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Excess lifetime Cancer risk and Radiation Pollution hazard indices in rocks and soil of some selected mining sites in Nasarawa State, Nigeria

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A U T H O R S I N F O

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A B S T R A C T

Radiation exposures from mining and mineral processing industries can lead to high incidence of disease conditions like nausea, lung cancer, sterility, fatigue, and diarrhoea among mine workers. The concentration of primodial radionuclides (238U, 232Th and 40K) in some selected mining sites in Nasarawa State, Nigeria, was examined in this study. Soil and rock samples from eight different mining sites were collected and analyzed for radionuclides activity concentration by gamma ray spectrometery using a scintillator detector NaI (Tl), while soil physical and chemical parameters were analyzed using standard methods. Data obtained was analyzed through descriptive statistics using SPSS statistical package. The results obtained for the annual gonadal dose equivalent, absorbed dose rate, outdoor annual effective dose equivalent, indoor annual effective dose equivalent and excess lifetime cancer risk were found to be above the globally permissible limits, for both rock and soil samples.

K E Y W O R D S (in alphabetical order): *Absorbed dose rate, cancer risk, Exces lifetime cancer risk, radionuclides, spectroscopy*

1. Introduction

Knowing the concentration levels of natural radionuclides in soil and their distribution in the environment is of great interest in several fields of science (El-Aydarous 2007). The levels of natural radioactivity in geological materials, mainly rocks and soil occurs in varying concentrations (Santos *et al.* 2005; Tzortzis and Tsertos 2004), while natural radionuclides present in soil are responsible for the background radiation exposure of the populace. The types of rock from which the soils originate determine the terrestrial background radiation. Igneous rocks such as granite have higher radiation levels, while lower levels are associated with sedimentary rocks, although some shale and phosphate rocks have a relatively high content of radionuclides (NCRP Report 1993). Background radiations, also known as radioactivity level, from the natural radionuclides depend on the amount of the radioactive materials in the environment. The background radiation can be high if the environment is polluted either from human or natural activities. The major anthropogenic source of radionuclide in the environment is mining activities. The majority of environmental problems associated with Naturally Occurring Radioactive Materials (NORM) in solid minerals mines and processing occurs during the process of drilling, leaching, handling, storage, transportation of mineral ores and the use of contaminated equipment or waste media without controls, which usually lead to the spread of NORM contaminating the environment, resulting in potential radiation exposure of members of the public (Innocent *et al.* 2013)

When radon inert gas, resulting from the thorium and uranium decay series, is inhaled in poorly ventilated underground mines, this may lead to exposure that is above the current radiation exposure limits, and could cause high incidence of lung cancer, nausea, asthma, sterility, fatigue, diarrhoea etc. among mine workers (UNSCEAR 2000). Rocks used for construction of building is one possible way of exposition to radiation in the environment. Since radiation cannot be felt by the human sense organs, it is very important that the total amount of radiation emitting-NORMs in mining areas to be accurately known and kept to a level as low as reasonably achievable, in order to safeguard human lives and to ensure a radiation-pollution free environment. Measurement of natural radioactivity is crucial in implementing precautionary measures whenever it is found to exceed the recommended limit. Due to the health risks related with the exposure to NORMs and th inhalation of the short-lived decay products of radon, international bodies and organizations -such as International Commission on Radiological Protection (ICRP 1991) and Environmental Protection Agency (EPA 2007)- have proposed strong measures at minimizing such radiation exposure. This study seeks to establish the activity concentration of NORM level associated with solid mineral mining activities in Nasarawa State, Nigeria, using gamma ray spectroscopy NaI (Tl) detector system

and radiological health hazard indices, with the hope that results of the study will help for future assessment of gamma emitting-NORMs level in mining areas.

2. Materials and Methods

2.1 Study Area

Nasarawa state is located in the North central region of Nigeria and has thirteen (13) local government areas. It lies within the coordinates of 8° 32' - 8° 53' N and 7° 72' - 8° 18' E, and covers a land area of 27,117 square kilometers (Table 1). Nasarawa State shared boundary with Kaduna State to the north, Federal Capital Territory, Abuja to the west, Kogi and Benue state to the south and in the east by Taraba and Plateau. Nasarawa State is characterized by undulating lowlands and a network of hills. Nasarawa State falls within the southern guinea savanna zone. It is characterized by a tropical humid climate with two distinct seasons: the wet season starting from the beginning of May to the end of October, and the dry season between November and April. Nasarawa State's mainstay of the economy is agriculture, with the production of a variety of cash crops throughout the year. The eight mining sites selected for this study are located across Nasarawa state used for this study are located at Riri (RR), Rafin Gabas (RF), Moro (MM), Dugbu Mada (DM), Azara (AZ), Akiri (AK), Alamis Eggon (AE) and Adudu (AD) (Figure 1). Their rock types and associated minerals mined are shown in table 1.

