

Original Research Article

Measurement of radioactivity concentration in Pegmatite Rocks samples and dose assessment from Wamba in North Central Nigeria

ABSTRACT

Aims: To evaluate the radiological impact parameters on mine workers.

Study design: The research work was carried out by using a gamma-ray spectrometer with a NaI (TI) detector.

Place and Duration of Study: Centre for Energy and Research Development (CERD), Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria between September 2016 and June 2017.

Methodology: The activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K were determined in ten samples which were used to evaluate the absorbed dose rate, radium equivalent activity, external and internal hazard indices, representative level index, and annual effective dose equivalent.

Results: The average activity concentrations of ^{226}Ra ($24068.11\text{Bq kg}^{-1}$), ^{232}Th (387.72Bq kg^{-1}), ^{40}K (9509.24Bq kg^{-1}) and absorbed dose rate ($11720.77\text{nGy h}^{-1}$) were higher than their respective recommended world mean values of 35Bq kg^{-1} , 45Bq kg^{-1} , 420Bq kg^{-1} and 59nGy h^{-1} by UNSCEAR. The mean values of radium equivalent activity, external hazard index (H_{ex}), internal hazard index (H_{in}), representative level index, and annual effective dose equivalent of the area under study were determined as $25346.82\text{Bq kg}^{-1}$, 68.52, 135.43, 357.95, and $14374.36\mu\text{Sv y}^{-1}$ respectively. This study revealed that all the radiological parameters were higher than their respective recommended world average values.

Conclusion: With the high concentrations obtained in this study, it is therefore concluded that this may pose a serious health risk to the miners and the general public. It is therefore advised that necessary guidelines should be provided for the exploration of minerals in this mining site.

Keywords: Mining; Radiological protection; spectrometer; pegmatite; Absorbed dose rate

1. INTRODUCTION

Human exposure to radiation can be from either natural or artificial radioactivity. Activities like the mining of natural resources such as uranium and other minerals expose a lot of people to dangers which have generated a need for regulations [1, 2]. The naturally occurring radionuclide materials (NORMs) have been in existence since human creation. This has been observed to have spread across the earth's crust with the presence of many radioactive elements such as Uranium (U) and Thorium (Th) which are referred to as parent's radioisotopes and Potassium (K) which is also seen in geological formations of soils, rocks, plants, water, and air [3 - 5]. The level of radiation exposure can be determined by the type of rock that is mined. Higher radioactivity is observed to be mostly present in igneous rocks such as granite and pegmatite while lower levels of radioactivity are associated with sedimentary rocks with the exceptions of Shale and Phosphate rocks having a relatively high amount of radioisotopes [6]. The level of radionuclides in mined rocks helps to know the extent of radioactive pollutants infused into the surroundings [7]. Therefore, the measurement of radioisotopes in rock samples before use is very important in order to prevent radiation exposure.

Several researches have been conducted to estimate natural radiation exposure and likely radiological hazards on people [8 -13]. Some of these studies have established that the accumulation of ingested radionuclides through food, water, and inhalation of tiny particles could have serious health repercussions like leukemia, bone cancer, and high blood pressure [14, 15].

Other studies also revealed that the activity concentrations are not particular to a kind of rock alone but the release of these radionuclides over time causes cancer and other related health hazards which can later damage some essential organs in the body [16 - 19]. According to [20], it was revealed that in an environment of uranium operational mining sites, 68.33 % of the people living around this site do die before age 62.

Presently explorations of minerals in the area under study are done by small-scale miners whose activities are dangerous and are not controlled by any regulated bodies. In that case, the illegal mining currently going on in the area reveals that the Wamba pegmatites may be of economic importance. It is, therefore, necessary to unveil more pieces of information on the natural resources so that their economic mineral potential can be assessed.

This study focused on the extent of exposure of the miners to naturally occurring radionuclide materials (NORMs) by evaluating the radiological parameters and comparing with other literatures and with the United Nations Scientific Committee on Atomic Radiation Report [7] average values.

