Evaluation of Naturally Occurring Radionuclide in Soil Samples from Ajiwei Mining Sites in Niger State, Nigeria.

IK Suleiman[1], RU Ugbe[2] and M.Y. Onimisi[3]

[1,2&3] *Department of Physics, Nigerian Defence Academy, Kaduna, Nigeria.*

Authors' contributions

This study was carried out in collaboration amongst all the authors. Author IKS collected and prepared the field samples, participated in the laboratory procedures, performed the statistical analysis, wrote the draft of the manuscript and designed statistical analysis, and also Author RUU participated in the laboratory procedures and contributed in the statistical analysis. Author MYO supervised the analysis of the study. All authors read and approved the final manuscript.

ABSTRACT: *This study presents results of Activity Concentrations, Absorbed dose rate and the Annual Effective dose rates of naturally occurring radionuclides (^{40}K, ^{232}Th and ^{226}Ra) absorbed in 8 soil samples collected from different areas within the Ajiwei mining sites in Niger State, North Central Nigeria. A laboratory γ-ray spectrometry NaI (Tl) at the Centre for Energy Research and Training (CERT), Ahmadu Bello University Zaria, was used to carry out the analysis of the soil samples. The values of Activity Concentration for ^{40}K ranged from 421.6174 ± 7.9316 to 768.7403 ± 7.9315; for ^{226}Ra it ranged from 20.6257 ± 2.0858 to 44.0324 ± 5.0985 and for ^{232}Th the ranged is from 23.7172 ± 1.3683 to 62.7137 ± 4.1049 $Bq.Kg^{-1}$. While the Absorbed Dose for ^{40}K ranged from 17.5814 ± 0.3307 to 32.0565 ± 0.3307 $ηGy.h^{-1}$, for ^{226}Ra the range is from 9.5291 ± 0.9636 to 20.3430 ± 2.3555 $ηGy.h^{-1}$ and for ^{232}Th range from 14.3252 ± 0.4414 to 37.8791 ± 2.4794 $ηGy.h^{-1}$. The total average Absorbed Dose rate of the 8 soil samples collected is 63.7877 $ηGy.h^{-1}$ and the estimated Annual Effective Dose for the sampled areas range from 0.0636- 0.1028$mSvy^{-1}$ (i.e 64 – 103 $μSv.y^{-1}$), with an average Annual Effective Dose of 0.0782 $mSv.y^{-1}$ (i.e. 78.2 $μSv.y^{-1}$). These results show's that the radiation exposure level reaching members of the public in the study areas is lower than the recommended limit value of 1 $mSv.y^{-1}$ (UNSCEAR, 2000). Also the mean Radium Equivalents obtained ranged from 107.3259 $BqKg^{-1}$ (AJ1) to 179.4064 $BqKg^{-1}$ (AJ4). These results show that the recommended Radium Equivalent Concentration is ≤ 370 $BqKg^{-1}$ which is the requirement ^{for} soil materials to be used for dwellings, this implies that the soil from this site is suitable use for residential buildings. The mean External Hazard Index (H_{ext}) ranged from 0.1229 $Bqkg^{-1}$ (AJ3) to 0.4226 $Bqkg^{-1}$ (AJ7).. While the maximum allowed value of (H_{ext} = 1) corresponds to the upper limit of Ra_{eq} (370 $BqKg^{-1}$) in order to limit the external gamma radiation dose from the soil materials to 1.5 $mGy\ y^{-1}$. That is, this Index should be equal to or less than unity ($H_{ext} \leq$ = 1). Furthermore, the mean Internal Hazard Index (H_{ext}) ranged from 0.3456 $Bqkg^{-1}$ (AJ1) to 0.6453 $Bqkg^{-1}$ (AJ2) .Finally, the mean value of the Excess Alpha Radiation ($I_α$) ranged from 0.1031 $Bq.Kg^{-1}$ (AJ1) to 0.2202 $Bq.Kg^{-1}$ (AJ3. All these values for $I_α$ are below the maximum permissible value of $I_α$= 1 which corresponds to 200 $Bq.Kg^{-1}$. It can therefore be said that no radiological hazard is envisaged to dwellers of the study areas and the miners working on those sites area.*

Keywords*: Radionuclides", soil" mining",activity concentration" .absorbed dose " ,Niger state.*

I. INTRODUCTION

Radionuclide of natural origin is present in both working and public environments, although their activity concentrations vary considerably. Exposures to natural sources are in most cases not a matter for regulatory concern. However, there are situations where exposures to natural sources may warrant consideration as to whether controls should be applied. One such situation is where the conditions are conducive to the buildup of elevated concentrations of radon in air. Another situation is the mining and/or processing of material where the activity concentrations of radionuclide's of natural origin in the material itself, or in any material

arising from the process, are significantly elevated — such material, has come to be referred to as Naturally Occurring Radioactive Material (NORM). (IAEA-TECDOC-1472 – (2004)). In the past, regulatory attention has been focused mostly on exposures arising from the mining and processing of uranium ores because such activities are part of the nuclear fuel cycle. More recently, attention has been broadened to include exposures from other industrial activities involving NORM, in recognition of the potential for such activities to also give rise to significant exposures of workers and members of the public if not adequately controlled. More and more countries are now including provisions in their national legislation and regulations for the control of exposures to natural sources, and the body of radiological data on such exposures is growing rapidly. In recent times, there has been increase in the solid minerals mining in Niger State and some of the miners operate with operating license, while other operate without operating license, The areas, where the miners have been operating in recent time are in the exploitation of solid minerals such as copper, gold, quartz, limestone, diamond, tale, gypsum, calcite topaz apatite and a host of other minerals. This work examines the Ajiwei mining sites with a view of assessing the activity concentration and effective dose rate of naturally occurring radionuclides materials in these site. The exploration activities are also associated with a number of environmental degradations. One of such degradation is increase in radiation levels as a result of drilling the earth's crust in search of minerals, thereby stimulating major naturally occurring radioactive nuclei to release more radiations into the environment. Minerals are naturally occurring, solid chemical substances found in –situ in the earth's crust. A rock for example is an aggregate of several minerals. Therefore, it is of significance that the total amount of radioactivity in an environment is accurately known and kept to a level as low as reasonably achievable (ALARA) in order to safeguard the lives of the people, and ensure radiation- pollution free environment. Hence this work is an efforts geared towards protecting people and the environment from accumulation of higher doses of radiation. In the work, measurement of gamma radiation level in the mining sites of the selected areas was performed in the environmental laboratory using gamma spectroscopy system at the Centre for Energy Research and Training (CERT) Ahmadu Bello University (ABU), Zaria, Nigeria. This was used to assess the concentrations of NORM i.e. three most prominent primordial radionuclides, potassium, thorium and radium by determining the base line radioactivity associated with their occurrences in 8 soil samples collected from the Ajiwei mining sites of in Shiroro Local Government area in Niger State, North Central Nigeria. We also analyzed their possible effects on human lives due to occupational and settlement exposures from the mining sites. Finally, giving the results obtained, we made some recommendations.