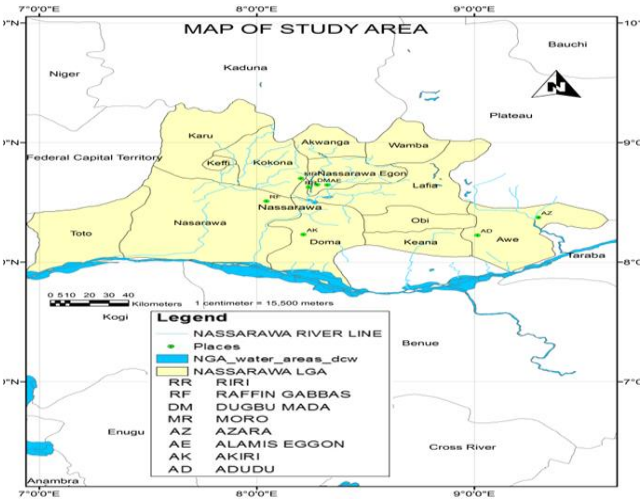

Figure 1: *Map of study area*

2.2 Geology and Relief

Nasarawa State is home of solid minerals containning granites, migmatites, pegmatites, and gneisses. The high land areas of the state are located towards the northern part of the state, notably in Wamba, Nassarawa Eggon and Akwanga Local government Areas. The state is drained by numerous fast-flowing streams/rivers that take their source from the Jos Plateau and flow into the River Benue -which also marks the state's southern boundary. Prominent among these are the Mada, Dep, Ayini, and Farin Ruwa rivers. The soils are derived mainly from the basement complex and old sedimentary rocks. Lateritic crust occurs in extensive areas on the plains, while hydromorphic soils (humicinceptisols) occur along the flood plains of major rivers along the state.

Table 1: Mining sites examined in the study, with materials mined

Location	Materials mined	Rock Found
Riri (RR)	Muscovite/tantalite	Pegmatite
RaffinGabas (RF)	Chalcopyrite	Pegmatite & Gneiss
Moro (MM)	Marble	Calcite & Limestone
DugbuMada (DM)	Mica	Pegmatite & Shale
Azara (AZ)	Baryte	Sandstone
Akiri (AK)	Copper	Shale
AlamisEggon (AE)	Iron ore	Shale & Sandstone
Adudu (AD)	Lead/Zinc	Shale & Sandstone

2.3 Samples Collection and Preparation

Twenty-four soil (24) and sixteen (16) rocks samples were collected between April-September 2015 from the sampling locations areas, which were then packed in cylindrical plastic containers, properly sealed with adhesive tape and labeled for easy identification. The soil samples were immediately taken to the National Institute of Radiation Protection and Research (NIRPR) Laboratory, University of Ibadan, Ibadan, Oyo State. In the laboratory, the soil and rock samples were first air dried for a week and then put in an oven and set to a temperature of 105ºC to allow it dry overnight in order to remove any available moisture. After drying, the samples were crushed and sieved with a mesh of diameter 2mm in order to remove organic materials, stones and lumps. Afterward, the homogenized samples were weighed and a mass of 250g of each sample was packed in a cylindrical plastic beaker of height 7cm by 6cm diameter -which is the same as the geometry of the sodium iodide's counting detector.

Adhesive tape were then used to hermetically sealed the cylindrical plastic that contained samples to be analysed were kept for 30 days so as to allow for ^{238}U and its short-lived progenies to reach secular radioactive equilibrium (Veiga *et al.* 2006) before gamma counting.

2.4 Experimental Setup and Procedure for Radioactivity Measurement

The experiments for radioactivity measurement of the rock and soil samples were analyzed in the laboratory at the National Institute of Radiation Protection and Research (NIRPR) University of Ibadan using a thallium activated Canberra vertical high purity 3″×3″ Sodium iodide [NaI(TI)] detector connected to ORTEC 456 amplifier. The detector used was connected to a computer program MAESTRO window that matched the gamma energies to a library of possible isotopes. The cylindrical plastic containers containing the samples were placed on the high geometry 7.6cm x 7.6cm NaI(TI) detector. The detector was lead-shielded (15cm thick lead on all four sides and 10cm thick on top). The energy resolution of 2.0keV and relative efficiency of 33% at 1.33MeV was achieved in the system with the counting time of 36,000 seconds to reduce statistical uncertainty. The standard International Atomic Energy Agency (IAEA) sources were used for calibration (IAEA 2003). From the counting spectra, the activity concentrations of ^{238}U, ^{232}Th and ^{40}K was

determined using computer program MAESTRO window. The peak corresponds to 1460 kev (40K) for ^{40}K, 1764.5 Kev (Bi-214) for ^{238}U, and 2614.5 kev (Ti-208) for ^{232}Th were considered in arriving at the activity levels (Bqkg-1).