2. MATERIAL AND METHODS

2.1 Study area

Wamba town is located mid - northern part of Nasarawa State, Nigeria (**Figure 1**) between Longitudes 8° 30'E and 8° 40'E and Latitudes 9° 00'N and 9° 07' N. It has an area of 1,156 km² and a population size of 72,894 people [21]. The pegmatite field of Wamba is one of the Pan- African rare - metal pegmatite broad belt which stretches from southwestern to central Nigeria [22].

It is found covering about 45 km² within the Pan-African reactivation zone. The exploration of minerals in this area started as early as 1912 with tin-bearing pegmatites in the 40 km of Wamba area and ceased in the 1960s. The study area is characterized by hosting several hills with an average temperature of 31° C. Due to the peculiarity of this area mining activities are predominant. Therefore the collection of pegmatite rock samples was done randomly to survey the natural radiation in the mining area. A total of ten samples were collected for radiation measurement and absorbed dose rate.

2.2 Sampling

A total of 10 pegmatite samples collected randomly from the mentioned study area were left to dry for some days under a thorough laboratory conditions in order to remove any liquid present. These rock samples were pulverized in a Rocklab milling machine (Model C RC3E, Serial number 1288) situated at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile- Ife Osun State, Nigeria. The samples were oven dried at 100 °C for 24 hours to ensure that they are free of humidity. The samples were sieved with a 2 mm mesh and thereafter, 150 g of each sample was packed into a cylindrical plastic container tightly closed, sealed, and stored for 28 days to ensure secular equilibrium between the parent radionuclides ²²⁶Ra, ²³²Th, and their respective daughters [23]. An identical empty plastic container was sealed to serve for background counting.

2.3 Instrumentations

The activity measurement was carried out using a well-calibrated 76 mm × 76 mm Thallium activated Sodium Iodide (NaI(Tl)) detector with coupled photomultiplier tube at the Centre for Energy and Research Development (CERD), Obafemi Awolowo University, Ile- Ife Osun State, Nigeria. The detector is shielded with a lead castle thickness of 5 cm and a resolution of about 8% at an energy of 0.662 MeV (¹³⁷Cs). The preamplifier provided a voltage of 750 V to the detector. The multichannel analyzer (MCA) connected through a preamplifier provides a stabilised spectrum which can be analyzed on an IBM personal computer. The energy and efficiency calibrations of the detector were done using a standard source which was shown in Table 1, with known gamma-ray energies prepared by the Isotope Products Laboratories, California, U.S.A. The calibration was performed by determining the sources of known radionuclides with energy ranging from 60 keV to 1332.50 keV. This was achieved by measuring the standard sources emitting known gamma-ray energies (¹³⁷Cs) 661.66 keV, (⁶⁰Co) 1173.24 and 1332.50 keV with channel numbers of 738, 1504, and 1743 respectively. The standard sources have the same geometry with that of the sample. The gamma counting was done for 18000 s.

The efficiency of a detector measures the number of pulses that occur for a given number of incident gamma rays, i.e., the fraction of all the photons that are emitted by the source or sample, which cause an event in the detector. This depends on the following: the detector features, counting geometry used, the sample shape, volume, and distance of the sample to the detector.

As soon as the counting time started, the computer started recording the photo peaks and the same time storing them. The accumulation of counts at a specific energy range is due to emitted photons from the sample in addition to the one from background interference. However, if the background is constant, then a sample with high activity will accumulate relatively more counts in the peak compared to the background. Therefore, as the total area of the peak increases, the relative background size reduces as well as the proportional background error. After the counting elapsed, the peaks were displayed. The radioactivity analysis was carried out by spectra- analysis program, SAMPO 90, which was used to

analyze the samples on the computer. The spectrum of each sample was analyzed and the identification of radionuclides were determined from the energy of the peak centroids. Also as a sample activity increases, the estimated standard error decreases, and as the activity decreases, the relative error increases. An empty container of the same geometry was sealed and counted for gamma-ray distribution count. This served as a background measurement which was done repeatedly at regular intervals for quality control. The spectrum obtained was recorded for analysis.

