 The results of the soil  $\gamma$ -ray spectroscopy analysis in the ten solid mineral mine sites of the five  
7 eastern states of Nigeria are presented in Tables 1. Table 2 presents the summary of the  
8 analyzed radionuclides and the radiation risk indices while Table 3 present the computed  
9 occupational risk estimation to workers in the solid mineral mine sites

10

#### 11 **3.2. Discussion of Results**

##### 12 **3.2.1 Specific Activity Concentration**

13 The specific radioactivity levels obtained for the three natural radionuclides <sup>40</sup>K, <sup>226</sup>Ra and  
14 <sup>232</sup>Th in the investigated soil samples collected within solid mineral mine sites are shown in  
15 Table 1. The analyzed data obtained for the Iron-stone mine site soil activity concentration in  
16 Ebonyi State, shows activity value range of 32.45- 80.58 Bq kg<sup>-1</sup>, 7.29- 30.66 Bq kg<sup>-1</sup> and  
17 25.88-67.61 Bq kg<sup>-1</sup> for <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th respectively. Their mean values are higher than  
18 the control values by 47%, 5% and 46% respectively, while the mean <sup>232</sup>Th activity  
19 concentration of 77.28 Bq kg<sup>-1</sup> obtained is above the *ICRP, IAEA* and *UNSEAR*, recommended  
20 permissible limit of 30 Bq kg<sup>-1</sup> for the public. This may be attributed to the parent rock material  
21 from which iron- stone was formed (*UNSEAR 2010; IAEA, 2011*). The activity concentration  
22 range for the kaolin mine sites soil samples in Imo State are 18.19-40.72 Bq kg<sup>-1</sup>, 54.33-91.64  
23 Bq kg<sup>-1</sup> and 37.46-142.42 Bq kg<sup>-1</sup>, for <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K, respectively, while their mean  
24 percentage elevation over the control values are 45%, 37% and 62% respectively. This  
25 elevation over the values obtained from the control sample can be attributed to the presence of  
26 these solid minerals within and around these sampled soils. At the silica mine site in Abia  
27 State, the range of activity concentration of the soil samples obtained are 127.08-289.79Bq kg<sup>-1</sup>  
28 <sup>1</sup>, 36.61-71.01 Bq kg<sup>-1</sup> and 72.04-112.45 Bq kg<sup>-1</sup> for <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th respectively and the  
29 degree of their mean values elevation over the control value are 54%, 48% and 77%  
30 respectively, with the mean activity concentration values of <sup>226</sup>Ra (52.64 Bq kg<sup>-1</sup>) and <sup>232</sup>Th  
31 (97.68 Bq kg<sup>-1</sup>) exceeding their *ICRP* maximum permissible limits for the public (*ICRP, 1996*).  
32 These high values may be attributed to the influence of these radionuclides presents in solid  
33 minerals that are within the sampled soil environment. The percentage elevation of <sup>40</sup>K, <sup>226</sup>Ra

1 and  $^{232}\text{Th}$  activity concentrations in the soil samples of the bitumen mine site in Enugu State  
2 over the control sample are 29 %, 41% and 62% respectively. The obtained activity  
3 concentrations in the soil samples from these mining sites compared favourably and agreed  
4 with the value reported from river sand sediment from across Enugu east in Enugu state  
5 (*Ugbede, 2020*). The  $^{232}\text{Th}$  ( $68.79 \text{ Bq kg}^{-1}$ ) mean value was found to be well above the ICRP  
6 recommended permissible limits. Similarly, the percentage increase of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$   
7 radioactivity levels in the sampled soil for the coal mine site at Enugu state over the control  
8 sample are 43%, 47% and 66% respectively, with  $^{232}\text{Th}$  activity concentration grossly exceeded  
9 the global permissible limit for the public. This high value of  $^{232}\text{Th}$  in the soil samples can be  
10 attributed to the high content of  $^{232}\text{Th}$  in coal mineral (*Faanu et al., 2011; Innocent et al., 2013;*  
11 *Wang et al., 2017*).

12 The radioactivity content range in the sampled soil at the clay mine sites in Imo State are 34.84-  
13  $275.58 \text{ Bq kg}^{-1}$ ,  $17.55\text{-}46.40 \text{ Bq kg}^{-1}$  and  $36.25\text{-}84.87 \text{ Bq kg}^{-1}$  in  $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$   
14 respectively. These range of values agrees with the reported natural activity concentration value  
15 in soil samples from Slovenia (*Kovács et al., 2013*). Their mean activity concentration  
16 percentage elevation over the control values is 51%, 50% and 47% respectively with  $^{232}\text{Th}$   
17 ( $58.91 \text{ Bq kg}^{-1}$ ) mean activity concentration still exceeding the global permissible limit for the  
18 public. The percentage elevation of  $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  activity levels in the sampled soil of  
19 the gypsum mine site at Enugu State over the control sample are 61%, 63% and 63%  
20 respectively. The  $^{226}\text{Ra}$  ( $49.46 \text{ Bq kg}^{-1}$ ), and  $^{232}\text{Th}$  ( $67.25 \text{ Bq kg}^{-1}$ ) mean activity levels are  
21 above the global permissible limit  $35 \text{ Bq kg}^{-1}$  for  $^{226}\text{Ra}$  and  $30 \text{ Bq kg}^{-1}$  for  $^{232}\text{Th}$  for the public.  
22 At the coal mine site in Abia State, the activity concentration range of the sampled soil obtained  
23 are  $25.67\text{-}174.22 \text{ Bq kg}^{-1}$ ,  $15.38\text{-}27.12 \text{ Bq kg}^{-1}$ , and  $37.99\text{-}64.36 \text{ Bq kg}^{-1}$  for  $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  
24  $^{232}\text{Th}$  respectively. The percentage mean radioactivity levels elevation over the control value  
25 are 55%, 28% and 54% respectively, with mean  $^{232}\text{Th}$  ( $55.31 \text{ Bq kg}^{-1}$ ) value observed to be  
26 above UNSCEAR recommended permissible limits for the general public (*UNSCEAR, 2000*).  
27 The activity concentration range of sampled soil at the limestone mine site in Ebonyi State as  
28 obtained are  $23.73\text{-}313.74 \text{ Bq kg}^{-1}$ ,  $18.73\text{-}48.26 \text{ Bq kg}^{-1}$  and  $29.70\text{-}70.41 \text{ Bq kg}^{-1}$ , for  $^{40}\text{K}$ ,  $^{226}\text{Ra}$   
29 and  $^{232}\text{Th}$  respectively. Their mean percentage elevation over the control values is 62%, 60%  
30 and 64% respectively with  $^{232}\text{Th}$  ( $48.78 \text{ Bq kg}^{-1}$ ) mean activity concentration agreeing with the  
31 value reported at Ezillo paddy rice field in Ebonyi State, but also exceeding the global  
32 permissible limit for the general public (*Ugbene and Osahon, 2021*). Similarly, the activity  
33 concentrations range for sampled soil at the glass stone mine site in Anambra State as measured

