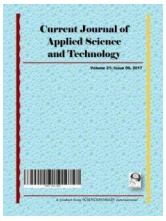

Current Journal of Applied Science and Technology

27(6): 1-12, 2018; Article no.CJAST.41562
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

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

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Authors' contributions

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

Article Information

DOI: 10.9734/CJAST/2018/41562
Editor(s):
(1) João Miguel Dias, Assistant Professor, Habilitation in Department of Physics, CESAM, University of Aveiro, Portugal.
Reviewers:
(1) Sainudeen Pattazhy, University of Kerala, India.
(2) Abdulwahed Mohamed Aboukarima, Agricultural Engineering Research Institute, Egypt.
Complete Peer review History: http://www.sciencedomain.org/review-history/25125

Original Research Article

Received 23rd March 2018
Accepted 1st June 2018
Published 14th June 2018

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) in 7 soil samples collected from different areas of Erena mining sites at (indicate the name of the town here) 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 48.5226 ± 3.5770 to 1002.9550 ± 9.7978; for ^{226}Ra it ranged from 23.2909 ± 2.2016 to 75.3187 ± 5.0984 and for ^{232}Th the range is from 23.8312 ±2.0525 to 59.2930 ± 2.3945Bq.Kg^{-1}. While the Absorbed Dose for ^{40}K ranged from 2.0234±0.1492 to 33.0293 ± 0.3567 ηGy.h^{-1}, for ^{226}Ra the range is from 10.7604 ± 1.3384 to 34.7972 ± 2.3555 ηGy.h^{-1} and for ^{232}Th the range is from 14.3940 ± 1.2391 to 35.8130 ± 1.4463 ηGy.h^{-1}. The total average Absorbed Dose rate of the 7 soil samples collected is 69.1480 ηGy.h^{-1} and the estimated Annual Effective Dose for the sampled areas range from 0.0025- 0.0668 mSvy^{-1}

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(i.e 3 – 67 μSv.y^{-1}), with an average Annual Effective Dose of 0.0848mSv.y^{-1} (i e 84.8 μSv.y^{-1}). These results shows 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} [6]. Also the mean Radium Equivalents obtained ranged from 82.7770 BqKg^{-1} (ER4) to 171.9653 BqKg^{-1} (ER2). 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 0.2236 Bqkg^{-1} (ER4) to 0.6686 Bqkg^{-1} (ER2), 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 0.3191 Bqkg^{-1} (ER4) to 0.6681 Bqkg^{-1} (ER2). Finally, the mean value of the Excess Alpha Radiation (I_α) ranged from 0.1165 Bq.Kg^{-1} to 0.3766 Bq.Kg^{-1}. 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 site area.

Keywords: Radionuclides; soil; mining; activity concentration; absorbed dose; Niger state.

1. 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) [1]. 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 Erena mining sites with a view of assessing the activity concentration and effective dose rate of naturally occurring radionuclide materials in the 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 effort geared towards protecting people and the environment from accumulation of higher doses of radiation.

In this 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 7 soil samples collected from the different areas of the Erena mining sites of (indicate the name of the town) in Shiroro Local Government area in Niger State, North Central Nigeria. We 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.

2. MATERIALS AND METHODS

2.1 Sample Collections and Preparation

The study area is located in the Erena 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 Fig. 1, 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 set to 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 2 mm in order to remove organic materials, stones and lumps. Thereafter, the homogenized samples were packed to fill cylindrical plastic beakers of 7 cm by 6 cm diameter which is the same as geometry of the counting detector. This satisfies the selected optimal sample container height [2]. 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 ± 0.01 g. Each plastic beaker accommodates approximately 300 g 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 [3]. The samples taken from Erena are labeled as ER1- ER7.

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(Tl) 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 the desired level of 900 Volts was attained.

ERENA MINING SITE

Fig. 1. Erena mining site area

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, also according to 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.