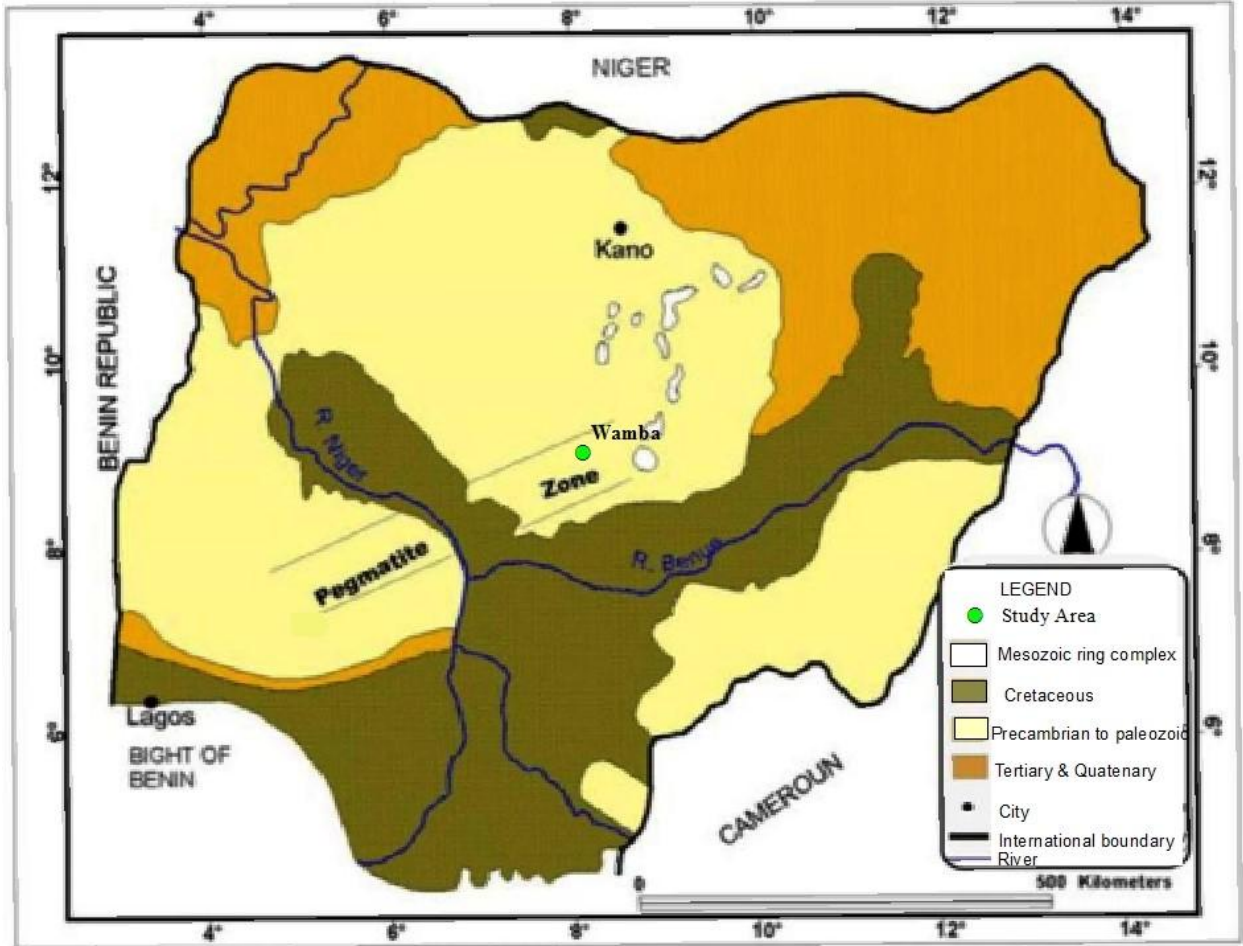


Figure 1: General Geology of Nigeria showing the Location of the Pegmatite Zone and the Study Area [24]

Table 1: Radionuclides used for Energy Calibration of NaI (TI)

| Radionuclides | Energy (keV) | Channel number |
|-------------------|--------------|----------------|
| ¹³⁷ Cs | 661.66 | 738 |
| ⁶⁰ Co | 1173.24 | 1504 |
| ⁶⁰ Co | 1332.50 | 1743 |

In **Table 2**, the activity concentration of the daughter radionuclide (²²⁶Ra) in the samples was obtained using the γ -ray peaks of 1120 keV from ²¹⁴Bi which is equivalent to the concentration of (²²⁶Ra) in the samples. The daughter radionuclide ²²⁸Ac was determined from its 911 keV γ -ray peak which was chosen as an indicator of ²³²Th. The concentration of ⁴⁰K was determined by measuring the photo peak of 1460 keV emitted during its decay.