1 are 21.00-70.10 Bq kg<sup>-1</sup>, 14.19-28.90 Bq kg<sup>-1</sup> and 74.18-588.93 Bq kg<sup>-1</sup> for <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th  
2 respectively. Their mean percentage rise of <sup>40</sup>K, <sup>226</sup>Ra and <sup>232</sup>Th activity concentrations in the  
3 soil samples over the control sample are 39%, 58% and 82% respectively, with <sup>232</sup>Th (189.11  
4 Bq kg<sup>-1</sup>) activity concentration grossly exceeded the public permissible limit.

5 The soil specific activity levels obtained in the entire surroundings of the mining sites for the  
6 different solid mineral clearly indicate that <sup>232</sup>Th radioactivity concentration is higher and  
7 exceed the three naturally occurring radionuclides examined permissible limits for the public.  
8 This is an indication that most of the solid minerals are laced with radioactivity with thorium  
9 activity most prominent, which may be attributed to the geological formation of the subsurface  
10 rocks of the studied area and the weathering processes that takes place. It was observed that  
11 the mean activity of <sup>226</sup>Ra and <sup>40</sup>K reported in this study-areas are above many reported values  
12 in literatures in similar environment within Nigeria, West Africa and other parts of the globe  
13 (*Faanu et al., 2011; González-Fernández et al., 2012; Innocent et al., 2013; Wang et al., 2017*).  
14 Moreover, the <sup>226</sup>Ra value obtained in this study is well within reported values in literatures in  
15 similar solid mineral mining environments in Nigeria and in other parts of the world (*Amrani  
16 and Tahtat, 2001; El Afifi et al., 2006; Kam and Bozkurt, 2007; Al-Hamarneh and Awadallah,  
17 2009; Ademola and Obed, 2012; Avwiri et al., 2013; Kovács et al., 2013; Ademola et al., 2014;  
18 Hannan et al., 2015*).

19

### 20 **3.2.2 Radiological Hazard Parameter Statistical Analysis**

21 Table 2 shows the summary of the result of the statistically analyzed specific activity levels  
22 and radiation hazard/ risk indices. The eight radiation risk parameters were computed using  
23 reported standard and internationally established equations in literatures (*Ashraf et al., 2010;  
24 UNSCEAR, 2010; Avwiri, et al., 2012; Gang, et al., 2012; Sivakumar, et al., 2014; Wang, et  
25 al., 2016*). From the result, the estimated Radium Equivalent ( $Ra_{eq}$ ) varied from 87.51 Bq kg<sup>-1</sup>  
26 to 300.13 Bq kg<sup>-1</sup> with a mean and mode values of 150.72 Bq kg<sup>-1</sup>, and 87.51 Bq kg<sup>-1</sup>  
27 respectively with a standard deviation of 61.25 Bq kg<sup>-1</sup>. This  $Ra_{eq}$  result obtained is above  
28 reported value obtained in s solid mineral mine site in south-western Nigeria and sampled soil  
29 valued obtained in some cities and towns in Nigeria (*Agbalagba, et al., 2012; Avwiri, et al.,  
30 2012; Innocent et al., 2013; Ademola et al., 2014; Aliyu et al., 2015; Ononugbo et al., 2017;  
31 Ugbede, 2020; Ugbede and Osahon, 2021*). The Absorbed dose rate (D) has a minimum value  
32 of 38.96  $\eta Gyh^{-1}$  and a maximum measured value of 133.00  $\eta Gyh^{-1}$  with 68.40  $\eta Gyh^{-1}$  be  
33 the mean. The mean absorbed dose value recorded exceeded the UNSCEAR, (2010)

1 recommended worldwide ambient value of  $59 \mu\text{Gyh}^{-1}$ . The outdoor Annual Effective Dose  
2 Equivalent (AEDE) has its values varied from  $48.26 \mu\text{Svy}^{-1}$  to  $160.78 \mu\text{Svy}^{-1}$  with the mean  
3 and mode values of  $83.65 \mu\text{Svy}^{-1}$  and  $48.26 \mu\text{Svy}^{-1}$  respectively across the study-area and a  
4 standard deviation value of  $32.66 \mu\text{Svy}^{-1}$ . The estimated average value of the outdoor Annual  
5 Effective Dose Equivalent of  $83.65 \mu\text{Svy}^{-1}$  correspond to the reported values obtained in  
6 measured soil samples in Bethlehem Province of Palestine and soil from open landfills site in  
7 Rivers State Nigeria, but it is higher the worldwide annual effective dose equivalent value of  
8  $70 \mu\text{Svy}^{-1}$  for outdoor (Agbalagba et al., 2012; Mohammad et al., 2014; Ononugbo et al., 2017;  
9 Vukasinovic et al., 2017; Ugbede, 2020).