The background counts were determined by counting an empty container of the same geometry as those of the samples and then subtracting from the gross count. The activity concentrations of the samples were determined using the net area under the photopeaks using the formula:

$$A_c = C_n / P_\gamma M \varepsilon \quad \textbf{(i)}$$

where A_c is the activity concentration of the radionuclide in the sample given in Bqkg^{-1}, C_n is the net count rate under the corresponding peak, P_γ is the absolute transition probability of the specific γ-ray, M is the mass of the sample (kg), and ε is the detector efficiency at the specific γ-ray energy.

2.5 Evaluation of Radiological Hazard Parameters

2.5.1 Radium Dose Equivalent

To evaluate the gamma radiation hazard to humans associated with the use of the soil/rocks from the mining sites in construction of houses (filling and local brick making), the radium equivalent activity was calculated. The result is a single index which describes the gamma output from the different mixtures of ^{238}U, ^{232}Th and ^{40}K in the samples. Radium equivalent activity (Ra_{eq}) is expressed mathematically by Berekta and Mathew (1985) and UNSCEAR (2000) as:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad \textbf{(ii)}$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

^{238}U were replaced by the decay product ^{226}Ra, although there may be disequilibrium between ^{238}U and ^{226}Ra. It was given a score of 1.03 according to UNSCEAR (2000).

2.5.2. Air-Absorbed Dose Rates

The outdoor air-absorbed dose rates due to terrestrial gamma radiation at about 1m above the ground were calculated from ^{238}U, ^{232}Th and ^{40}K activity concentration values in soil, while the other radionuclides (such as ^{137}Cs, ^{90}Sr and the ^{235}U decay series) were ignored as they contribute very little to the total dose from the environmental background (Kocher and Sjoreen 1985; Jacob *et al.* 1986; Leung *et al.* 1990). The conversion factors used to calculate the absorbed dose rate is given by UNSCEAR (1993) as:

$$D = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad \textbf{(iii)}$$

where D is the dose rate (nGy h^{-1}) at 1m above the ground due to ^{238}U, ^{232}Th and ^{40}K in the soil samples. A_U, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bqkg^{-1}, respectively.

2.5.3 Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent was estimated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv/Gy and the occupancy factors for outdoor and indoor are

0.2(5/24) and 0.8(19/24), respectively (Veiga *et al.* 2006).

The annual effective dose is determined using the following equations

AEDE (Outdoor) (μSv/y) = (Absorbed dose) nGy/h × 8760h × 0.7 Sv/Gy × 0.2×10^{-3} **(iv)**

AEDE (Indoor) (μSv/y) = (Absorbed dose) nGy/h × 8760h × 0.7 Sv/Gy × 0.8×10^{-3} **(v)**

2.5.4 External Hazard Index

To limit the external gamma-radiation dose from building materials, an extensively used hazard index, the external hazard index (H_{ex}) was obtained using the equation given by Berekta and Mathew (1985):

$$Hex = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \leq 1 \quad \textbf{(vi)}$$

where H_{ex} is the external hazard index and A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.5.5. Internal Hazard Index

Radon and its short-lived products are hazardous to the respiratory organs such as the lungs. So internal exposure to radon and its short-lived products is quantified by an internal hazard index and expressed mathematically by Berekta & Mathew (1985) as:

$$Hin = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \leq 1 \quad \textbf{(vii)}$$

where H_{in} is the internal hazard index and A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.5.6 Representative Gamma Index

According to the European Commission (EC), gamma activity concentration index ($I_{\gamma r}$) help to identify whether a dose standard is met (EC, 1999) and this was estimated using the formula:

$$I\gamma = A_{Ra}/150 + A_{Th}/100 + A_K/1500 \leq 1 \quad \textbf{(viii)}$$

2.5.7 Annual Gonadal Equivalent Dose

According to UNSCEAR (1982), the reproductive organs are considered as organs of interest. Therefore the Annual Gonadal Equivalent Dose (AGED) for the workers/residents of the study area due to the exposure to ^{226}Ra, ^{232}Th and ^{40}K was estimated using the equation given by Arafa (2004) as:

$$AGED = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad \textbf{(ix)}$$

Where A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

2.5.8 Excess lifetime cancer risk (ELCR)

The possibility of contacting cancer by mineworkers and residents of the study area, who will probably spend majority or all their life time in this environment, can be evaluated using the excess lifetime cancer risk (ELCR) even in the absence of outbreak radioactive components. The annual effective dose calculated was used to estimate the excess lifetime cancer risk (ELCR) is calculated using the equation:

ELCR = AEDEO × Average duration of life (DL) × Risk factor (RF) **(x)**

where *AEDEO, DL* and *RF* is the annual effective dose equivalent, average duration of life was set

to 70 years, and risk factor (Sv-1), fatal cancer risk per sievert. For low dose background radiations which are considered to produce stochastic effects, ICRP uses a 0.05 threshold value for the public (Taskin et al. 2009).