Table 2: Spectral Energy Windows used in Analysis using NaI(Tl) Gamma Spectroscopy

| Element analysed | Isotope Used | Energy (keV) |
|-------------------|-------------------|--------------|
| ²³² Th | ²²⁸ Ac | 911 |
| ²²⁶ Ra | ²¹⁴ Bi | 1120 |
| ⁴⁰ K | ⁴⁰ K | 1460 |

The background radioactivity distribution in the environment around the detector was determined by counting the empty sealed container for 18000 s. The background measurements were repeated at regular intervals for quality control. The spectrum obtained was recorded for analysis. The specific activity concentration of the natural radionuclide, A , ($Bq\ kg^{-1}$) of each sample in this study was evaluated using Eq. (1) [25, 26].

$$A = \frac{C}{p_{\gamma}wt\varepsilon} \quad (1)$$

where C is the net counts of the radioisotope in the samples, p_{γ} is the absolute gamma-ray emission probability (gamma ray yield), w is the net dry sample weight (kg), t is the sample measurement time (18000 s) and ε is the absolute efficiency of the detector.

The specific activity concentration (C_x) of the radionuclide was obtained by direct comparison with the same radionuclide in a given standard. The specific activity in the sample and the corresponding specific activity in the standard (C_s) are related by:

$$C_x = C_s \frac{M_s A_x}{M_x A_s} \quad (2)$$

where M_s is the mass of the standard, M_x is the mass of the sample, A_s is the area of the standard and A_x is the area of the sample.

The concentration of natural radionuclides to the absorbed dose rate in the air (D_R) depends on the concentration of the radionuclides present in the pegmatite rock samples. Absorbed dose radiation dose in an exposed person per unit mass at 1m above the ground level is defined as the quantity of ionizing energy present in the body in Gray/second....(Gy/s). This was determined using Equation (3).

$$D_R (nGy h^{-1}) = 0.462 C_{Ra} + 0.604 C_{Th} + 0.0417 C_K \quad (3)$$

where C_{Ra} , C_{Th} and C_K are the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K , in the rock samples ($BqKg^{-1}$) respectively.

2.4 Evaluation of Radiological Impact Parameters

2.4.1 Radium Equivalent Activity (Ra_{eq})

The radium equivalent activity ($Bq kg^{-1}$) represents a weighted sum of activities of ^{226}Ra , ^{232}Th and ^{40}K . Ra_{eq} is related to the external gamma dose and internal dose due to radon and its daughters. In this study, Ra_{eq} was calculated using equation (4) [27].

$$Ra_{eq} = C_{Ra} + 1.43 C_{Th} + 0.077 C_K \quad (4)$$

where C_{Ra} , C_{Th} , and C_K are the activity concentrations ($Bq kg^{-1}$) of ^{226}Ra , ^{232}Th , and ^{40}K , in the rock samples respectively.

2.4.2 External Hazard index (H_{ex})

The external hazard index (H_{ex}) connotes the level of health hazard incurred from gamma radiation that comes from the materials used in building walls of a dwelling. Equation (5) was used in calculating for external hazard index [7].

$$H_{ext} = \left(\frac{C_U}{370}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_K}{4810}\right) \quad (5)$$

where C_{Ra} , C_{Th} , and C_K are the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K ($Bq kg^{-1}$) in respectively.

2.4.3 Internal Hazard index (H_{in})

The internal hazard index (H_{in}) also defined as the inhalation exposure of the respiratory organs to radon and its daughter nuclei inside a house was calculated using Equation (6) [7].

$$H_{int} = \left(\frac{C_U}{185}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_K}{4810}\right) \quad (6)$$

C_{Ra} , C_{Th} , and C_K are the activity concentrations in $Bq kg^{-1}$ of ^{226}Ra , ^{232}Th , and ^{40}K respectively.