3. RESULTS AND DISCUSSION

The peak area of each energy in the spectrum was used to compute the activity concentrations in each of the samples by the use of the following equation (reference the equation):

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

where, C = activity concentration of the radionuclides in the sample given in $BqKg^{-1}$, Cn = Count rate = 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 (give the energies emitted by the calibration sources 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 for 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 of the results evaluated. The background count rate was done for 29000 seconds and the results obtained are is given in Table 1.

The gross area count G_c is related to the area count through the expression [3].

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

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 [3].

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

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 present the values of the conversion factor (σ) for the ^{40}K, ^{226}R and ^{232}Th [4].

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 Fig. 2.

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 ($\eta Gy.h^{-1}$) due to gamma

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

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) [5] below.

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

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 Fig. 3 present 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 7 soil samples investigated.

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 [6,7] and [8] 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) =

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

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

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

Equation (5) can simply be written as

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

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 (4) present the calculated Annual Effective Dose Rates (E_d) $(mSv.y^{-1})$ for the investigated soil samples.

Table 3. Activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in Erena 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.	ER1	792.0684	55.8517	36.0319	883.9520
2.	ER2	624.1058	75.3187	33.9794	733.4039
3.	ER3	268.2737	62.5724	23.8312	354.6773
4.	ER4	48.5226	35.3418	30.5587	114.4231
5.	ER5	646.1897	48.0881	39.9088	734.1866
6.	ER6	1002.9550	23.2909	59.2930	1085.5389
7.	ER7	570.2955	45.5388	40.2509	656.0852
8.	Total	3952.4107	346.0024	263.8539	4562.2650
9.	Mean	564.6301	49.4289	37.6934	651.7524

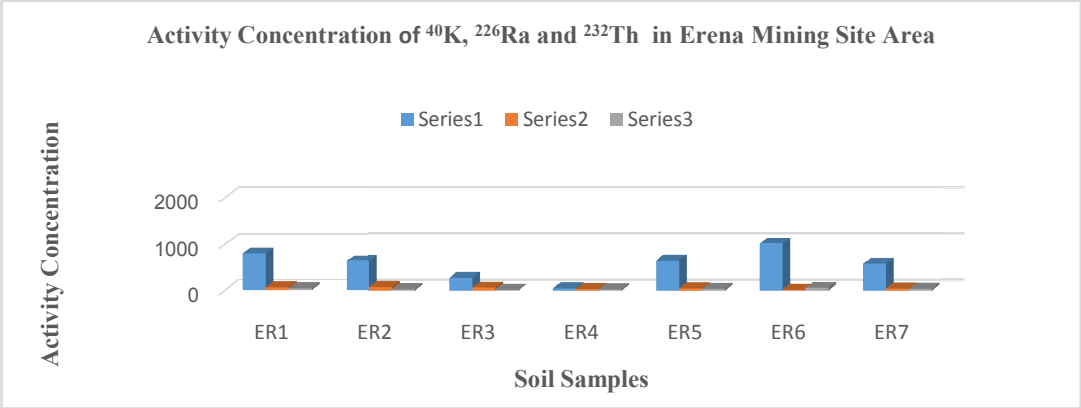

Fig. 2. Activity concentration of ^{40}K, ^{226}Ra and ^{232}Th in Erena mining site area
KEY: Series 1= ^{40}K ; Series 2 = ^{226}Ra and Series = ^{232}Th

Table 4. Absorbed dose rate D (ŋGy.h^{-1}) of ^{40}K, ^{226}R and ^{232}Th Erena 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.	ER1	33.0293	25.8035	21.7633	80.5961
2.	ER2	26.0252	34.7972	20.5236	81.3460
3.	ER3	11.1870	28.9084	14.3940	54.4894
4.	ER4	2.0234	16.3279	18.4575	36.8088
5.	ER5	26.9461	22.2167	24.1049	73.2677
6.	ER6	41.8232	10.7604	35.8130	88.3966
7.	ER7	23.7813	21.0389	24.3115	69.1317
8	Total	164.8155	159.8530	159.3678	484.0363
9.	Mean	23.5451	22.8361	22.7668	69.1480