2.5.9 Analysis of Physical and Chemical Parameters of Soil Samples

The pH and electrical conductivity were measured by weighing 20g of air-dried soil samples (passed through 2-mm sieve) into a 50-ml beaker. After twenty (20) ml of distilled water were added, the mixture was allowed to stay for 30 minutes while occasionally stirred with a glass rod. pH meter electrodes were then inserted into the partly settled suspension to measure its pH and the electrical conductivity. The organic carbon content in soil samples was determined by wet oxidation method according to Walkley and Black (1934), and converted to organic matter by multiplying the percentage organic carbon by a factor of 1.729 (Black 1965). The particle size analysis was carried out by hydrometer method using sodium hexametaphosphate as the dispersant (Bouyoucos 1951). Exchangeable bases (cations) were determined using ammonium acetate method according to Thomas (1982).

2.5.10 Statistical Analysis

Descriptive statistical tools such as mean, range, standard deviation and so on were calculated for the obtained data. A correlation matrix was used to check for relationship between the soil radionuclide contents, chemical and physical parameters of the soil. A correlation matrix is a table showing correlation coefficients between sets of variables. Each random variable (Xi) in the table is correlated with each of the other values in the table (Xj). This allows to see which pairs have the highest correlation etc.

3. Results & Discussion

3.1 Physico-Chemical Properties of Soil Samples from Selected Mining Sites

The results of the physical and chemical parameters of soil samples from the eight mining sites are presented in Table 2. The obtained values for the following parameters include : pH (5.92 – 6.84), Electrical conductivity (EC) (18 – 77 dS/m), Organic carbon (OC) (0.14 – 0.66 g/kg), Organic matter content (OMC) (0.24 – 1.14 g/kg), %sand (61.52 – 87.52), %clay (0.48 – 16.48), %Silt (10-26%), Potassium (K) (5-13 mg/kg), Sodium (Na) (5 – 23 mg/kg), Calcium (Ca) (1.59 – 15.03 mg/kg) and Magnesium (Mg) (0.44 – 17.53 mg/kg) respectively. The soil of the sampling areas are slightly acidic, while the results of the elemental composition show that the soil samples of the mining sites are sandy loam soil using USDA classification (Miller 1994) with the magnitude being %sand > %silt > %clay.

Table 2: Physical and Chemical Parameters of soil samples per mining site (mean value ± SD)

Samples	pH	EC	OC	OMC	SAND	CLAY	SILT	K	Na	Ca	Mg
RR	6.28±0.25	23.00±7.00	0.19±0.05	0.32±0.09	84.19±5.77	3.15±1.15	12.67±4.62	8.67±2.52	12.33±4.16	12.16±2.49	11.88±4.89
RF	6.21±0.33	90.33±12.56	0.19±0.04	0.33±0.07	84.85±3.06	2.48±0.00	12.67±3.06	9.67±2.08	10.66±3.67	2.52±0.41	0.63±0.19
MM	6.24±0.17	55.33±11.01	0.63±0.26	1.08±0.45	75.52±10.00	5.81±6.11	18.67±4.16	8.33±3.06	9.67±4.16	7.82±1.73	5.22±1.49
DM	6.55±0.07	76.33±19.22	0.68±0.07	1.17±0.12	63.52±2.00	12.48±0.00	24.00±2.00	9.00±3.61	10.33±3.21	2.18±1.08	2.80±1.85
AZ	6.30±0.26	66.00±10.54	0.27±0.09	0.47±0.16	62.19±1.15	14.48±2.00	23.33±1.15	11.67±1.15	17.00±2.00	4.12±0.77	1.90±1.47
AK	6.26±0.29	63.00±11.00	0.37±0.02	0.64±0.04	76.85±2.31	3.15±1.15	20.00±2.00	5.00±1.73	11.00±4.36	2.55±0.88	1.93±2.08
AE	6.37±0.13	32.00±5.00	0.25±0.01	0.43±0.02	76.85±1.15	8.48±3.46	14.67±4.62	5.33±0.58	9.67±4.04	6.89±0.44	3.57±0.13
AD	6.55±0.25	61.33±13.80	0.57±0.04	0.99±0.07	72.85±8.33	7.81±3.06	19.33±7.02	8.00±1.00	20.67±2.52	6.74±0.79	3.29±0.59

Table 3: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th of rock samples per mining site (range and mean value ± SD)