2.4.4 Representative level index (I_γ)

To ascertain whether a particular sample conforms to the standard dose limit set for building materials [28], the representative level index or gamma index (I_γ) is used to estimate the level of γ – radiation hazard associated with the natural radionuclides in specific investigated samples. Equation 7 was used to evaluate the gamma index for samples in this study.

$$I_\gamma = 0.0067C_U + 0.01C_{Th} + 0.00067 C_K \quad (7)$$

C_{Ra} , C_{Th} , and C_K are the activity concentrations in $Bq kg^{-1}$ of ^{226}Ra , ^{232}Th , and ^{40}K respectively.

Therefore, (I_γ) must be ≤ 1 which also corresponds to an annual effective dose of ≤ 1 mSv.

2.4.5 Annual Effective Dose Rate (AEDR)

This is the dose that an individual receives after being exposed to radiation outside especially through the air. The absorbed doses evaluated in $nGy h^{-1}$ were converted to annual effective dose in $\mu Sv y^{-1}$ by [7]. This was calculated using equation (8).

$$AEDR_{outdoor} (\mu Sv y^{-1}) = D_R (nGy h^{-1}) \times 8760 (h y^{-1}) \times 0.7 (Sv Gy^{-1}) \times 0.2 \times 10^{-3} \quad (8)$$

where D_R is the absorbed dose rate ($nGy h^{-1}$), 8760 is the time conversion factor ($h y^{-1}$),

0.7 is the dose conversion factor ($Sv Gy^{-1}$) and 0.2 is the outdoor occupancy factor.

3. RESULTS AND DISCUSSION

The daughter lines for ^{226}Ra and ^{232}Th used in this study were ^{214}Bi and ^{228}Ac respectively. The results of the radioactivity concentrations were presented in Table 3. It was revealed that all the three radionuclides ^{226}Ra , ^{232}Th , and ^{40}K investigated in the pegmatite rock samples were observed to have the highest activity concentrations in sample 1 and the lowest concentrations in samples 6. The mean activity concentrations of ^{226}Ra measured was $24068.11 \pm 368.03 Bq kg^{-1}$ which is higher than the world average value of $35 Bq kg^{-1}$. The mean activity concentration of ^{232}Th estimated in this research was $387.72 \pm 18.50 Bq kg^{-1}$, and thus higher than the world average value of $45 Bq kg^{-1}$. The average activity concentration of ^{40}K was $9509.24 \pm 335.11 Bq kg^{-1}$ which is higher than the world average value of $420 Bq kg^{-1}$. Both the ^{226}Ra and ^{40}K contributed to the increase in the activity concentrations in the pegmatite rock samples. The possible reasons for higher values of ^{226}Ra could be as a result of geological differences in the formation of the rock, cosmogenic and terrestrial radionuclides. The increase in the activity concentration of ^{40}K is because of the presence of aluminum silicates of potassium, sodium, calcium, or barium.

Table 3: Specific activity of ^{226}Ra , ^{232}Th and ^{40}K in Pegmatite Rock Samples in $Bq kg^{-1}$

| Samples | ^{226}Ra | ^{232}Th | ^{40}K |
|------------|------------------|-------------------|------------------|
| K1 | 716.42±11.56 | 7.98±0.39 | 650.70±31.83 |
| K2 | 27755.55±424.28 | 418.58±19.96 | 10473.55±12.27 |
| K3 | 30028.46±459.02 | 842.49±40.18 | 16726.56±818.12 |
| K4 | 5825.98±89.17 | 82.80±3.96 | 1627.15±79.60 |
| K5 | 6616.20±101.24 | 92.80±4.44 | 3354.09±164.06 |
| K6 | 65809.11±1005.94 | 962.84±45.91 | 22015.65±1076.81 |
| K7 | 1950.28±30.10 | 25.36±1.22 | 1313.38±64.24 |
| K8 | 18036.72±275.82 | 200.65±9.58 | 6943.71±339.63 |
| K9 | 38854.63±593.93 | 550.27±26.24 | 14765.44±722.20 |
| K10 | 45087.76±689.23 | 693.45±33.07 | 17222.13±842.36 |
| Min. | 716.42±11.56-65 | 7.98±0.39- 962.84 | 650.70±31.83 |
| Max. | 65809.11±101.24 | 962.84±45.91 | 22015.65±1076.81 |
| Mean value | 24068.11±368.03 | 387.72±18.50 | 9509.24±335.11 |