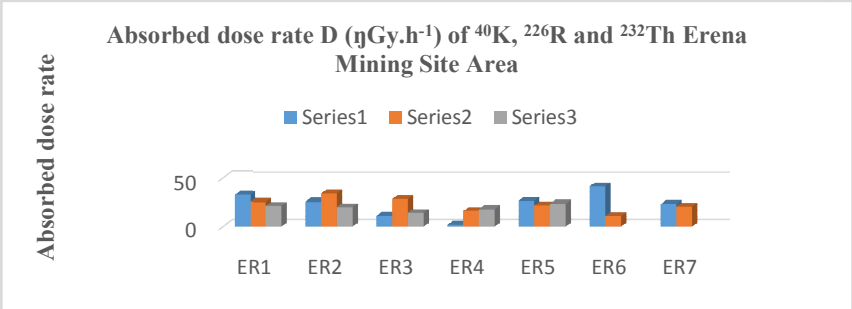

Fig. 3. Absorbed dose rate D (ŋGy.h^{-1}) of ^{40}K, ^{226}R and ^{232}Th Erena mining site area
KEY: Series 1= ^{40}K ; Series 2 = ^{226}Ra and Series = ^{232}Th

Table 5. Annual effective dose rates $E_d(mSv.y^{-1})$ for Erena 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.	ER1	O.0405	0.0316	0.0267	0.0988
2.	ER2	0.0319	0.0427	0.0252	0.0998
3.	ER3	0.0137	0.0354	0.0668	0.0668
4.	ER4	0.0025	0.0200	0.0226	0.0451
5.	ER5	0.0330	0.0272	0.0296	0.0899
6.	ER6	0.0513	0.0132	0.0439	0.1084
7	ER7	0.0292	0.0258	0.0298	0.0848
8.	Total	0.2323	0.2386	0.2446	0.5936
9	Mean	0.0332	0.3409	0.0349	0.0848

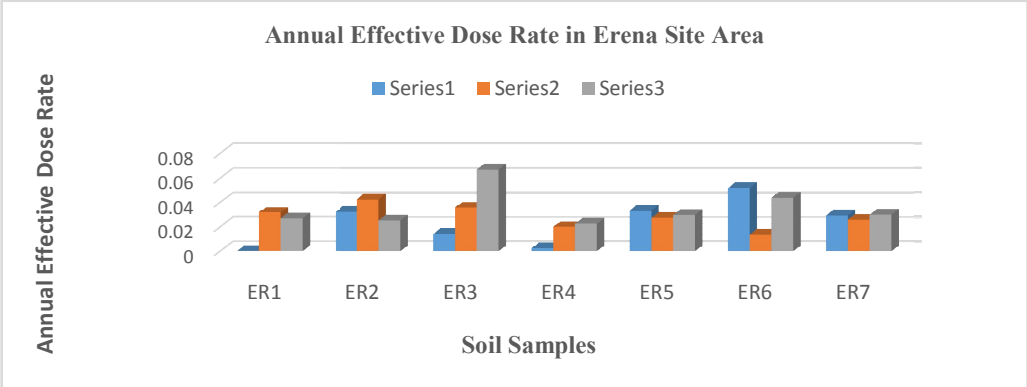

Fig. 4. Annual Effective Dose Rate in Erena Site Area
KEY: Series 1= ^{40}K; Series 2 = ^{226}Ra and Series = ^{232}Th

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 an 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 the relation (indicate the reference):

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

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} [9]. The results obtained for Ra_{eq} are presented in Table (6) and figure (5). The results obtained show 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 for in dwellings by as given by OECD (Organization for Economic Cooperation Development) and cited by [10] 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.

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 [11] and supported by [12] and was used by [13]. 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 $BqKg^{-1}$) [13]. A widely used hazard index (reflecting external exposure) called the external hazard index Hex is defined as follows [5].

Table 6. Radium Equivalent in the investigated Soil Samples

Soil Sample ID	Radium Equivalent Ra_{eq} of the Soil Samples Bqkg-1
ER1	168.3665
ER2	171.9653
ER3	117.3081
ER4	82.7770
ER5	154.9142
ER6	108.07984
ER7	147.0104

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

The results obtained are shown in Table 7 and figure 6. The mean external hazard index ranged from 0.2236 $Bqkg^{-1}$ (ER4) to 0.5003 $Bqkg^{-1}$ (ER6).