II. MATERIALS AND METHODS

2.1 Sample Collections and Preparation

The study area is located Lat 27^0.00 min N Long 11^0.13 min E, as shown in figures 1&2, in the Ajiwei mining site in Shiroro Local Government area in Niger State, North Central Nigeria. A framework for the protection of the environment against the hazards of radiations from the minerals mining requires a logical methodology for proper assessment of the dose rate arising from the naturally occurring radionuclide. The methodology that was employed in carrying out this work includes careful collection of soil samples (of about 1 kg each) from the mining site as shown in Figure 1 and Figure 2, initially filled into polyethylene bags separately from respective points in equal measures sealed and labeled for easy of identification and transported to CERT ABU Zaria, Nigeria, for laboratory analysis. In the laboratory, the soil samples were put in an oven at a temperature of 105°C to allow for drying overnight in order to remove any available moisture. After drying, the samples were crushed and sieved with a mesh having holes each of diameter of 2mm in order to remove organic materials, stones and lumps. Thereafter, the homogenized samples were packed to fill cylindrical plastic beakers of 7cm by 6cm diameter which is the same as geometry of the counting detector. This satisfies the selected optimal sample container height.(Ibeanu IGE et al (2000)). The samples were carefully sealed using vaseline, candle wax and masking tape in order to prevent trapped radon gas from escaping.They were then weighed on a digital weighing balance with a precision of ±0.01g . Each plastic beaker accomodates approximately 300g of the soil sample. The sealed samples were kept for a minimum period of 30 days so as to allow for ^{226}Ra and its short-lived progenies to reach secular radioactive equilibrium before gamma counting(Okeyode IC, Akanni AO (2009;2(7)). The samples taken from Ajiwei are labeled as AJ 1- AJ8.

Figure 1: Ajiwei Mining Site Area.

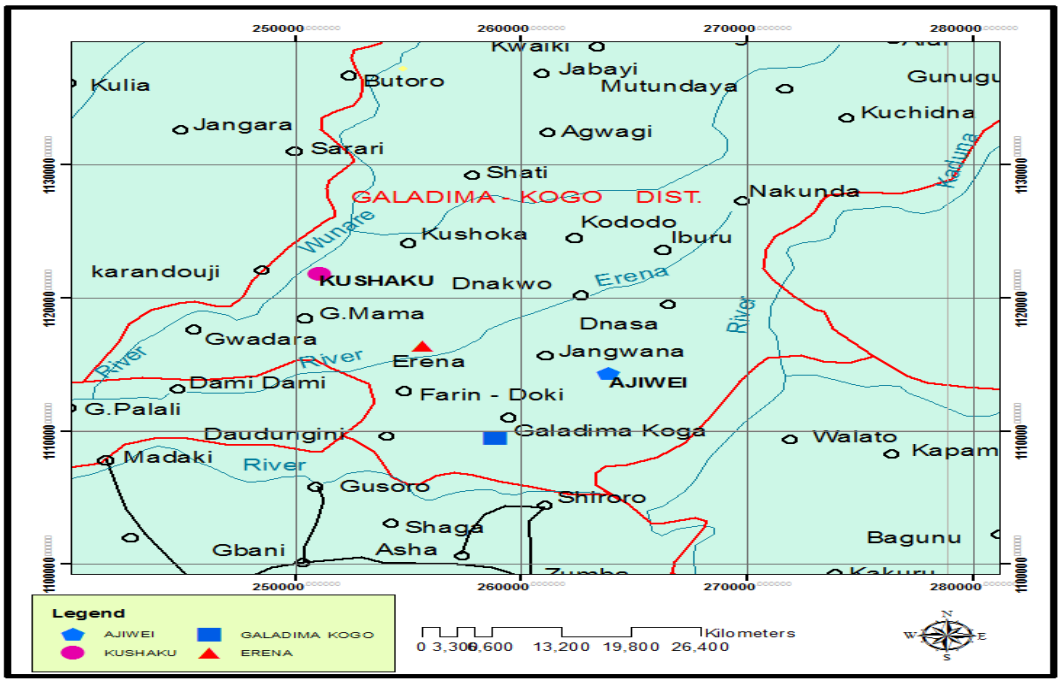


Figure 2 : Map of Ajiwei Mining Site Area.

2.2 The Experimental Set-up and Procedures for Sodium Iodine Thallium (NaI (Ti)) Detector Gamma Spectroscopy System.

The gamma-ray spectrometry operation of the NaI(TI) system was done in four procedures; i.e Initial Procedure, Startup Procedures, Spectrum Acquisition Procedure and Shut Down Procedure. The initial procedure was to ensure equipment settings were adhered to in terms of voltage supply to the equipment regulation as specified, however the initial high voltage supply was switch off. The startup procedure was to ensure that the operator was consciously starting the experiment by turning on the set up from the power button to booting of the

computer according to laid down regulations. The operating voltage for this equipment which was given as 900 volts was attained by turning the control knob in steps of 100, until one attains the desired level of 900 Volts was attained. The spectrum acquisition procedure which puts the set up in the spectra acquisition mode was carefully executed. After the computer booting process, the acquisition command was preset by setting the live time limits (which was about 29000 seconds i.e 8 hours 3 minutes 20 seconds), then the analog –to- digital converter (ADC) set up and the manual control to adjust the amplifier gain was setup according to specification and finally the startup command was given to commence counting for the background of the sample, for a specified time limit. The acquired spectrum and values of the live time were duly recorded in the already created save medium. After the completion of the experiment, the shutdown command or procedure allows for proper demobilization of the equipment, in accordance with the specified protocol, most especially the stepwise reduction of the voltage level from the highest operating point of 900 volts down to the 0 level. Then the computer was shut down. NaI (TI) gamma spectroscopy detection is one of the most preferred ways, to characterize dispersed radionuclides in or on the soil to ascertain possible changes in the environmental radioactivity. Most radiation measurement systems in nuclear science and technology use pulse height analysis to sort out different radiation energies striking the detector. This is called pulse height or energy spectrometry. It is used to identify the emission of unknown radionuclides and discriminate against background radiation sources, scattered radiation, etc. Pulse height spectrometry is used to examine the amplitudes of the signal (i.e. electrical current or light) from a radiation detector in order to determine the energies or for counting those detectors that provide output signals with amplitudes proportional to radiation energy detected.

III. RESULTS AND DISCUSSION

The peak area of each energy in the spectrum was used to compute the activity concentrations in each of the soil sample by the use of the equation (1):

$$C\ (Bq.kg^{-2}) = C_n / C_{fk} \qquad (1)$$

where C = activity concentration of the radionuclides in the sample given in $BqKg^{-1}$ Cn = Count rate (count per second) = count per second (cps) = Net/Live time. C_{fk} = calibration factor of the detecting system.

3.1 Calibration and Efficiency Determinations

Calibration of the system for the energy and efficiency were done with two calibration point source, Cs-137 and Co-60. These were done with the amplifier gain that gives 72% energy resolution for the 66.16 Kev of Cs-137 and counted for 30 minutes.