Sample Location	Potassium(Bq/Kg)	Uranium(Bq/Kg)	Thorium(Bq/Kg)
RR(Range)	8086.60-8504.88	24.07-26.71	8.29-8.79
Average	8295.74±449.86	25.39±2.66	8.54±0.45
RF (Range)	5837.49-6250.50	22.10-23.46	7.93-9.61
Average	6044.00±279.66	22.78±1.60	8.77±0.38
MM (Range)	BDL	BDL	BDL
Average			
DM (Range)	6147.37-6490.52	16.49-18.37	11.15-11.82
Average	6332.45±237.45	17.43±1.41	11.49±0.54
AZ (Range)	1731.90-1821.90	17.03-17.42	7.03-7.42
Average	1776.90±135.29	17.23±0.33	7.23±0.33
AK (Range)	2143.16-2254.38	18.13-20.21	6.67-7.07
Average	2198.77±119.21	19.17±2.10	6.87±0.47
AE (Range)	7247.42-8521.04	19.18-24.26	16.49-17.32
Average	7884.23±267.57	21.72±1.95	16.91±0.81
AD (Range)	12364.88-13035.99	24.77-26.77	11.10-11.79
Average	12700.44±528.33	25.77±2.08	11.45±0.52
UNSCEAR (2000) World Range (Average)	140-850 (420)	17-60 (33)	11-64 (45)

Mean Detection Limits (MDL): ^{40}K=15.44; ^{238}U=8.09; ^{232}Th=3.09

3.2 Activity Concentration of ^{40}K, ^{238}U and ^{232}Th in rock and soil samples from the selected mining sites

The radioactivity concentrations of ^{238}U, ^{40}K and ^{232}Th in soil and rock samples were found to be low-level activities for both ^{238}U and ^{232}Th in the studied locations, whereas there were very high for ^{40}K in all the mining sites except for the rock samples collected from in Moro (MM) mining sites (where activity concentrations of ^{238}U, ^{40}K and ^{232}Th measured were below detection limits (BDL)) (Table 3). The average concentrations of ^{238}U in the soil and rock samples were slightly higher compared to that of ^{232}Th. This may be due to the fact that ^{238}U is found in more abundance than ^{232}Th in the environment (Ashraf *et al.* 2001; Nevas *et al.* 2002).

The result of the activity concentration of ^{40}K, ^{238}U and ^{232}Th of rock samples from the eight mining sites, presented in Table 4, showed that for all the locations ^{40}K ranged from <15.44-13035.99 Bq/kg, ^{238}U ranged from <8.09-26.77 Bq/kg and ^{232}Th ranged from <3.09-17.32 Bq/kg respectively. Both ^{40}K and ^{238}U were highest in Adudu (AD), while ^{232}Th was highest in the Alamis Eggon (AE) site. The Moro site had the lowest activity concentration for ^{40}K, ^{238}U and ^{232}Th. Both ^{238}U and ^{232}Th values were within the world range of 17 – 60 Bq/kg and 11 – 64 Bq/kg, whereas ^{40}K were far higher than the recommended safe limit of 140 – 850 Bq/kg given by UNSCEAR (2000). It was also found that the rock samples at Moro (MM) have all the radionuclides activity below detection limit which is due to the fact that the rock of that area is calcite (Table 3). The calcite rock contains carbonate zone through which the radionuclides become incorporated into the carbonate phase during solid solution reactions. This incorporation into the carbonate phase may hinder the radionuclide release rates for some radionuclides (John and Robert 2007) and thereby reduce the radionuclide concentrations.

Also, in Table 4 the activity concentration of ^{40}K, ^{238}U and ^{232}Th of soil samples from each of the mining sites is shown. ^{40}K ranged from 3001.87 – 14402.00 Bq/kg, ^{238}U from 11.82 – 31.61 Bq/kg and ^{232}Th from 3.28 – 17.98 Bq/kg respectively. The Azara (AZ) site had the highest value of ^{40}K, while Adudu (AD) site had the highest value for both ^{238}U and ^{232}Th. Both ^{238}U and ^{232}Th values were within the world range of 17 – 60 Bq/kg and 11 – 64 Bq/kg, whereas ^{40}K were far higher than the recommended safe limit of 140 – 850 Bq/kg given by UNSCEAR (2000).

The activity concentrations vary from site to site. In all sampling sites, mean activity concentration is of the order ^{232}Th <^{238}U <^{40}K, which is in agreement with the previous similar studies carried out by Gbadebo (2011), Okedeyi *et al.* (2012a;b). Potassium activities varied widely due to the heterogeneous nature of the soil characteristics. The relatively high values of ^{40}K were comparable with the values reported by Jankovic *et al.* (2011) and Okeyode and Akanni (2009), and this may be as a result of its

abundance in the earth crust (Tchokossa *et al.* 1999). High concentration of ^{40}K could be due to the presence of abundant radioactive clay minerals such as smectite kaolinite which is formed from feldspars components of rock samples from the mining sites which contains potassium as their constituent elements. This increasing trend of ^{40}K in the soils of the study area is supported by the presence of loamy and clay binding materials in the studied soils of the mining sites (El-Gamal *et al.* 2007).