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

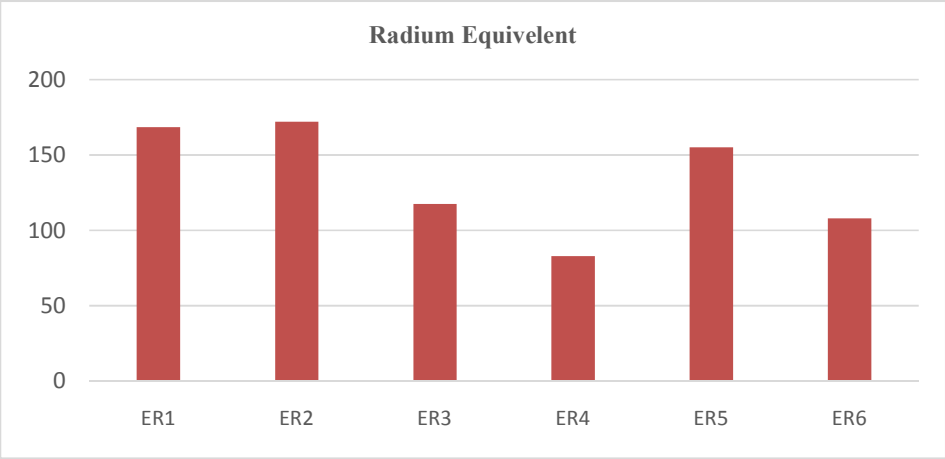

Fig. 5. Radium Equivalent in Erena Site Area

quantified by the internal hazard index H_{in}, which is given by the equation [9] :

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

The values of the indices (H_{ex}, H_{in}) must be less than unity for the hazard to be negligibl [8]. Hence results obtained are shown in Table 8 and Fig. 7.

Table 7. External hazard index of the soil samples

Soil sample ID	External hazard index of the soil samples
ER1	0.4548
ER2	0.4646
ER3	0.3169
ER4	0.2236
ER5	0.4184
ER6	0.5003
ER7	0.3971

Table 8. Internal Hazard Index of the soil samples

Soil Sample ID	Internal Hazard index of the soil samples
ER1	0.6057
ER2	0.6681
ER3	0.4860
ER4	0.3191
ER5	0.5483
ER6	0.5633
ER7	0.5202

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 [14]:

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

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 are shown in Table 9 and Fig. 8**.** 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

Soil Sample ID	Excess alpha radiation of the soil samples
ER1	0.2793
ER2	0.3766
ER3	0.3129
ER4	0.1767
ER5	0.2404
ER6	0.1165
ER7	0.2277