Table 4 revealed the estimated absorbed dose rate (D_R) which ranged from 362.49 to 31888.00 $nGy h^{-1}$ with a mean concentration value of $11720.77 nGy h^{-1}$. The mean value of the absorbed dose rate was found to be higher than the world average value of $59 nGy h^{-1}$

[7]. This could be a result of large quantity of uranium and other radionuclides present in the rock samples. The Radium activity equivalent (Ra_{eq}) values obtained varied from 777.87 to 68878.11 $Bq\ kg^{-1}$ with a mean value of 25346.82 $Bq\ kg^{-1}$. The Ra_{eq} mean value exceeded the maximum limit of 370 $Bq\ kg^{-1}$ recommended by [29]. The evaluated values of the external hazard index (H_{ex}) and internal hazard index for the pegmatite rock samples in this study ranged from 2.11 to 186.16 with a mean value of 68.52. The calculated values of (H_{in}) for the rock samples ranged from 4.04 to 364.02 with a mean value of 135.43 as shown in Table 4. Both external and internal indices mean values were higher than the world average value of 1 unity [7].

The representative level index I_{γ} was calculated using equation (7). For the radiation hazard to be negligible it must be less than unity. The evaluated values varied from 14.84 to 1340.49 with an average value of 357.95. The average value obtained is much greater than the world recommended value of 1 unity. The annual effective dose rate (AEDR) ranged from 444.5 to 39107.4 $\mu Sv\ y^{-1}$ with a mean concentration of 14374.36 $\mu Sv\ y^{-1}$. The AEDR average value is thus higher than the recommended safety limit value of 70 $\mu Sv\ y^{-1}$ for an individual [7].

Table 4: The evaluated radium equivalent Ra_{eq} , dose rate, External hazard index (H_{ex}), Internal hazard index (H_{in}) and gamma index of the samples under investigation.

| Sample code | Ra_{eq} | D | H_{ex} | H_{in} | I_{γ} | AEDR |
|-------------|-----------|----------|----------|----------|--------------|----------|
| K1 | 777.87 | 362.49 | 2.11 | 4.04 | 14.84 | 444.56 |
| K2 | 29159.18 | 13277.76 | 78.82 | 153.83 | 570.45 | 16283.84 |
| K3 | 32518.68 | 15067.80 | 87.89 | 169.05 | 620.15 | 18479.15 |
| K4 | 6002.83 | 2808.32 | 16.41 | 32.15 | 118.43 | 3444.12 |
| K5 | 7006.78 | 3250.25 | 18.93 | 55.38 | 135.49 | 3986.11 |
| K6 | 68878.11 | 31888.00 | 186.16 | 364.02 | 1340.49 | 39107.44 |
| K7 | 2087.54 | 970.20 | 5.63 | 10.90 | 40.14 | 1189.85 |
| K8 | 18857.49 | 8738.84 | 50.96 | 99.70 | 367.37 | 10717.31 |
| K9 | 40776.53 | 18888.58 | 110.20 | 215.22 | 792.44 | 23164.95 |
| K10 | 47403.18 | 21955.50 | 128.12 | 249.98 | 920.17 | 26926.23 |
| Min. | 777.87 | 362.49 | 2.11 | 4.04 | 14.84 | 444.56 |
| Max. | 68878.11 | 31888.00 | 186.16 | 364.02 | 1340.49 | 39107.44 |
| Mean value | 25346.82 | 11720.77 | 68.52 | 135.43 | 357.95 | 14374.36 |

Table 5. Comparison of the mean activity concentration with some selected studies.