3.3. Radiological Parameters

The values of the estimated radiological hazard indices such as 'Absorbed Dose Rate' (D), 'Radium Equivalent activity' (Raeq) 'Indoor Annual Effective Dose Rate' (IAEDR), 'Outdoor Annual Effective Dose Rate' (OAEDR), 'External Hazard Index' (Hex), 'Internal Hazard Index' (Hin), 'Representative Gamma Index' (Iγ) and 'Annual Gonadal Equivalent Dose' (AGED) from the activity concentration of ^{238}U, ^{232}Th and ^{40}K respectively help to assess the possible health effects of the radionuclides on people living in the study area, are presented (Table 5-6).

The results obtained for the annual gonadal dose equivalent and gamma absorbed dose rate (nGyh-1) at 1m above the ground due to ^{232}Th, ^{238}U and ^{40}K were above the permissible limit of 300μSv/yr and 60nGy/h (UNSCEAR 2000) for both rock and soil samples. This implies that the gonadal values may pose some threat to the reproductive organs of the miners and people in the areas of study.

Radium equivalent activity which is used to describe the gamma output from different mixtures of radium, thorium and potassium was below the permissible values of 370Bq/kg (UNSCEAR 2000) in rock samples of mining sites from Moro (MM), Azara (AZ) and Akiri (AK) and soil samples of Riri (RR), Raffin Gabbas (RF), Moro (MM) and Alamis Eggon (AE), while the values were above the permissible limit in soil and rock samples of other mining sites. Similarly, external hazard index and internal hazard index were less than the world permissible value of unity for rock samples of mining sites from Moro (MM), Azara (AZ) and Akiri (AK), while Riri (RR), Raffin Gabbas (RF), Moro (MM) and Alamis Eggon (AE) had values that were less than unity in soil samples. This indicates that the values may lead to various respiratory and external diseases in locations with higher values. Furthermore, the present values of indoor and outdoor annual effective dose equivalent were higher than the world average values (70μSv/y for outdoor and 450μSv/y for indoor) except in rock samples of Moro (MM). The indoor annual effective doses were in the range of 821.25 to 2655.07μSv/yr with an average of 1365.724μSv/yr for soil and 2.72 to 2690.38μSv/yr for rock while the outdoor annual effective doses were in the range of 205.31 to 663.77μSv/yr with an average value of 341.43 for soil and 0.70 to 672.59μSv/yr for rock

Table 4: Activity concentrations of ^{40}K, ^{238}U and ^{232}Th of soil samples per mining site (range and mean value ± SD)

Sample Location	Potassium(Bq/Kg)	Uranium(Bq/Kg)	Thorium(Bq/Kg)
RR(Range)	3193.30-4300.61	11.82-27.41	7.55-10.42
Average	3692.59±195.18	18.47±2.32	8.86±0.54
RF (Range)	3001.87-4383.30	16.42-27.82	7.64-10.55
Average	3659.59±186.46	20.45±2.34	8.87±0.50
MM (Range)	3640.84-4984.58	19.04-26.93	14.00-15.69
Average	4237.96±223.77	23.29±2.45	14.67±0.67
DM (Range)	7695.14-9644.77	21.38-26.53	8.09-15.59
Average	8711.92±446.03	23.39±2.63	12.68±0.76
AZ (Range)	10928.02-12221.65	15.90-18.31	10.50-14.35
Average	12517.22±529.09	16.99±2.64	12.77±0.87
AK (Range)	7110.14-9811.91	16.98-21.21	3.28-11.19
Average	8344.65±428.50	19.66±2.31	6.79±0.41
AE (Range)	3663.55-4505.54	17.27-19.76	6.94-8.52
Average	4061.56±331.05	18.54±0.99	7.81±0.36
AD (Range)	4462.26-5394.74	24.19-31.61	13.40-17.98
Average	4943.74±254.17	28.67±2.97	15.55±1.02
UNSCEAR (2000) World Range (Average)	140-850 (420)	17-60 (33)	11-64 (45)