10 The estimated value of the Annual gonadal equivalent dose (AGED) varied from  $263.62 \mu\text{Svy}^{-1}$   
11 to  $879.51 \mu\text{Svy}^{-1}$  with a mean value of  $454.70 \mu\text{Svy}^{-1}$ . The estimated value recorded is above  
12 the ambient level recommended world permissible value of  $300 \mu\text{Svy}^{-1}$  and values obtained in  
13 reported research of wasteland soil in Namibia, but they are below the values reported in  
14 southern dump site sampled soil and Northern soil samples from solid mineral mining  
15 environment Nigeria as reported in literatures (UNSCEAR, 2010; Aliyu et al., 2015; Ononugbo  
16 et al., 2017; Onjefu et al., 2021). The accumulative dose rate at the present exposure rate over  
17 a twenty years' time may impair the reproductive organs (ovaries and testis) of those working  
18 and living around these mine sites if not properly shielded.

19 The mean results of the estimated health hazard indices indicates that External hazard index  
20 ( $H_{ex}$ ) has a mean value of 0.41, while the estimated Internal hazard index ( $H_{in}$ ) value is 0.50  
21 and the Representative gamma index ( $I_{\gamma}$ ) had a value of 1.06. The results are comparable  
22 favourably with the values reported in Wasteland soil of Okakarara in Namibia, the shore  
23 sediment of North dune beach in Namibia and the values reported in soil and sediment of Al-  
24 Nigella in Egypt (Onjefu et al., 2017; Ahmed et al., 2020; Onjefu et al., 2021). The mean hazard  
25 indices values obtained for  $H_{ex}$  and  $H_{in}$  are less than the 1.0 (critical value), the general public  
26 recommended permissible limit, however, Representative gamma index ( $I_{\gamma}$ ) value of 1.06  
27 obtained was slightly above the UNSCEAR recommended value for the general public  
28 (UNSCEAR, 2010). These obtained estimated values of the Excess Life Cancer Risk (ELCR)  
29 result ranged from  $165.45 \times 10^{-6}$  to  $559.31 \times 10^{-6}$  with a regular value of  $289.14 \times 10^{-6}$ . This mean  
30 ELCR value of  $289.14 \times 10^{-6}$  obtained is approximately the recommended ambient public  
31 permissible limit of  $0.29 \times 10^{-3}$  (UNSCEAR, 2000). This implies that the likelihood of radiation  
32 induced health risks among residence and workers in the environs of these mine sites is  
33 probable, especially for prolong and continuous radiation exposures from these studied

1 minerals sites. The statistical analysis of the results of radionuclides and the radiological risk  
2 indices are indicated in figure 3, while figure 4 shows the sequential chart distribution of the  
3 three natural radionuclides investigated with the radiological risk parameters examined. It was  
4 observed from figure 3 that the histogram showing the spatial dispersion of specific activities  
5 of the three natural radionuclides ( $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$ ) in the analyzed soil samples from the  
6 investigated sites, were asymmetrical distribution with the skewness of 0.19, 0.61, 2.53  
7 respectively. The median values for  $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  were 99.80, 32.23 and 68.34  $\text{Bq kg}^{-1}$   
8 respectively, thus data obtained in this study were accepted as reliable for use in the  
9 determination of the radiological risk (*Kessaratikoon et al., 2019*). From figure 4, the two rigs  
10 in the sequence chart are an indicative of the areas of high aggregation of the activity  
11 concentrations and areas of strong correlation of activities concentration with radiological risk  
12 parameters.

### 13 **3.2.3 Occupational Risk Estimate**

14 This model account for the occupational hazard associated with work environment, which in  
15 this study is the solid mineral mining sites. As a result of constant working at the sites and in  
16 most cases not wearing the appropriate Personnel Protective Equipment (PPE), workers are  
17 often exposed to radionuclide. The three major paths for this exposure are according to *Kolo et*  
18 *al. (2016)*:

19 The total of these three different paths of exposure gives the total effective dose which is the  
20 concerned parameter. To be within the safe ICRP limit, the Total Effective Dose from these  
21 three pathways must not be more than  $1.0\text{m Sv y}^{-1}$  for the public (*ICRP, 1991*).

22 The result presented in Table 3 of the Occupational Risk Estimate indicates that the external  
23 exposure to gamma radiation ( $D_{\text{ext}}$ ) has the highest Occupational risk ranging from  $0.51\text{mSv y}^{-1}$   
24  $^1$  to  $1.3\text{ mSv y}^{-1}$ , followed by Internal exposure from inhalation of radiation from solid mineral  
25 dust and contaminated air ( $D_{\text{inh}}$ ) ranging from  $0.01\text{ mSv y}^{-1}$  to  $0.99\text{ mSv y}^{-1}$  and the least is  
26 Internal exposure from any accidental ingestion of radiation from solid minerals ( $D_{\text{ing}}$ ) ranging  
27 from  $0.08\text{ mSv y}^{-1}$  to  $0.24\text{ mSv y}^{-1}$ . The reason for this result distribution is obvious as one in  
28 a mining site would be exposed externally on the skin and inhalation before even having to  
29 experience accidental ingestion. This result indicates that the external organs like the eye and  
30 skin of the people working at these mining sites may be at risk of eye and skin radiation related  
31 infections. However, the overall results suggests that the effect put together is within control  
32 limit as the whole organs of the body fights together to wear the would-be effect from one  
33 pathway.

## 1 **Conclusion**

2 The evaluation of natural radioactivity levels of sampled soil from some selected solid minerals  
3 mining sites and soil from non-mineral mining areas (control) in the Eastern region of Nigeria  
4 has been investigated using gamma spectroscopy analysis. The measured soil activities of  $^{40}\text{K}$ ,  
5  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  were deploy to compute the percentage gamma radiation elevation over the  
6 control sample and the risk parameters. Radioactivity analysis of the sampled soil shows that  
7 some radionuclides values measured exceeded their standard limits. The overall average  
8 percentage rise in  $^{40}\text{K}$ ,  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  value in the mine sites soil samples over the control soil  
9 samples are 48.6%, 43.7% and 62.3% respectively, with thorium having the highest percentage  
10 rise. This affirmed previous research report of  $^{232}\text{Th}$  be the major contributor of the dose that  
11 can be received from the terrestrial environment. The occupational risk estimation results  
12 indicate that the external organs of the people working and living around these mining sites are  
13 at risk which may lead to eye and skin radiation related infections. The exceeding of global  
14 recommended permissible and ambient limits of certain radiation hazard indices estimated  
15 compared to previously reported values from similar mineral mining environment is an  
16 indication of a radiologically contaminated environment, which is attributable to the solid  
17 minerals mining and processing in the studied areas. The researcher therefore recommends that  
18 proper kitting of workers and discouragement of people residing around these mining sites to  
19 reduce the radiation impact on people and the environment.