3.2 Standards to check for the calibration

The standards used to check for the calibration are the IAEA Gamma Spectrometric reference materials RGK-1 for K-40, RGU -1 for the Ra-226 (Bi – 214 peak) and RTG -1 For Th-232 (Ti -208). Background area count corresponding to the three radionuclides (i.e. ^{40}K, ^{226}R &^{232}Th) were measured and the evaluation of the results evaluated. The background count rate was done for 29000 seconds and the results obtained are given Table (1):-

Table 1: Background count rate used in the evaluations of the samples.

Serial	Isotope	Background Count (CPS)	Background Count (Bq/kg)
1.	^{40}K	0.2219± 0.017	345.1011±25.5940
2.	^{226}R	0.0229± 0.0109	26.5353± 12.6304
3.	^{232}Th	0.01202± 0.0078	137.0582± 8.8940

The gross area count $G_c$is related to the area count by through the expression (Okeyode IC and Akanni AO - 2009).

$$N_c = G_c - B_c \quad (2)$$

where B_c is the background area count, (area count recorded by the detector in the absence of the samples). Using equation (2), the net area counts N_c was calculated from the gross area counts G_c generated by the gamma spectroscopy system. Consequently, the net count per second (cps) was also calculated for the three radionuclides (^{40}K, ^{226}R & ^{232}Th).

3.3 Activity Concentrations

The activity concentrations for the natural radionuclides in the measured samples were computed using the following relation (Okeyode IC and Akanni AO (2009).

$$A_c = \frac{Nc}{lt}\sigma - 1 \quad (3)$$

where L_t is the lifetime of the counting, and σ is the conversion factor. It is constant for each radionuclide at a constant geometry and it is the characteristics of the efficiency of NaI (TI) detector assembly used in the analysis of the sample.

In Table 2, we presents the values of the conversion factor (σ) for the ^{40}K, ^{226}R and ^{232}Th (Umar AM, Onimisi MY, Jonah SA 2012).

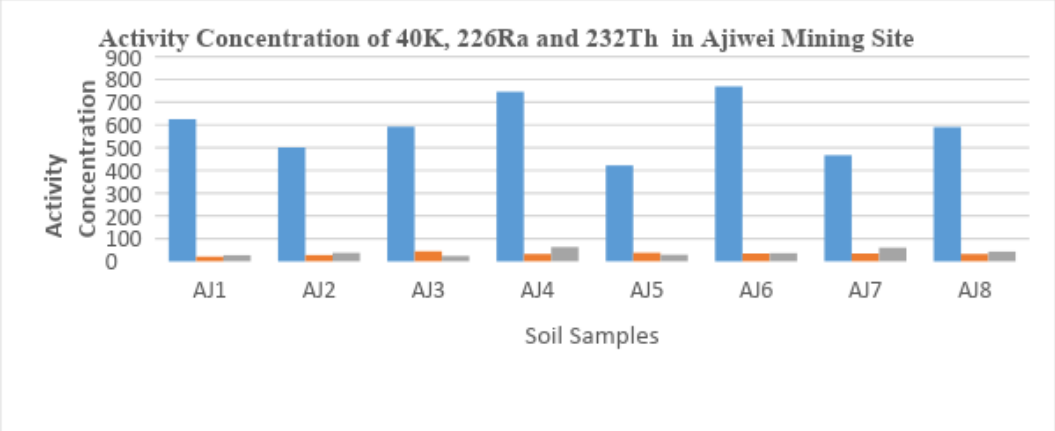
Table 2 presents the values of the conversion factor (σ) for the ^{40}K, ^{226}R and ^{232}Th.

Serial	Nuclides	CPS/Bq-kg^{-1}	Gamma ray line (KeV)
1.	^{40}K	0.000643	1460
2.	^{226}R	0.000863	1764
3.	^{232}Th	0.000877	2614.5

All the raw data obtained from the detector were converted to conventional units using calibration factors to determine the activity concentrations of ^{40}K, ^{226}R and ^{232}Th respectively. Using equation (3), the activity concentrations were calculated and the results obtained are presented in Table (3) and Figure (3).

Table 3: Activity Concentration of ^{40}K, ^{226}Ra and ^{232}Th in Ajiwei Mining Site Area.

Serial	Soil Sample ID	Activity Concentration of ^{40}K in Bqkg^{-1}	Activity Concentration of ^{226}Ra in Bqkg^{-1}	Activity Concentration of ^{232}Th in Bqkg^{-1}	Total Activity Concentration in Bqkg^{-1}
1.	AJ1	624.1058	20.6257	27.0239	671.7554
2.	AJ2	500.7776	27.5782	37.2862	565.642
3.	AJ3	590.9798	44.0324	23.7172	658.7294
4.	AJ4	745.4121	32.3291	62.7137	840.4549
5.	AJ5	421.6174	37.5435	28.9623	488.1232
6.	AJ6	768.7403	34.5307	35.8039	863.4667
7.	AJ7	466.4075	34.6466	60.0798	561.1339
8.	AJ8	590.6687	32.2132	42.6453	665.5272
9.	Total	4708.7092	263.5022	275.5870	5314.8327
10.	Mean	588.5887	32.9378	34.4484	664.3541



KEY: Series 1= ^{40}K ; Series 2 = ^{226}Ra and Series = ^{232}Th

Figure 3: Activity Concentration of ^{40}K, ^{226}Ra and ^{232}Th in Ajiwei Mining Site Are

3.4. Absorbed Dose Rates (D)

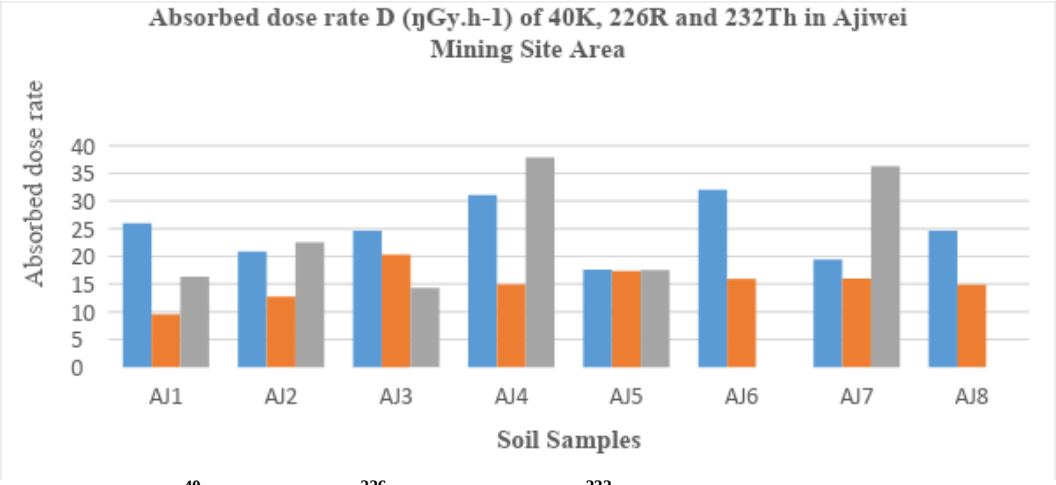
The Absorbed Dose is the energy imparted by radiation per unit mass of irradiated material. The gray **(Gy),** which has units of (j/ kg), is the SI unit of absorbed dose, and is the amount of radiation required to deposit 1 joule of energy in a kilogram of any kind of matter. The external absorbed dose rate D (ŋGy.h^{-1}) due to gamma radiation in air at 1 meter height above the ground level due to activity concentrations of ^{40}K, ^{226}R and ^{232}Th for the 7 soil samples were evaluated based on international standard guide lines using equation (4) (UNSCEAR . No.224, NY 2000) below.