Mean Detection Limits (MDL): ^{40}K=15.44; ^{238}U=8.09; ^{232}Th=3.09

Table 5: Mean radiation hazard indices in the rock samples per mining site

Sample Location	Raeq (Bq/kg)	D (nGy/h)	AEDEO (µSv/yr)	AEDEI (µSv/yr)	AGED (µSv/yr)	Hin	Hex	Iyr	ELCR (10^{-3})
Ririr (RR)	676.37	362.82	444.96	1779.85	2719.02	1.83	1.89	5.79	1557.36
Raffin Gabbas (RF)	500.71	267.86	328.50	1314.00	2004.87	1.35	1.41	4.27	1149.75
Moro (MM)	1.25	0.55	0.68	2.72	3.79	0.00	0.00	0.01	0.24
Dugbu Mada (DM)	521.46	279.06	342.23	1368.94	2090.28	1.41	1.46	4.45	1197.81
Azara (AZ)	164.39	86.42	105.99	423.96	641.41	0.44	0.49	1.37	370.97
Akiri (AK)	198.30	104.69	128.40	513.59	778.37	0.54	0.59	1.66	449.40
Alamis Eggon (AE)	652.99	349.02	428.04	1712.16	2613.45	1.76	1.82	5.57	1498.14
Adudu (AD)	1020.08	548.43	672.59	2690.38	4115.43	2.75	2.82	8.76	2354.07
World Limit (UNSCEAR, 2000)	**370**	**60**	**70**	**450**	**300**	**1**	**1**	**1**	**0.29 (10^{-3})**

Table 6: Mean radiation hazard indices in the soil samples per mining site

Location	Raeq (Bq/kg)	D (nGy/h)	AEDEO (µSv/yr)	AEDEI (µSv/yr)	AGED (µSv/yr)	Hin	Hex	Iyr	ELCR (10^{-3})
Ririr (RR)	315.48	167.87	205.88	823.51	1253.62	0.85	0.90	2.67	720.58
Raffin Gabbas (RF)	314.92	167.41	205.31	821.24	1249.38	0.85	0.91	2.66	718.59
Moro (MM)	370.59	196.34	240.80	963.18	1464.01	1.00	1.06	3.12	842.80
Dugbu Mada (DM)	712.34	381.75	468.18	1872.72	2860.82	1.92	1.99	6.09	1638.63
Azara (AZ)	1007.84	541.23	663.77	2655.07	4061.91	2.72	2.77	8.65	2323.20
Akiri (AK)	671.91	361.16	442.92	1771.69	2709.35	1.81	1.87	5.76	1550.22
Alamis Eggon (AE)	342.45	182.65	224.00	296.01	1365.26	0.92	0.97	2.91	784.00
Adudu (AD)	431.57	228.79	280.59	1122.36	1705.92	1.17	1.24	3.64	982.07
World Limit (UNSCEAR, 2000)	**370**	**60**	**70**	**450**	**300**	**1**	**1**	**1**	**0.29 (10^{-3})**

Table 7: Pearson correlation coefficient of radionuclides, physical & chemical parameters analysed for soil samples from <u>all</u> eight mining sites

	PH	EC	ORGANIC CARBON	ORGANIC MATTER	%SAND	%CLAY	%SILT	K	Na	Ca	Mg	^{40}K	^{238}U	^{232}Th
PH	1													
EC	-.222	1												
ORGANIC CARBON	.335	.167	1											
ORGANIC MATTER	.334	.169	1.000**	1										
%SAND	-.106	-.233	-.339	-.339	1									
%CLAY	.179	.110	.150	.150	-.873**	1								
%SILT	.016	.293	.435*	.436*	-.897**	.568**	1							
K	-.055	.338	.137	.135	-.164	.129	.160	1						
Na	.087	.235	.147	.146	-.187	.089	.235	.458*	1					
Ca	.031	-.650**	-.097	-.100	.364	-.267	-.372	.075	.094	1				
Mg	-.078	-.544**	-.086	-.089	.240	-.241	-.186	.138	-.020	.875**	1			
^{40}K	.506*	.112	.445*	.444*	-.552**	.573**	.412*	.204	.563**	-.127	-.204	1		
^{238}U	.042	-.430*	-.252	-.254	.087	.122	-.258	-.408*	-.276	.129	-.049	-.163	1	
^{232}Th	.210	-.534**	.055	.053	.127	.017	-.230	-.235	-.260	.213	.039	.042	.787**	1

both of which were higher compared with the world average value of 450µSvy^{-1}(indoor annual effective doses) and 70µSvy^{-1} respectively (UNSCEAR 2000). Excess lifetime cancer risks values estimated for this study were found to be higher than average world standard of 0.29x10^{-3}, suggesting that individuals exposed to this

radiation may develop cancer within their lifetime due to ionization of tissues (UNSCEAR, 2000).