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## 23 **Ethical Approval**

24 This paper abides by all ethical standard of the journal and contain no ethical issues whatsoever.

## 25 **Consent to Participate**

26 All authors consent was sorted and agreed before the research work commenced. All authors  
27 also consent to participate in the writing of this article and the submission of the final paper to  
28 this journal.

## 29 **Consent to Publish**

30 This is to certify that all authors consents were sorted and approval gotten to publish this paper  
31 in this Journal. We the authors declare that there is no conflict of interest among us in this  
32 research work.

## 33 **Authors' contributions**

1 The research work was conceived by Dr. Agbalagba E.O and redesign for wider readability by  
2 Prof. Stephen O. Egarievwe, while Dr. Mohammed S. Chaanda did the geological identification  
3 and characterization of sites and solid minerals in each site. All the three authors contributed  
4 mutually from the development and data analysis in this research work. Dr. Agbalagba E.O.  
5 did the writing which other authors vetted and agreed before sending for consideration in this  
6 Journal.

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### 10 **Availability of Data and Material**

11 The datasets generated and/or analyzed during the current study are not publicly available, but  
12 will be made available from the corresponding author on reasonable request

### 13 **Competing Interests**

14 Not applicable

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**List of Tables**

**Table 1: Activities (Bq kg<sup>-1</sup>) of <sup>40</sup>K, <sup>226</sup>Ra, <sup>232</sup>Th from solid mineral mining soils in South-Eastern Nigeria**

S/N	geographical location	Mining State	Mineral found	<sup>40</sup> K (Bq kg <sup>-1</sup> ) Mean (Range)	<sup>226</sup> Ra (Bq kg <sup>-1</sup> ) Mean (Range)	<sup>232</sup> Th (Bq kg <sup>-1</sup> ) Mean (Range)
1	N06°22'45" E007°27'52"	Ebonyi	Ironstone	54.26 (32.45-80.58)	20.45 (7.29-30.66)	48.18 (25.88-67.61)
2	N06°45'44" E007°16'17"	Imo	Kaoline	81.65 (37.46-142.42)	31.83 (18.19-40.72)	71.08 (54.33-91.64)
3	N06°28'08" E007°27'03"	Abia	Silica	179.15 (127.08-289.79)	52.64 (36.61-71.01)	97.68 (72.04-112.45)
4	N06°05'27" E007°26'34"	Enugu	Bitumen	34.80 (21.93-60.46)	32.66 (21.25-40.41)	68.79 (48.74-91.00)
5	N06°25'47" E007°28'00"	Enugu	Coal 1	117.03 (64.11-238.10)	36.37 (26.09-43.73)	69.94 (60.87-80.04)
6	N06°09'56" E007°29'07"	Imo	Clay	117.34 (34.84-275.58)	35.23 (17.55-46.40)	58.91 (36.25-84.87)
7	N06°31'05" E007°26'34"	Enugu	Gypsum	136.0 (87.40-161.82)	49.46 (41.24-53.65)	67.25 (42.08-90.54)
8	N06°23'53" E007°27'15"	Abia	Coal 2	82.58 (25.67-174.22)	22.47 (15.38-27.12)	55.31 (37.99-64.36)

9	N06°24'34" E007°28'52"	Ebonyi	Limestone	155.68 (23.73-313.74)	30.66 (18.73-48.26)	48.78 (29.70-70.41)
10	N06°24'54" E007°27'45"	Anambra	Glass-sand	48.02 (21.00-70.10)	19.85 (14.19-28.90)	189.11 (74.18-588.93)
<b>Overall Mean Value</b>				<b>100.22±8.20</b>	<b>33.15±3.31</b>	<b>77.31 ±6.10</b>
<b>Control (Mean)</b>				28.60	19.63	25.92
<b>Global Recommended Value (UNSEAR 2010)</b>				<b>400</b>	<b>35</b>	<b>30</b>

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**Table 2. Risk Estimate for workers in solid mineral mining site**

Variables	K-40 (Bq kg <sup>-1</sup> )	Ra-226 (Bq kg <sup>-1</sup> )	Th-232 (Bqkg <sup>-1</sup> )	Raeq (Bq kg <sup>-1</sup> )	D (ηGyh <sup>-1</sup> )	AEDE (μSvy <sup>-1</sup> )	AGED (μSvy <sup>-1</sup> )	Hex	Hin	I <sub>γ</sub>	ELCR x10 <sup>-6</sup>
Mean	100.22	33.15	77.31	150.72	68.40	83.65	454.70	0.41	0.50	1.06	289.14
Median	99.80	32.23	68.34	136.45	60.61	74.33	409.40	0.37	0.46	0.95	260.17
Mode	34.80	19.88	44.30	87.51	38.96	48.26	263.62	0.24	0.29	0.61	167.24
Std. Deviation	48.71	11.18	43.34	61.25	26.63	32.66	179.23	0.17	0.17	0.43	114.30
Skewness	0.19	0.61	2.53	1.81	1.73	1.73	1.71	1.81	1.18	1.80	1.73
Kurtosis	-1.14	-0.33	6.94	3.67	3.34	3.34	3.26	3.67	1.28	3.64	3.34
Minimum	34.80	19.88	44.30	87.51	38.96	48.26	263.62	0.24	0.29	0.61	165.45
Maximum	179.15	52.65	193.11	300.13	133.00	161.80	879.51	0.81	0.86	2.10	559.31