$$D\ (\text{ŋGy.h}^{-1}) = 0.0417A^{40}{}_{K} + 0.462A^{226}{}_{Ra} + 0.604A^{232}{}_{Th} \qquad (4)$$

where A^{40}K, A^{226}R and A^{232}Th; are the activity concentrations of ^{40}K, ^{226}R and ^{232}Th respectively in Bq.kg^{-1}. The conversion factors 0.0417, 0.462 and 0.604 are expressed in ŋGy.h^{-1}/ Bq.kg^{-1}**.** The absorbed dose rates in air are usually related to human absorbed dose in order to assess radiological implications. Hence, Table (4) and figure (4) presents the results of the external Absorbed Dose rate D (ŋGy.h^{-1}) in air at 1m above the ground level due to activity concentrations of ^{40}K, ^{226}R and ^{232}Th for the 8 soil samples investigated. ,

Table 4: Absorbed dose rate D (ŋGy.h^{-1}) of ^{40}K, ^{226}R and ^{232}Th in Ajiwei mining Site Area

Serial	Sample ID	^{40}K(ŋGy.h^{-1})	^{226}Ra(ŋGy.h^{-1})	^{232}Th(ŋGy.h^{-1})	Total D(ŋGy.h^{-1})
1.	AJ1	26.0252	9.5291	16.3224	51.8767
2.	AJ2	20.8824	12.7411	22.5209	56.1444
3	AJ3	24.6439	20.3430	14.3252	59.3121
4.	AJ4	31.0837	14.9360	37.8791	83.8988
5.	AJ5	17.5814	17.3451	17.4932	52.4197
6.	AJ6	32.0565	15.9531	21.6256	69.6352
7.	AJ7	19.4492	16.0067	36.2882	71.7441
8.	AJ8	24.6309	14.8825	25.7578	65.2712
9.	Total	196.3532	121.7366	192.2124	510.3022
10	Mean	24.5441	15.2171	24.0266	63.7877



KEY: Series 1= ^{40}K ; Series 2 = ^{226}Ra and Series = ^{232}Th

Figure 4: Absorbed dose rate D (ŋGy.h^{-1}) of ^{40}K, ^{226}R and ^{232}Th in Ajiwei mining Site Area.

3.5. Annual Effective Dose Rates (E_d)

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose in air to effective dose (0.7Sv.Gy^{-1}) and outdoor occupancy factor (0.2) proposed by (UNSCEAR 2000; Harb et al., 2010 and (Agbalagba et al, 2011)) were used. In this work therefore, we calculated the annual effective dose rates (mSv.yr^{-1}) using their formula:

Annual effective dose rate (mSv/yr) (E_d) =

$$E_d = D\ (\text{ŋGy.h}^{-1}) \times 8760\ (\text{hr.y}^{-1}) \times 0.2 \times (0.7 \times 10^3\ \text{mSv}) \times (10^9\text{ŋGy})^{-1} \quad (5)$$

where 8760 (i.e. 365 x 24 hours of the day) is the numbers of hours in one year.

Equation (5.5) simplifies into such that,

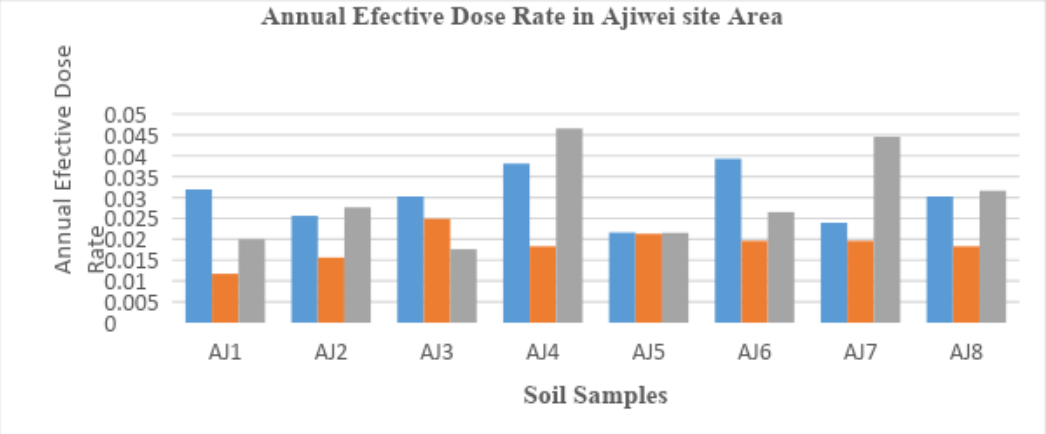
$$E_d = D \times 1.21 \times 10^{-3}\ (\text{mSv/yr}) \quad (6)$$

where E_d is the annual effective dose rate in $(mSv\ .y^{-1})$and D is the value of absorbed dose rate earlier calculated from equation (4). Table (5) and figure (5) present the calculated Annual Effective Dose Rates (E_d) $(mSv\ .y^{-1})$ for the investigated soil samples.

Table 5: Annual Effective Dose Rates $E_d(mSv\ .y^{-1})$ for Ajiwei Area

Serial	Sample ID	^{40}K $(mSv\ .y^{-1})$	^{226}R $(mSv\ .y^{-1})$	^{232}Th $(mSv\ .y^{-1})$	Total D $(mSv\ .y^{-1})$
1.	AJ1	0.0319	0.0117	0.0200	0.0636
2.	AJ2	0.0256	0.0156	0.0276	0.0689
3.	AJ3	0.0302	0.0249	0.0176	0.0727
4.	AJ4	0.0381	0.0183	0.0465	0.1028
5.	AJ5	0.0216	0.0213	0.0215	0.0643
6.	AJ6	0.0393	0.0196	0.0265	0.0854
7	AJ7	0.0239	0.0196	0.0445	0.0880

8.	AJ8	0.0302	0.0183	0.0316	0.0800
9	Total	0.2106	0.1297	0.2358	0.6257
10	Mean	0.0263	0.0162	0.0295	0.0782



KEY: Series 1= ^{40}K; Series 2 = ^{226}Ra and Series = ^{232}Th

Figure 5: Annual Effective Dose Rate in Ajiwei Site Area.