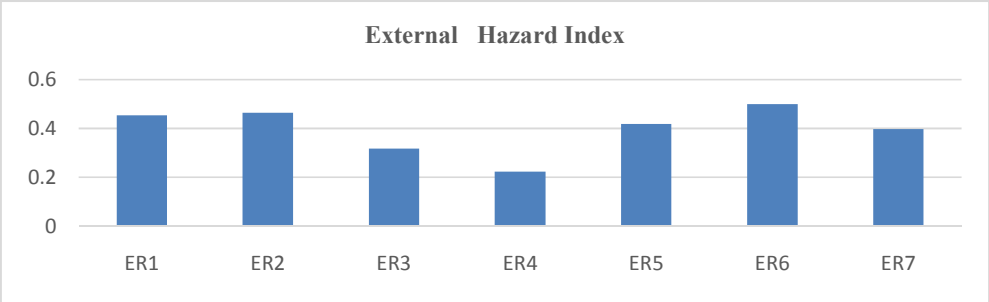

Fig. 6. External hazard index in Erena site area

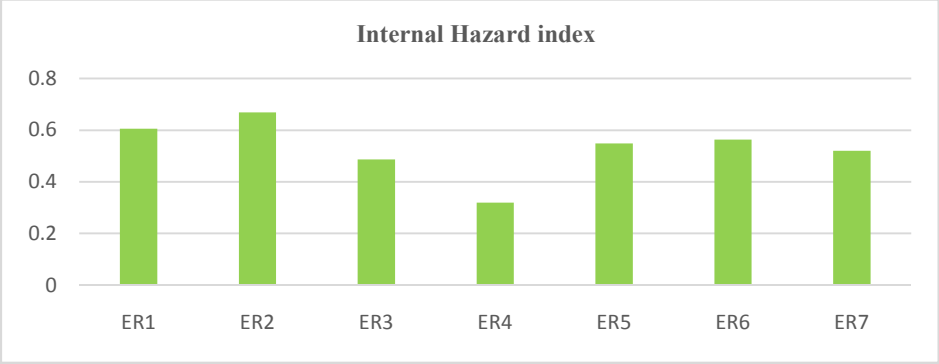

Fig. 7. Internal hazard index in Erena site area

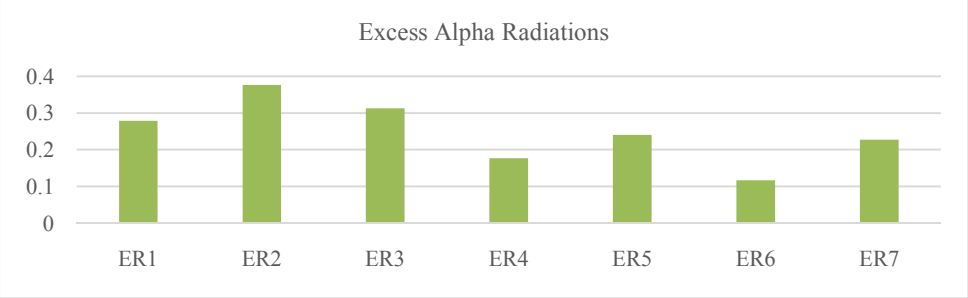

Fig. 8. Excess Alpha radiations in Erena site area

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: [15]

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.

4. 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.

5. DISCUSSION

The method of gamma spectrometry was used to measure the radioactivity concentration of soil samples collected from the mining sites of Erena 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 ER6 with 1002.9550 $BqKg^{-1}$. 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 ER1 with 792.0684 $Bqkg^{-1}$. The least radioactivity concentration of ^{40}K was found in soil samples ER4 with 48.5226 $Bqkg^{-1}$ .The highest radioactive concentration of ^{226}Ra was found in soil sample ER2 with 75.3187 $Bqkg^{-1}$(Table 3, Fig.2). 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 ER3 and SP4 with 62.5724 $Bqkg^{-1}$ respectively. Soil sample ER6 had the lowest radioactivity concentration of 23.2909 $Bqkg^{-1}$.Also, the highest radioactive concentration of ^{232}Th was found in soil sample MW4 with 59.2930 $Bqkg^{-1}$(Table 3 and Fig.2).This could be due to presence of abundant radioactive thorium minerals such as monazite, zircon and thorianite [3].The least radioactivity concentration of ^{232}Th was also found in soil sample ER3 with 23.8312 $Bqkg^{-1}$.The result also shows that the total concentration of ^{266}Ra is 346.0024$BqKg^{-1}$.which is much higher than that of ^{232}Th which has a total concentration of 263.8539 $BqKg^{-1}$, while ^{40}K leads the table of radioactivity concentrations with total value of 3952.4107 $BqKg^{-1}$. From Table 4, and Fig 3, it shows that the absorbed dose rate due to the three radionuclides is highest for soil sample ER6 with absorbed dose rate of 41.8232ηGy.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 69.1480 ηGy.h^{-1}. According to Table 4, ^{40}K had the highest value of total absorbed dose rate of 164.8155 ηGy.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 ^{226}Ra which has the total absorbed dose rate of 159.8530 ηGy.h^{-1}, while ^{232}Th had the least total absorbed dose rate of 159.3678 ηGy.h^{-1}.