**Table 3: Occupational Risk Estimate for workers in solid mineral mining sites**

<b>Code Name</b>	<b>Mineral Mined</b>	<b>Ra-226 (Bq kg<sup>-1</sup>)</b>	<b>Th-232 (Bq kg<sup>-1</sup>)</b>	<b>K-40 (Bq kg<sup>-1</sup>)</b>	<b>D<sub>ext</sub> (mSv y<sup>-1</sup>)</b>	<b>D<sub>inh</sub> (mSv y<sup>-1</sup>)</b>	<b>D<sub>ing</sub> (Sv y<sup>-1</sup>)</b>	<b>Total Eff. Dose (μSv y<sup>-1</sup>)</b>
LS	Limestone	30.63	48.87	155.68	0.97	0.50	0.10	51.30
CL1	Coal	36.37	69.96	117.03	0.99	0.71	0.13	72.40
CY	Clay	35.23	59.10	117.34	0.97	0.01	0.12	61.70
BN	Bitumen	32.66	69.44	34.80	0.73	0.71	0.12	71.42
IS	Ironstone	20.45	47.98	54.26	0.53	0.48	0.08	49.26
SC	Silica	52.64	97.72	179.15	1.47	0.99	0.18	10.11
KL	Kaolin	31.80	70.04	81.65	0.82	0.71	0.12	72.02
GM	Gypsum	49.49	67.25	136.04	1.30	0.69	0.15	71.14
GS	Glass-sand	19.88	193.11	48.02	0.51	0.02	0.24	19.27
CL2	Coal	22.48	53.31	82.58	0.64	0.54	0.09	54.73

## **List of Figures**



Figure 1: Geological Map of Nigeria showing the location of the area studied [59]

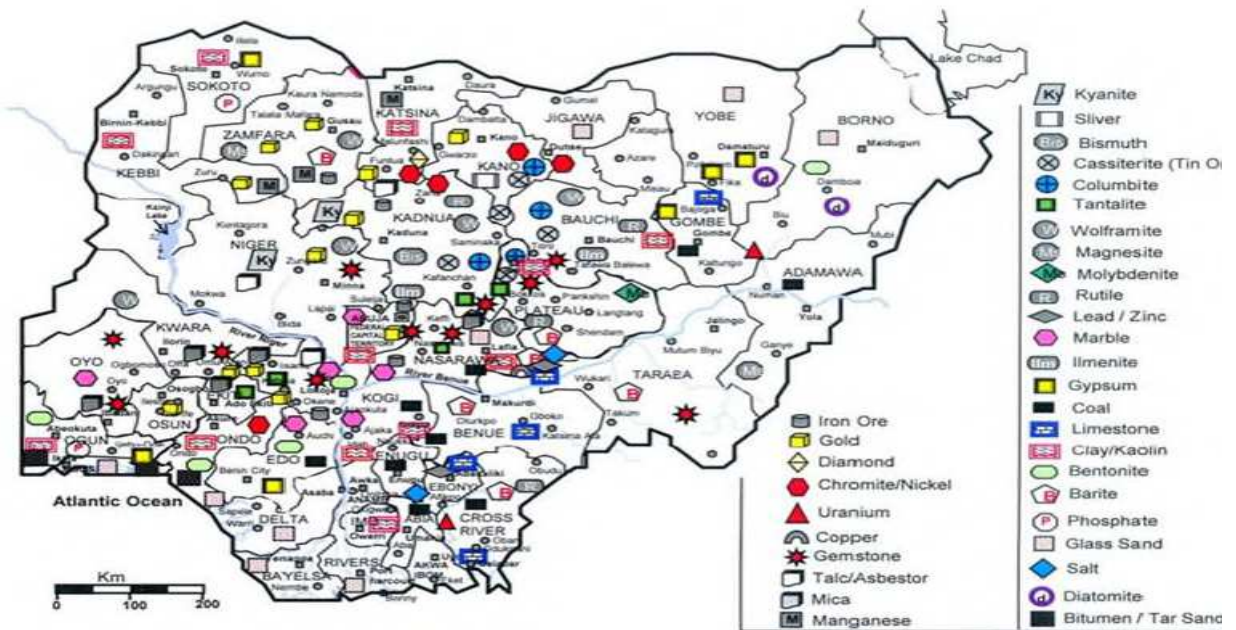


Figure 2: Solid Minerals and Locations Found in Commercial Quantity in Nigeria (Source: Report of the Vision 2020 National Technical Group on Minerals and Metals Development)[60]