3.6. Radium Equivalent

The Magnitude of radiation exposure from natural soil materials is strictly connected with the radium, thorium and potassium contents in the soil material and also on ventilation conditions; hence the Ra-equivalent concentration Ra_{eq} is a useful and instructive quantity which is internationally accepted parameters that is applied to describe the suitability or otherwise of a soil material for construction or farming purposes. The radium equivalent in the samples was estimated using equation (7):

$$Ra_{eq} = C_{Ra} + (C_{Th} \times 1.43) + (C_k \times 0.077) \leq 370 \text{ Bqkg}^{-1} \quad (7)$$

The value of this parameter should be less than 370 Bqkg^{-1} so as to keep the annual radiation dose below 1.5 mGy y^{-1} (UNSCEAR 2000). The results obtained for Ra_{eq} are presented in Table (6) and figure (6). The results obtained shows that, the mean radium equivalents ranged from 82.7770 BqKg^{-1} (ER4) to 171.9653 BqKg^{-1}(ER2).The results show that the recommended radium equivalent concentration of $\leq$ 370 BqKg^{-1} for soil materials to be used or dwellings by as by OECD (Organization for Economic Cooperation Development) and cited by Ahmad Hussein, (1998) is met by the soils collected around the mine sites. This behavour of radium equivalent activity is similar to that of radiation dose rate i.e. if the value of absorbed dose rate is high, the value of radium equivalent activity is also high and vice-versa.

Table 6: Radium Equivalent in the investigated Soil Samples.

Serial	Soil Sample ID	Radium Equivalent Ra_{eq} of the Soil Samples Bqkg-1
1.	AJ1	107.3259
2.	AJ2	119.4574
3.	AJ3	123.4534
4.	AJ4	179.4064
5.	AJ5	111.4241
6.	AJ6	144.9232

7.	AJ7	156.4741
8.	AJ8	138.6775

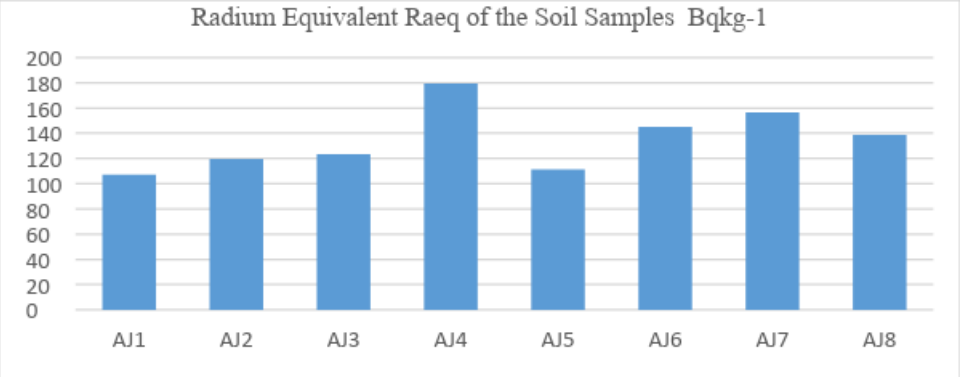


Figure 6: Radium Equivalent in the investigated Soil Samples.

3.7. External Hazard Index

The external hazard index (H_{ext}) is a criterion used for evaluation of external exposure to gamma radiation in the air. This has served as safety criterion in many countries of the world. It was proposed by Krisiuk et al (1971) and supported by Stranden (1976) and was used by Berektka and Mathew in 1985. In order to limit the external gamma radiation dose from the soil materials to 1.5 mGy y^{-1} this index should be equal to or less than unity ($H_{ext} \leq = 1$). The maximum allowed value ($H_{ext} = 1$) corresponds to upper limit of Ra_{eq} (370 $BqKg^{-1}$). (Beretka and Matthew), A widely used hazard index (reflecting external exposure) called the external hazard index Hex is defined as follows (UNSCEAR 2000).

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_k/4810 \quad (8)$$

The results obtained are shown in Table 7 and figure 7**.** The mean external hazard index ranged from 0.2236 $Bqkg^{-1}$ (ER4) to 0.5003 $Bqkg^{-1}$ (ER6).

Table 7: External Hazard index of the Soil Samples in Ajiwei Mining Sites

Serial	Soil Sample ID	External Hazard index of the Soil Samples
1.	AJ1	0.2898
2.	AJ2	0.3226
3.	AJ3	0.1229
4.	AJ4	0.4845
5.	AJ5	0.3010
6.	AJ6	0.3913
7.	AJ7	0.4226
8.	AJ8	0.3746

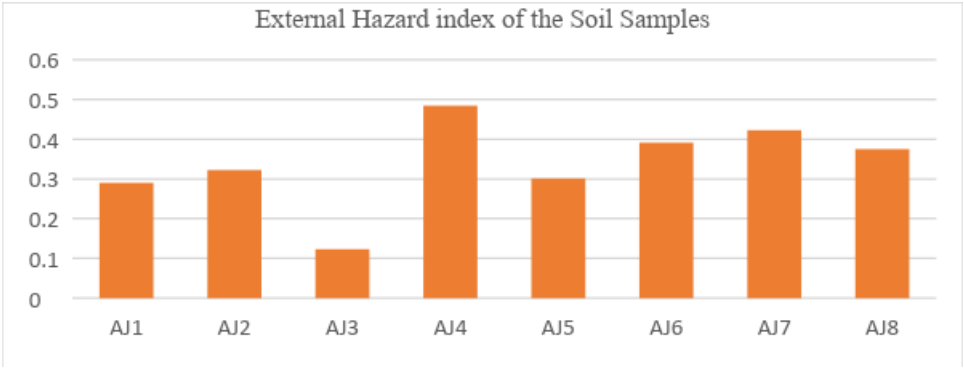


Figure 7: External Hazard Index in Ajiwei Mining Site Area.

3.8. Internal Hazard Index

Radon and its short lived progeny are also hazardous to the respiratory organs. Thus in addition to the external hazard index, internal exposure to radon and its daughter progenies is quantified by the internal hazard index H_{in} which is given by the equation (UNSCEAR 2000) :

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_k/4810 \quad (9)$$

The values of the indices (H_{ex}, H_{in}) must be less than unity for the hazard to be negligible (Agbalagba et al 2011). Hence results obtained are shown in Table 8 and figure 8.

Table 8: Internal Hazard Index of the Soil Samples inAjiwei Mining Sites.

Serial	Soil Sample ID	Internal Hazard Index of the Soil Samples
1.	AJ1	0.3456
2.	AJ2	0.6453
3.	AJ3	0.4525
4.	AJ4	0.5719
5.	AJ5	0.4024
6.	AJ6	0.4847
7.	AJ7	0.5163
8.	AJ8	0.4616