From Table 5 and figure 4, the annual effective dose rate in air at the study area ranged from 0.0137 - 0.1084 $mSv.y^{-1}$ and the average annual effective dose rate in air at the study area is was 0.0848 $mSv.y^{-1}$ which is slightly less than the maximum recommended world average outdoors exposure to external terrestrial radiation [6]. Thus, the exposure level for the members of general public is still within the recommended value of 1 $mSv.y^{-1}$ [16] & [5].

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} [6]. The results obtained for Ra_{eq} as presented in Table 6, shows that, the mean radium equivalents obtained ranged from 82.7770 $BqKg^{-1}$ (ER4) to 171.9653 $BqKg^{-1}$ (ER2). This results show that the recommended radium equivalent concentration of $\leq$ 370 Bq Kg^{-1} for soil materials to be used for dwellings by OECD (Organization for Economic Cooperation Development) [10] 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 [11] and supported by [12] and was used by [13]. 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 $BqKg^{-1}$)[13] .These results as obtained are shown in Table 7 and figure 6, which show that the mean external hazard index (H_{ext}) ranged from 0.2236 $Bqkg^{-1}$ (ER4) to 0.5003 $Bqkg^{-1}$ (ER6). 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 0.3191 Bqkg^{-1} (ER4) to 0.6681 Bqkg^{-1} (ER2) as shown in Table 8 and Fig. 7. The mean value of Excess Alpha Radiation (I_α) ranged from 0.1165 Bq.Kg^{-1} to 0.3766 Bq.Kg^{-1}, and this is presented in Table 9 and figure 8. All these values for I_α are below the maximum permissible value of 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 Erena study areas and the miners working on these sites.

6. 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) obtained from 7 soil samples collected from different areas within the Erena 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 use to carry out the analysis of the soil samples. The values of Activity Concentration for ^{40}K range from 48.5226 ± 3.5770 to 1002.9550 ± 9.7978; for ^{226}Ra range from 23.2909 ± 2.2016 to 75.3187 ± 5.0984 and for ^{232}Th range from 23.8312 ±2.0525 to 59.2930 ± 2.3945 Bq.Kg^{-1}. While the Absorbed Dose for ^{40}K range from 2.0234±0.1492 to 33.0293 ± 0.3567 ηGy.h^{-1}, for ^{226}Ra range from 10.7604 ± 1.3384 to 34.7972 ± 2.3555 ηGy.h^{-1} and for ^{232}Th range from 14.3940 ± 1.2391 to 35.8130 ± 1.4463 ηGy.h^{-1}. The total average Absorbed Dose rate of the 7 soil samples collected is 69.1480 ηGy.h^{-1} and the estimated Annual Effective Dose for the study areas range from 0.0025- 0.0668mSvy^{-1} (i.e 3 – 67 μSv.y^{-1}), with an average Annual Effective Dose of 0.0848mSv.y^{-1} (ie 84.8 μSv.y^{-1}). These results show that the radiation exposure level for members of the public in the study areas is lower than the recommended limit value of 1 mSv.y^{-1} [6]. Also the mean Radium Equivalents obtained ranged from 82.7770 BqKg^{-1} (ER4) to 171.9653 BqKg^{-1} (ER2) these results show that the recommended Radium Equivalent Concentration is $\leq$ 370 BqKg^{-1} for soil materials to be used for dwellings is applicable to the soils collected around the mine site. The mean External Hazard Index (H_{ext}) ranged from 0.2236 Bqkg^{-1} (ER4) to 0.6686 Bqkg^{-1} (ER2), because the maximum allowed value (H_{ext} = 1) which corresponds to 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} this index should be equal to or less than unity ($H_{ext} \leq$ = 1). Also the mean Internal Hazard Index (H_{ext}) ranged from 0.3191 Bqkg^{-1} (ER4) to 0.6681 Bqkg^{-1} (ER2) .Finally mean value of Excess Alpha Radiation (I_α) range from 0.1165 Bq.Kg^{-1} to 0.3766 Bq.Kg^{-1}. 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 study areas and the miners working on those sites.

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 INTERESTS

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

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history/25125