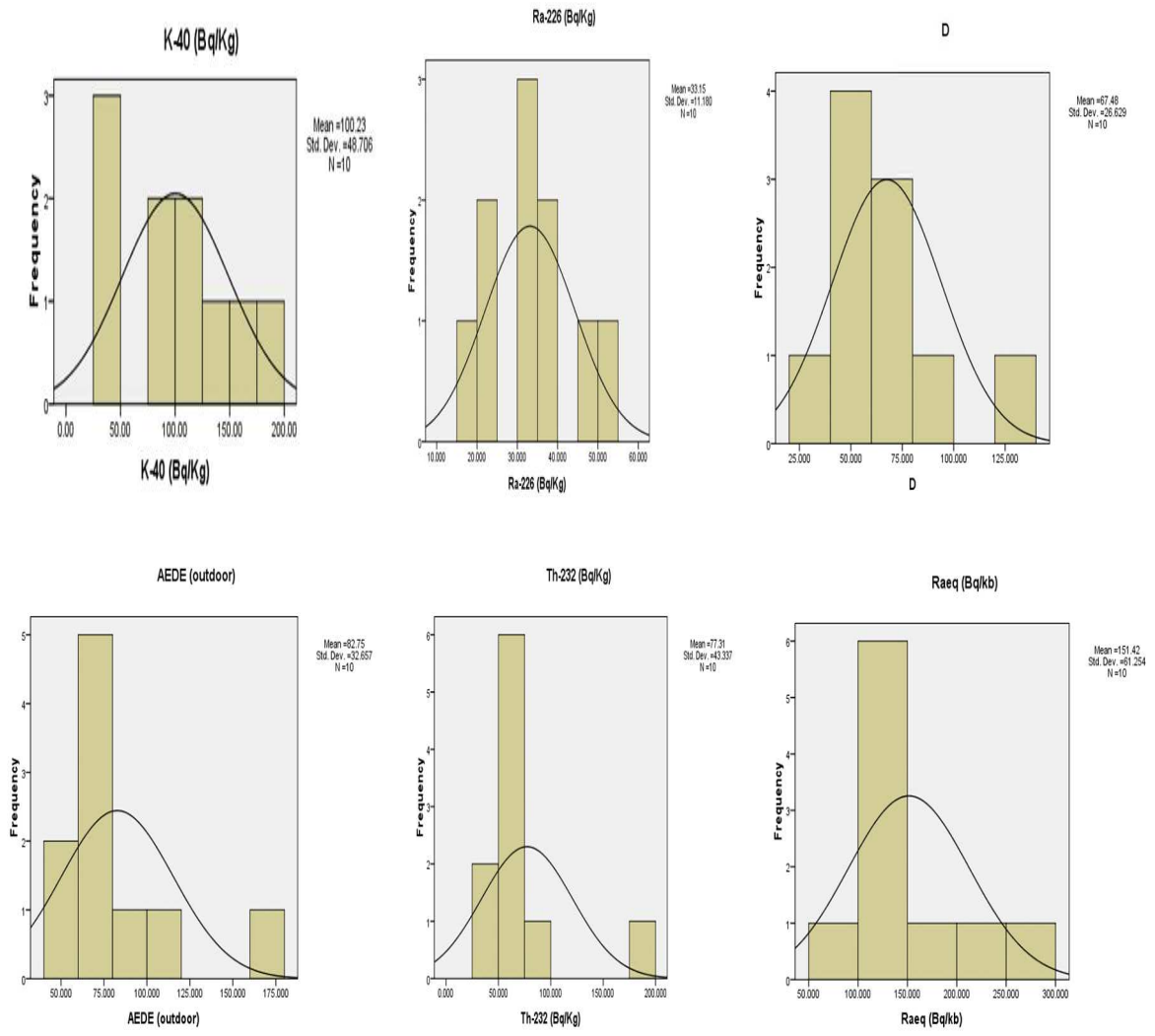


Figure 3: Histogram and Skewness plot of some Radiation parameters.

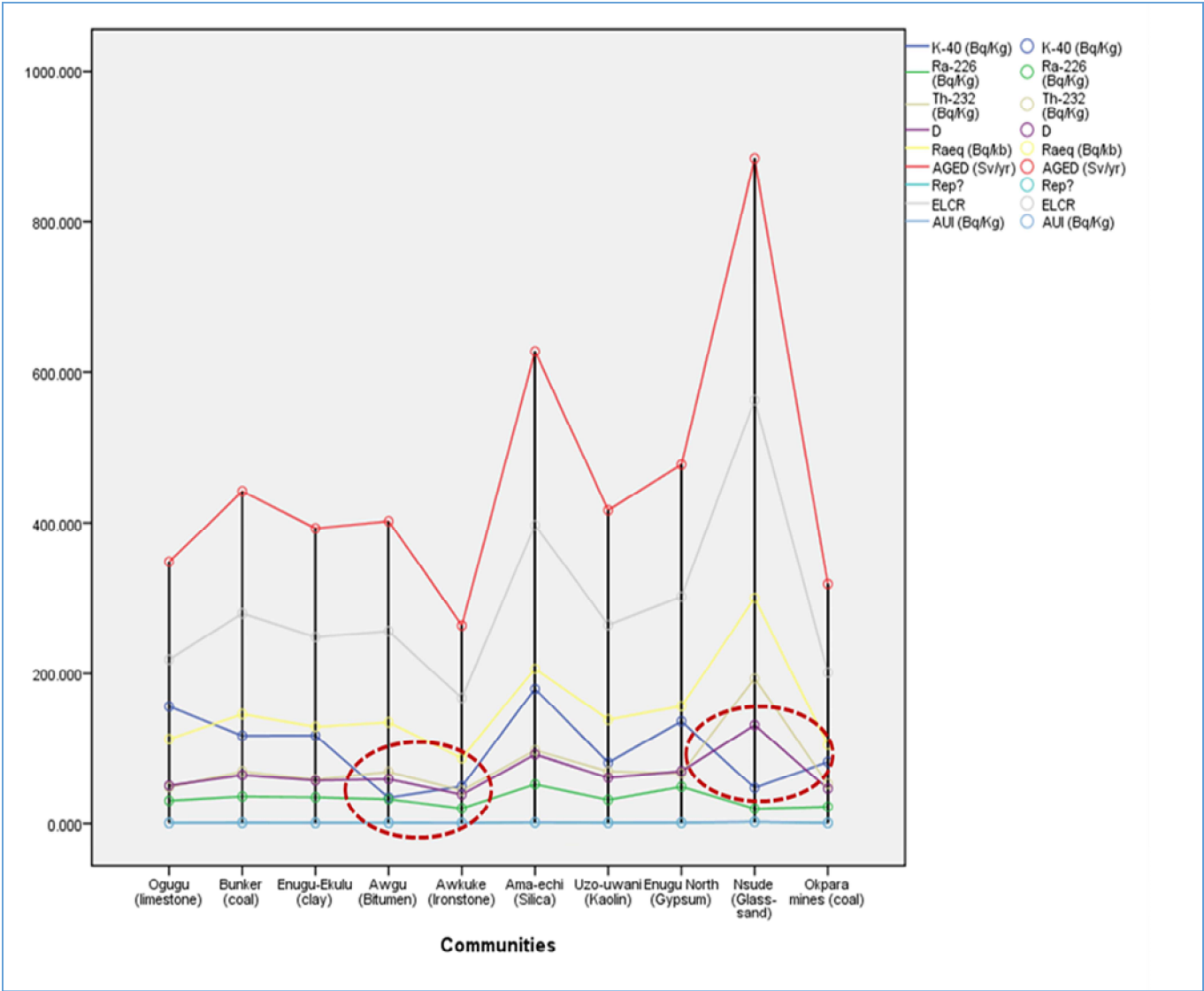


Figure 4: Sequence Chart of the Statistical Analysis.