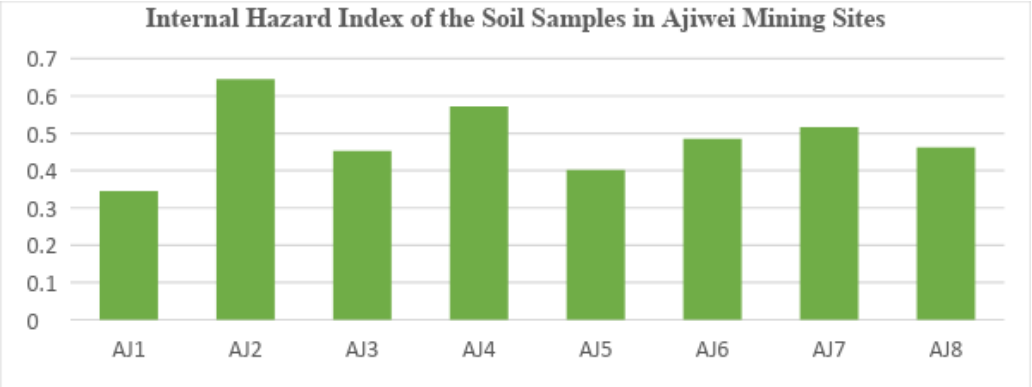


Figure 8: Internal Hazard Index of the Soil Samples in Ajiwei Mining Sites

3.9. Excess Alpha Radiation

The use of soils from and around these mining sites may pose external radiation and internal hazard to the dwellers and miners as a result of inhalation of radon and its decay products, which are predominantly alpha emitters. The excess alpha radiation due to radon inhalation originating from soil materials is estimated using the relation below (Isinkaye and Shitta, 2009):

$$I_{\alpha} = C_{Ra}/ 200 \qquad (10)$$

The mean value of excess alpha radiation (I_{α})calculated in this work ranged from 0.1165 $Bq.Kg^{-1}$ to 0.3766 $Bq.Kg^{-1}$, These results obtained are shown in Table 9 and figure 9**.** All these values for I_{α} are below the maximum permissible value of I_{α}=1 which corresponds to 200 $Bq.Kg^{-1}$. It can therefore be said that no radiological hazard is envisaged to dwellers and miners in the of study areas.

Table 9: Excess Alpha Radiation of the soil samples in Ajiwei Mining Sites

Serial	Soil Sample ID	Excess Alpha Radiation of the Soil Samples
1.	AJ1	0.1031
2.	AJ2	0.1379
3.	AJ3	0.2202
4.	AJ4	0.1616
5.	AJ5	0.1877
6.	AJ6	0.1727
7.	AJ7	0.1732
8.	AJ8	0.1611

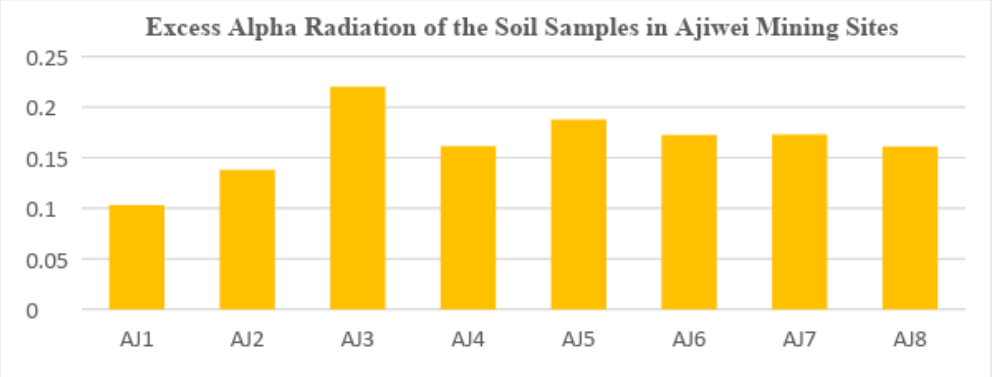


Figure 9: Excess Alpha Radiation of the soil samples in Ajiwei Mining Sites.

IV. RECOMMENDED DOSE LIMIT EXPOSURE TO NATURAL RADIATION SOURCES.

The Table 10 below gives an average worldwide exposure to natural radiation sources for occupational persons and member of the public.

Table 10: Recommended Dose Limit Exposure to Natural Radiation Sources.

APPLICATION	DOSE LIMIT	
	OCCUPATIONAL EXPOSED PERSON	MEMBER OF THE PUBLIC
Effective Dose	20 mSv per year average over 5 consecutive calendar years	1 mSv in a year
Equivalent dose to :		
1. Lens of the eye	150 mSv in a year	15 mSv in a year
2. Skin	500 mSv in a year	50 mSv in a year
3. Hands and Feet	500 mSv in a year	No limit specified

SOURCE: HRD-WHS-GUI-144.6 Appendix C (2012 October).

NOTE 1: With the further provision that the effective dose must not exceed 50mSv in any single year (provided the 100 mSv (max) dose averaged over 5 years is maintained). Recommended tissue weighting factors are listed in the Radiation Safety guidelines to determine whole body dose and tissue relationship

V. DISCUSSION

The method of gamma spectrometry was used to measure the radioactivity concentration of soil samples collected from the mining sites of Ajiwei in Shiroro Local Government area of Niger State, North Central Nigeria. The result shows that, the highest radioactivity concentration of ^{40}K was found in soil sample AJ6 with 768.7403 $BqKg^{-1}$ (AJ6) this high value could be due to the presence of abundant radioactive minerals such as kaolinite, feldspars and so on in the sample. The radioactivity concentration order was followed by soil sample AJ4 with 745.4121 $Bqkg^{-1}$. The least radioactivity concentration of ^{40}K was found in soil samples AJ5 with 421.6174 $Bqkg^{-1}$ .The highest radioactive concentration of ^{226}Ra was found in soil sample AJ3 with 44.0324 $Bqkg^{-1}$(Table 3, Fig.3). This high value of ^{226}Ra concentration could be due to high presence of uranium minerals such as uraninite, zircon, and monazite and so on. The radioactivity concentrations orders of ^{226}Ra were followed by soil samples AJ5 and AJ7 with 37.5435 and 34.6466 $Bqkg^{-1}$ respectively. Soil sample AJ1 had the lowest radioactivity concentration of 20.6257 $Bqkg^{-1}$.Also, the highest radioactive concentration of ^{232}Th was found in soil sample AJ4 with 62.7137 $Bqkg^{-1}$(Table 3 and Fig.3).This could be due to presence of abundant radioactive thorium minerals such as monazite, zircon and thorianite (Okeyode et al., 2009).The least radioactivity concentration of ^{232}Th was also found in soil sample AJ3 with 23.7172 $Bqkg^{-1}$.The result also shows that the total concentration of ^{266}Ra is 263.5022 $BqKg^{-1}$ which is less than that of ^{232}Th which has a total concentration of 275.5870 $BqKg^{-1}$, while ^{40}K leads the table of radioactivity concentrations with total value of 4708.7092 $BqKg^{-1}$.From Table 4, and Fig 4, it shows that the absorbed dose rate due to the three radionuclides is highest for soil sample AJ4 with absorbed dose rate of 83.8988 $ŋGy.h^{-1}$, this might be due to accumulation of mineral sands from different mining sites. The average absorbed dose rate of the soil samples is 63.7877 $ŋGy.h^{-1}$.According to Table 4, ^{40}K had the highest value of total absorbed dose rate of 196.3532 $ŋGy.h^{-1}$ among the three radionuclides detected in the soil samples collected, thus it had the highest dose level in the study areas follow by ^{232}Th which has the total absorbed dose rate of 192.2124 $ŋGy.h^{-1}$, while ^{226}Ra had the least total absorbed dose rate of 121.7366 $ŋGy.h^{-1}$. From Table 5 and figure 5, the annual effective dose rate in air at the study area ranged from 0.0636 - 0.1028 $mSv.y^{-1}$ and the average annual effective dose rate in air at the study area was 0.0782 $mSv.y^{-1}$ which is slightly less than the maximum recommended world average outdoors exposure to external terrestrial radiation. (UNSCEAR, 2000). Thus, the exposure level for the members of general public is still within the

recommended value of 1 $mSv.y^{-1}$ (IAEA, 1999) &UNSCEAR (2000; No.224 NY):).