3.4 Pearson Correlation Matrix

Pearson correlation coefficient of radionuclides, physical and chemical properties in soil samples of selected mining sites is shown in Table 7. The statistical evaluation of the analyzed parameters in the study areas indicated that there is a strong and positive correlation between organic matter and organic carbon (1.000), %silt and %clay (0.568), magnesium (mg) and calcium (Ca) (0.875), uranium and thorium (0.787), and sodium and potassium (^{40}K) (0.563) at 0.01 level of significance. This result is similar to the findings of Okedeyi *et al.* (2012a) where it was observed that there is a strong and positive correlation between organic matter and organic carbon, %silt and %clay and %silt and %sand. The relatively high radionuclide contents (in particular ^{40}K)in the soil and rock samples from the mining sites may be linked with the strong and positive correlation that exists between silt and clay contents of the soil samples, and this is in accordance with the findings of Gbadebo, (2011). Elevated levels of radionuclides in soils have been associated with finer materials such as silt and clay (Frederickson 1948; Baeza *et al.* 1995). There also exists strong negative correlation between electrical conductivity (EC) and calcium(-0.650), magnesium (-0.544) and thorium (-0.534); %sand and %clay (-0.873), %silt (-0.897) and potassium (^{40}K) (-0.552) at 0.01 level of significance indicates that increase in one will definitely leads to decrease in the other and vice versa.. The negative values of correlation matrix were suggestive of external sources of radionuclides in the area (Gbadebo, 2011).

Comparison of the results of this research with similar studies in Nigeria (Table 8) and around the world (Table 9) shows that the activity concentrations of ^{232}Th and ^{238}U in soil samples of this research work were lesser when compared with results locally and internationally but within the world standard set by (UNSCEAR 2000), while the activity concentrations of ^{40}K were extremely higher than the world standard and the result obtained from other area around the world.

4. Conclusion

The results obtained in this work indicated the existence of natural radionuclides

Table 8: Study results' comparison with similar research about Nigeria

Reserch	Location	^{238}U	^{232}Th	^{40}K
Gbadebo & Amos (2010)	Ewekoro	7.78	8.99	17.63
Girigisu *et al.* (2013)	Kebbi	23.85	18.80	425.96
Augustine & Aku (2014)	Itagunmodi	55.30	26.40	505.10
Okedeyi *et al.* (2012b)	Abeokuta	63.04	39.63	444.69
Masok et al. (2015)	Jos	132.6	351.40	319.60
Shittu *et al.* (2015)	Abuja	74.74	199.23	1021.27
Innocent *et al.* (2013)	Zamfara State	12.12	60.12	426.51
Ademola & Obed (2012)	Oke-Ogun	39.80	12.70	384.20
This study	**Nasarawa State**	**21.18**	**11.77**	**6271.15**
UNSCEAR (2000)	World Average	33	45	420

Table 9: Study results' comparison with similar research around the world

Research	Country	^{238}U	^{232}Th	^{40}K
Faanu *et al.* (2011)	Ghana	13.6	24.2	162.1
Manlanca *et al.* (1993)	Brazil	61.7	58.5	564
Amrani & Tahtat (2001)	Algeria	41	27	422
Berekta & Mathew (1985)	Australia	51.5	48.1	114.7
El Afifi *et al.* (2006)	Egypt	78	33	337
Alnour *et al.*, (2012)	Malayia	39	52	611
Asgharizadel *et al.* (2011)	Iran	74	44	586
Cetin *et al.* (2012)	Turkey	70	83	1234
Kinyua *et al.*, (2011)	Kenya	93.36	150.5	732.46
Abd El-mageed *et al.(* 2011)	Yemen	54	127	1743
This study	**Nigeria**	**21.18**	**11.77**	**6271.15**
UNSCEAR (2000)	World Average	33	45	420

at the various selected mining sites in Nasarawa State, Nigeria. The radioactivity concentrations of ^{238}U, ^{40}K and ^{232}Th in soil and rock samples taken from some mining sites in Nasarawa State as analyzed using sodium iodide detector showed that there were low-level activities in the studied locations for both ^{238}U and ^{232}Th, whereas there were very high activities for ^{40}K in all the mining sites except for the Calcite rock samples collected from mining sites in Moro (MM) in which all measured radionuclide activity were below detection limits (BDL).The measurement showed that ^{40}K has the largest contribution to the specific activities in all the soil samples analyzed. The results obtained for the annual gonadal dose equivalent and absorbed dose rate were above the permissible limit of 300μSv/yr and 60nGy/h (UNSCEAR 2000) for both rock and soil. This implies that the gonadal values may pose some threat to the health of the mine workers and the citizens. The results also show that the indoor annual effective dose from natural radioactivity had an average value higher than the natural world recommended value. The high level of gamma dose rates obtained may not have any immediate health hazards but could lead to some radiological problems for long-term exposure of people living or working around the mining fields, since the fields are radiologically unsafe. Therefore, rock and soil of the mining sites may not be suitable for construction of houses.

Based on this study, constant monitoring of the mining sites and periodic education of the mining workers is suggested. It is highly recommended that workers in all the mining sites should always put on their facemasks (Personal Protective Equipment) to protect themselves from the levels of radioactive contamination. Furthermore, mining areas should be far away from residential areas while routine assessment of radionuclide concentration in mine rocks and soils should be carried out.

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