# Figures

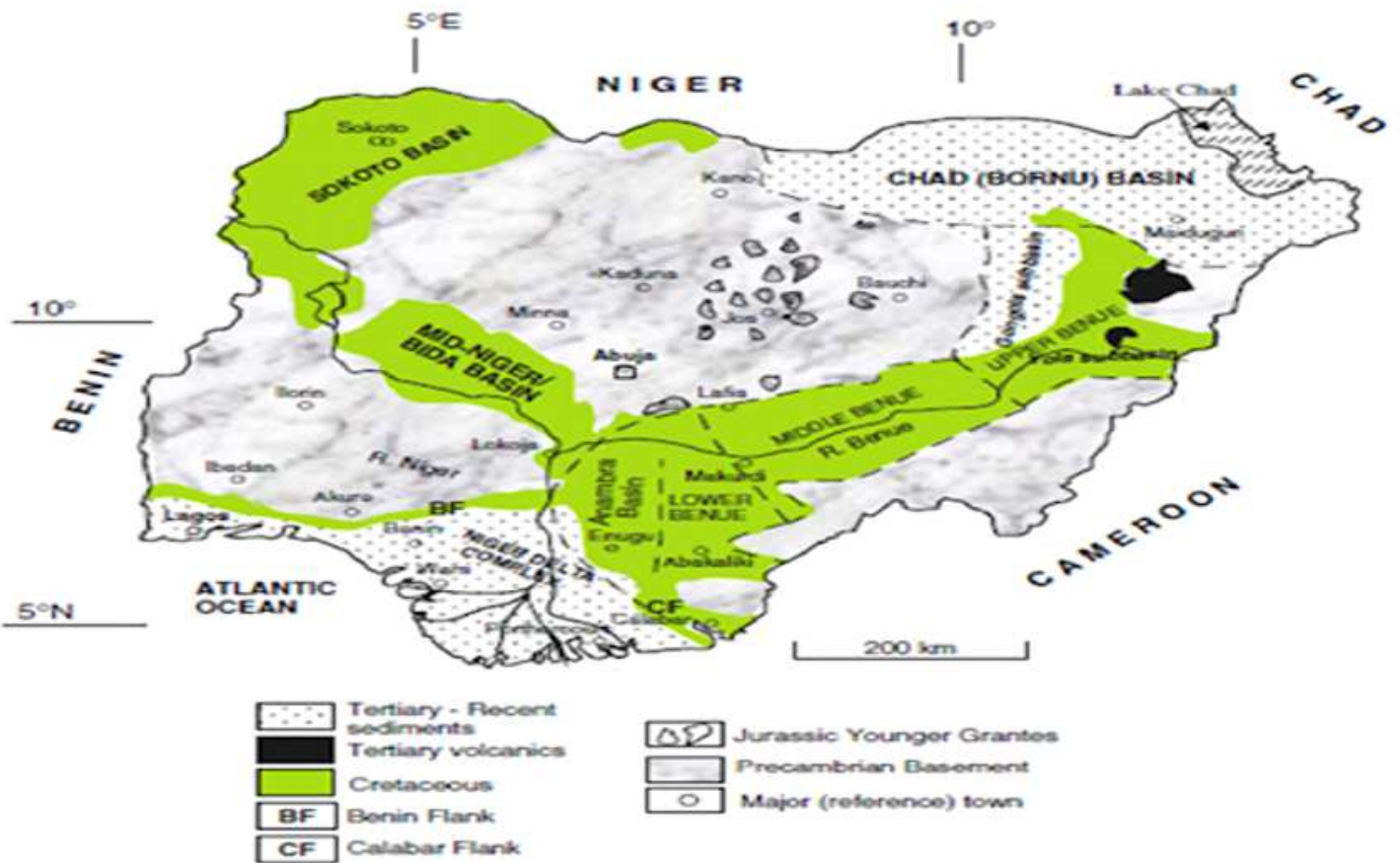


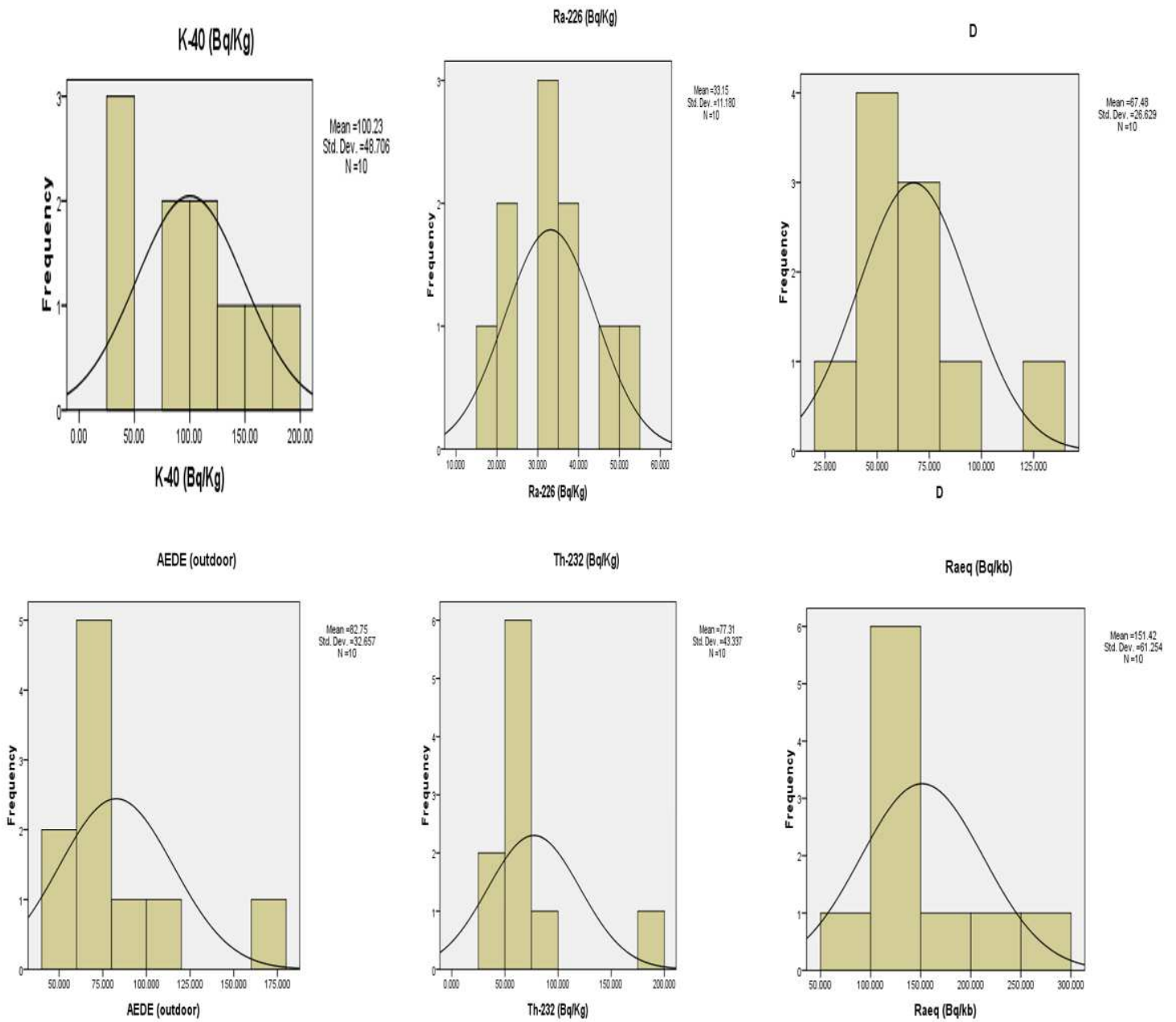
Figure 1

Geological Map of Nigeria showing the location of the area studied [59] Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



Figure 2

Solid Minerals and Locations Found in Commercial Quantity in Nigeria (Source: Report of the Vision 2020 National Technical Group on Minerals and Metals Development)[60] Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



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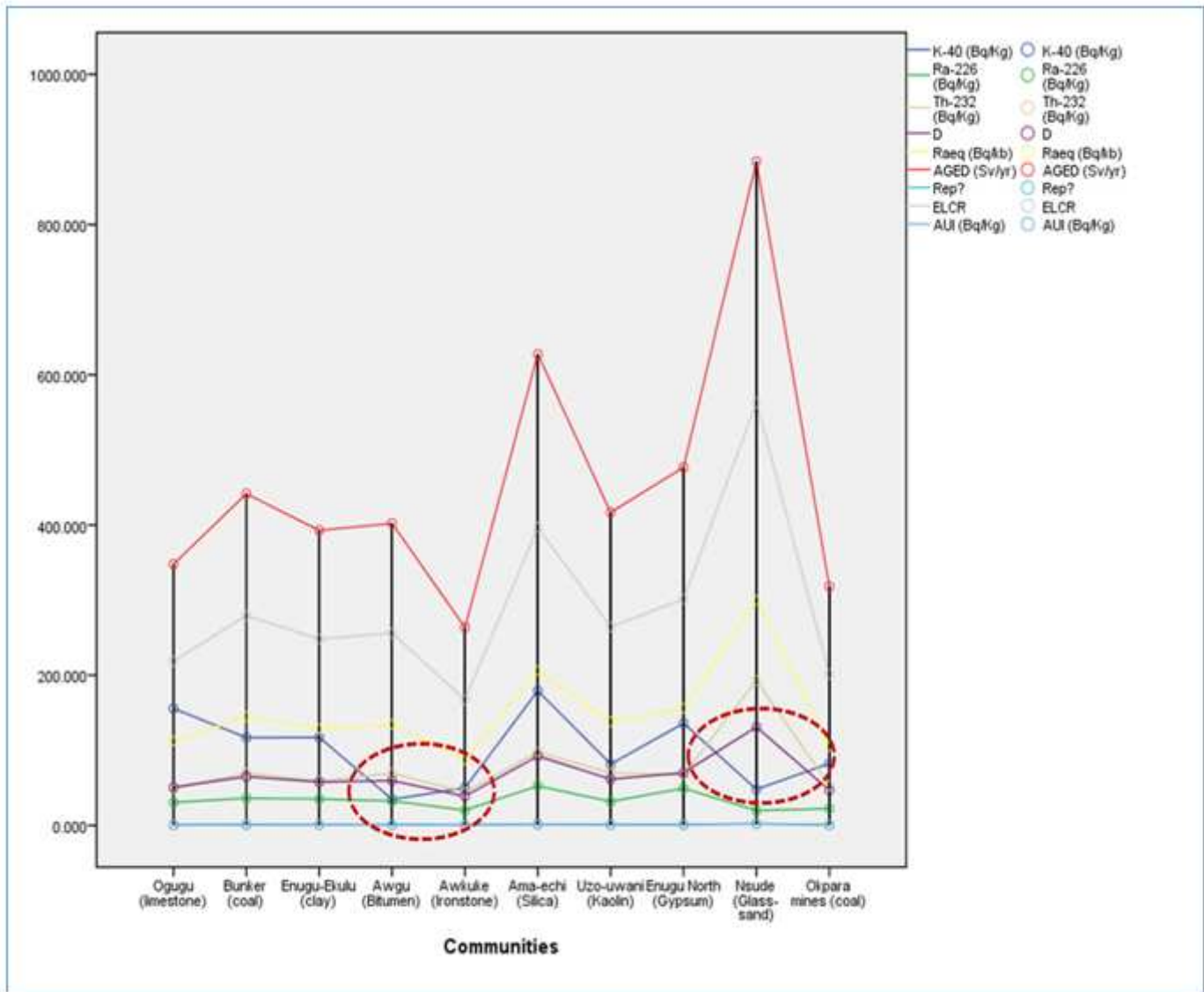


Figure 4

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