Therefore, this is an indication that the mining activities in the study areas do not appear to have any impact on the radiation burden of the environment. The Ra-equivalent concentration (Ra_{eq}) is a useful and instructive quantity which is an internationally accepted parameters that is applied to describe the suitability or otherwise of any soil material for construction or farming purposes, Hence the value of this parameter should be less than 370 $Bqkg^{-1}$ so as to keep the annual radiation dose below 1.5 mGy y^{-1}(UNSCEAR, 2000). The results obtained for Ra_{eq} as presented in Table 6 and figure 6, shows that, the mean radium equivalents obtained ranged from 107.3259 $BqKg^{-1}$ (AJ1) to 179.4064 $BqKg^{-1}$ (AJ4). This results show that the recommended radium equivalent concentration of $\leq$ 370 $BqKg^{-1}$for soil materials to be used for dwellings by OECD (Organization for Economic Cooperation Development) Ahmad Hussein, 1998) is applicable to the soils collected around the mine sites. These behavour of radium equivalent activity is similar to that of radiation dose rate i.e. if the value of absorbed dose rate is high, the value of radium equivalent activity is also high and vice-versa.The external hazard index (H_{ext}) is also a criterion used for evaluation of external exposure to gamma radiation in the air, this has served as a safety criterion in many countries of the world. It was proposed by Krisiuk et al (1971) and supported by Stranden (1976) and was used by Berektka and Mathew in 1985.In order to limit the external gamma radiation dose from the soil materials to 1.5 mGy y^{-1} this index should be equal to or less than unity ($H_{ext} \leq = 1$). The maximum allowed value (H_{ext}= 1) corresponds to upper limit of Ra_{eq} (370$BqKg^{-1}$). (Beretka and Matthew) .These results as obtained are shown in Table 7 and figure 7, which show that the, mean external hazard index (H_{ext}) ranged from 0.1229 $Bqkg^{-1}$ (AJ3) to 0.4226 $Bqkg^{-1}$ (AJ7). The use of soils from and around these mining sites may pose external radiation and Internal Hazard as a result of inhalation of radon and its decay products, which are predominantly alpha emitters to dwellers and miners. The mean Internal Hazard index (H_{ext}) ranged from 0.3456 $Bqkg^{-1}$ (AJ1) to 0.6453 $Bqkg^{-1}$ (AJ2) as shown in Table 8 and figure 8.The mean value of Excess Alpha Radiation (I_α) ranged from 0.1031 $Bq.Kg^{-1}$ (AJ1) to 0.2202 $Bq.Kg^{-1}$ (AJ3) and this is presented in table 9 and figure 9. All these values for I_α are below the maximum permissible value which is I_α=1 which corresponds to 200 $Bq.Kg^{-1}$. It can therefore be said that no radiological hazard is envisaged to dwellers of this Ajiwei study areas and the miners working on these sites.

VI. CONCLUSION

This study presents results of Activity Concentrations, Absorbed dose rate and the Annual Effective dose rates of naturally occurring radionuclides (^{40}K, ^{232}Th and ^{226}Ra) absorbed in 8 soil samples collected from different areas within the Ajiwei mining sites in Niger State, North Central Nigeria. A laboratory γ-ray spectrometry NaI (Tl) at the Centre for Energy Research and Training (CERT), Ahmadu Bello University Zaria, was used to carry out the analysis of the soil samples. The values of Activity Concentration for ^{40}K ranged from 421.6174 ± 7.9316 to 768.7403 ± 7.9315; for ^{226}Ra it ranged from 20.6257 ± 2.0858 to 44.0324 ± 5.0985 and for ^{232}Th the ranged is from 23.7172 ± 1.3683 to 62.7137 ± 4.1049 $Bq.Kg^{-1}$. While the Absorbed Dose for ^{40}K ranged from 17.5814 ± 0.3307 to 32.0565 ± 0.3307 $ŋGy.h^{-1}$, for ^{226}Ra the range is from 9.5291 ± 0.9636 to 20.3430 ± 2.3555 $ŋGy.h^{-1}$ and for ^{232}Th range from 14.3252 ± 0.4414 to 37.8791 ± 2.4794 $ŋGy.h^{-1}$. The total average Absorbed Dose rate of the 8 soil samples collected is 63.7877 $ŋGy.h^{-1}$ and the estimated Annual Effective Dose for the sampled areas range from 0.0636- 0.1028$mSvy^{-1}$ (i.e 64 – 103 $\mu Sv.y^{-1}$), with an average Annual Effective Dose of 0.0782 $mSv.y^{-1}$ (i.e. 78.2 $\mu Sv.y^{-1}$). These results show's that the radiation exposure level reaching members of the public in the study areas is lower than the recommended limit value of 1 $mSv.y^{-1}$ (UNSCEAR, 2000). Also the mean Radium Equivalents obtained ranged from 107.3259 $BqKg^{-1}$ (AJ1) to 179.4064 $BqKg^{-1}$ (AJ4). These results show that the recommended Radium Equivalent Concentration is $\leq$ 370 $BqKg^{-1}$ which is the requirement ^{for} soil materials to be used for dwellings, this implies that the soil from this site is suitable use for residential buildings. The mean External Hazard Index (H_{ext}) ranged from 0.1229 $Bqkg^{-1}$ (AJ3) to 0.4226 $Bqkg^{-1}$ (AJ7).. While the maximum allowed value of (H_{ext} = 1) corresponds to the upper limit of Ra_{eq} (370 $BqKg^{-1}$) in order to limit the external gamma radiation dose from the soil materials to 1.5 mGy y^{-1}. That is, this Index should be equal to or less than unity ($H_{ext} \leq = 1$). Furthermore, the mean Internal Hazard Index (H_{ext}) ranged from 0.3456 $Bqkg^{-1}$ (AJ1) to 0.6453 $Bqkg^{-1}$ (AJ2) .Finally, the mean value of the Excess Alpha Radiation (I_α) ranged from 0.1031 $Bq.Kg^{-1}$ (AJ1) to 0.2202 $Bq.Kg^{-1}$ (AJ3. All these values for I_α are below the maximum permissible value of I_α= 1 which corresponds to 200 $Bq.Kg^{-1}$. It can therefore be said that no radiological hazard is envisaged to dwellers of the study areas and the miners working on those sites area.

ACKNOWLEDGEMENTS

We are grateful to the staff and

management of Nigerian Defence Academy Kaduna, Nigeria and Centre for Energy Research and Training, Ahmadu Bello University Zaria, Nigeria for their support and encouragement during the course of this work.

COMPETING INTEREST

There is no competing interest whatsoever that could have influenced the results of this study in any manner.

REFERENCES

[1.] Agbalagba, E.O and Onoja, R.A. (2011). Evaluation of natural radioactivity in soil, Sediment and water samples of Niger Delta (Biseni) flood plain lakes, Nigeria. *Journal of Environmental Radioactivity*, 102,667-671.

[2.] Ahmad, M.N and Hussein, A.J (1998).Natural radioactivity in Jordian soil and buiding materials and the associated irradiation hazards .*J. Environ. Radioactive* 39(1): 9-22.

[3.] Ajayi,O.S. (2009) : Measurement of activity concentrations of ^{238}U, ^{232}Th and ^{40}K for the assessment of radiation hazards from soil of southern region of Nigeria where thirty (38) samples were analysed and obtained range of activity for the respective nuclides from which radiological indices were estimated. *Radiation Environ Biophys , 48, 323-332*.

[4.] Alatise O.O., Babalola,I.A., Olowofela.,J.A,(2008).Studies on the radiation level and radionuclide distribution of prominent NORM in the soil of coastal areas of Southern Nigeria provided useful baseline data for effective monitoring of potential radioactive fallout due to industrial activities in the five coastal oil producing states. *Journal of Environmental Radioactivity, 99(11), 1746- 1749.*

[5.] Auwal, M.M. Funtua, Mallam, S.P.,Abdullahi, A.S. (2010).Distribution of some natural gamma radionuclides in soils around the centre for energy research and training (CERT) Ahmadu Bello University, Zaria, Zaria- *Nigeria. Journal of American Science,6(12),995-1001.*

[6.] Beretka, J and Mathew. P (1985). Natural radioactivity of Australian building materials industrial wastes and by-products. *Health Physics.48, 87-95*.

[7.] Faweya A.E.B and Oniya E.O.(2012;10(5)): A study on Radiological Safety Assessment and Physico- Characterization of soil mixed with mine tailings used as building materials from Oke-Kusa Mining sites in Ijero, Nigeria. Nature and Science, 10(5).

[8.] CERTZ (1999): *Operation of Sodium Iodide-Thallium Gamma Spectrometry System Manual, Centre for Energy Research and Training Manual, ABU, Zaria, Nigeria*.

[9.] Christiana A, Onimisi MY and Jonah SA (2010): Determination of Naturally Occurring radionuclide's along River Kaduna, *Personal Communication*.

[10.] Harb, S., Salahel, D. K Abbady, A., Mostafa, M (2010): *Activity concentration for surface soil samples collected from Armant, Qena, Egypt*. Proceedings of the 4th Environmental Physics Conference, Hurghada, Egypt. 2010: 2010 ;(4): 49-57.

[11.] HRD-WHS-*GUI-144.6 Appendix C* - Dose Limits for Exposure to Ionizing Radiation 2012 October Page 1 of 1.

[12.] Ibeanu, I.G.E., Funtua I.I, Adeyeme D.J., Bappah A.I., Umar I.M. (2000) *Radiation Monitoring Programme for the Centre for Energy and Training (CERT) Nuclear research site and environs*. Second technical report of the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria CVERT /MNSR/RMP/02.

[13.] IAEA (1999): *Safety report on radiation protection and the management of a radioactive waste in mine, oil and gas industries*, International Atomic Energy Agency, New York.

[14.] IAEA (2011): *Nuclear Safety Review for the Year 2010,* International Atomic Energy Agency, Publication by the IAEA in Austria.

[15.] IAEA-TECDOC-1472 (2004); Naturally occurring radioactive materials (NORM IV)
Proceedings of an international conference held in Szczyrk, Poland, 17–21 May 2004
October.

[16.] Innocent A, Onimisi MY, and Jonah SA,(2013): A Study to Evaluate the Naturally occurring Radionuclides Materials (NORM) ii soil samples collected from some mining

sites in Zamfara State, Nigeria using NaI(TI)detector. *British Journal of Applied Science & Technology- 3(4):684-692.*

[17.] Isinkaye M.O and Faweya, E.B.(2006).Occurrence of natural radionuclides in refuse dumpsites within the city of Ado-Ekiti. South Western Nigeria. *Cent. Euro.J of occup.and Environ. Med. 12(1):9-14.*

[18.] Jonah, S.A, Okunade, I.O., Ibeanu, I.G.E., Jimba, B.W. (2002). Natural radionuclides and elemental composition of chemical fertilizers used in Nigeria. *Nucl. Sci* .4(1), 49-52.

[19.] Jibrin and Okeyode I.C. (2012).Natural radionuclides in the sediments of Ogun River in South Western Nigeria determined using Gamma-ray Spectrometry compared well withthe values from other countries of normal radiation areas. *Radiation Physics and Chemistry, 81,103-112.*

[20.] Krisuik, E.M Tarasov, S.I. Shamov, V.P, Shalak, N.I. Lisa Chenko, E.P and Gomelsky, L.G.A (1971). *Study on radioactivity in building materials* (Leningradi: Research Institute for Radiation Hygiene).

[21.] Mangset W.E and Sheyin A.T, 2009).Measurement of Radionuclides in processed mine tailings in Jos,Plateau State using NaI(TI)detector. *Bayero Journal of pure and Applied Science 2(2): 56-60.*

[22.] Odumo, O.B., Mustapha, A.O., Patel, J.P., Angeyo, H.K., (2011): Radiological survey and assessment of the naturally occurring radioactive materials (NORM) in the migori artisanal gold mining belt of southern Nyanza, *Kenya Applied Radiation and Isotopes, 69,912-916.*

[23.] Okeyode I.C and Akanni A.O. (2009): Determination of some physical parameters of Olumo rock, Abeokuta Ogun-State, Nigeria, *Indian Journal of Science and Technology* Vol.2 No 7, 0974-6846.

[24.] Serway and Raymond A; (2009). *College Physics Belmont*, CA: Brooks Cole. p.876

[25.] Stranden E. (1976). Some aspects on radioactivity of building materials. *Physical Norvegica.* 8:167-177.

[26.] Titaeva, N.A, Alexakhin, R.M, Taskaev, A.I and Maslov, V.I (1978): Migration of heavy natural radionuclides in a humid climate zone, Natural Radiation Environment (111). *Techanical Information Centre US Department of Energy 724-737.*

[27.] Umar A.M., Onimisi M.Y., Jonah S.A. (2012): Baseline measurement of natural radioactivity in soil, vegetation and water in the industrial district of the Federal Capital Territory (FCT) Abuja, Nigeria, *British Journal of Applied Science & Technology* 2(3): 266-274.

[28.] UNSCEAR (2000): *Radiological Protection Bulletin,* United Nations Scientific Committee on the Effects of Atomic Radiation No. 224, New York.

[29.] UNSCEAR (2000): Annex B: *Exposures to Natural Radiation Sources Report to the general assembly with scientific annexes*. United Nations Scientific Committee on the effect of Atomic Radiation, New York.

[30.] UNSCEAR (2000): *Source and effects of ionizing radiation report to the general assembly with scientific annexes*. United Nations Scientific Committee on the effect of Atomic Radiation, New York.

[31.] UNSCEAR (2000): *Radiological Protection Bulletin,* United Nations Scientific Committee on the Effects of Atomic Radiation No. 224, New York.