| Sample used | ^{238}U | ^{232}Th | ^{40}K | Place | Country | References |
|-------------|-----------|------------|----------|-----------|---------|------------|
| Soil | 3.00 | 33.30 | 122.10 | Sango-Ota | Nigeria | [30] |
| Soil | 67.40 | 507.19 | 8217.77 | Abua/Odua | Nigeria | [31] |
| Soil | 32.52 | 56.23 | 403.96 | Nasarawa | Nigeria | [32] |
| Rock | 11.51 | 15.42 | 4441.06 | Asa | Nigeria | [12] |
| Soil | 11.90 | 17.72 | 70.44 | Maiganga | Nigeria | [33] |
| Soil | 12.14 | 23.23 | 270.14 | Ile-Ife | Nigeria | [34] |
| Soil | 24.50 | 51.80 | 344.90 | Anatolia | Turkey | [35] |

| | | | | | | |
|------|----------|--------|---------|---------|---------|---------------|
| Rock | 12.25 | 45.17 | 639.24 | Aravali | India | [36] |
| Rock | 24068.11 | 387.72 | 9509.24 | Wamba | Nigeria | Present study |

4. CONCLUSION

The mean activity concentrations of ^{226}Ra (24068.1±368.0), ^{232}Th (387.7±18.5), ^{40}K (9509.2±335.1) Bq kg^{-1} and absorbed dose rate of $11720.77 \text{ nGy h}^{-1}$ were higher when compared to the United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations Sources and Effects of Ionizing Radiation values of 30 Bq kg^{-1} , 35 Bq Kg^{-1} , 400 Bq kg^{-1} and 60 nGy h^{-1} , respectively. This may pose a serious health risk to the miners and the general public. The result of this study can serve as baseline data for the distribution of radioactivity present in pegmatite rock in the area and also allow more research work to be carried out to investigate the radioactive background level of the area. This will provide necessary guidelines for fruitful exploration of pegmatite so that their economic potential can be of use to the country at large. The illegal mining currently going on could be curbed to the barest minimum so that the general populace will not be prone to radiation hazards.

REFERENCES

1. Silini G. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Radiation Protection Dosimetry. 2000, Vol. 1.
2. International Atomic Energy Agency. Naturally occurring radioactive materials (IV). In Proceedings of the international conference held in Szczyrk, Poland. IAEA TECDOC 1972, 2005.
3. Joshua EO, Ademola JA, Akpaonowo MA, Oyabanjo OA, Olorode DO. Natural radionuclides and hazard of rock samples collected from Southeastern Nigeria. Radiat Meas, 2009, 44: 401- 404.
4. Sadiq AA, Agba EH. Background radiation in Akwanga, Nigeria. Working and Living environ Protect, 2011,8: 7-11
5. Kant K, Gupta R, Kumari R, Gupta N, Garg M. Natural radioactivity in Indian vegetation samples. Int. J Rad Res, 2015. 13(2): 143-150
6. Uosif MA. Gamma ray spectroscopic analysis of selected samples from the Nile river sediments in Upper Egypt. Radiat Prot Dosim. 2007. 123(2):215–220.
7. United Nations Scientific Committee on the Effects of Atomic Radiation, United Nations Sources and Effects of Ionizing Radiation. UNSCEAR Report Publication. New York, USA, 2000.
8. Reda E, Mohammed AA, El-Montaser MS, Atef E. Natural radioactivity levels and Radiological Hazards in Soil Samples around Abu Karqas Sugar Factory, Egypt. Journal of Environ. Sci. Tech; 2018.11(1): 28-38.
9. Usikalu MR, Maleka PP, Ndlovu NB, Zongo S, Adiuka JA, Abodunrin TJ. Radiation dose assessment of soil from Ijero Ekiti, Nigeria. Cogent engineering 6: 2019, 1586271, 1-11.

10. Gautam YP, Kumar A, Sharma AK, Ravi PM, Tripathi RM. Evaluation of internal dose, due to the ingestion of primordial radionuclide ⁴⁰K around Narora site, India. *Ambit J Res Environ Studies*, 2015, 1: 01-12.
11. Zubair M, Shafiqullah, Measurement of natural radioactivity in several sandy-loamy samples from Sijua, Dhanbad, India. *J. heliyon*. 2020, e03430.
12. Orosun MM, Usikalu MR, Oyewumi KJ, Achuka JA. Radioactivity levels and transfer factor for granite mining field in Asa, North-central Nigeria. 2020, *Heliyon* 6 e04240.
13. Adabanija MA, Anie ON, Oladundoye MA. Radioactivity and gamma ray spectrometry of basement rocks in Okene area, Southwestern Nigeria. *NRIAG Journal of Astronomy and Geophysics*, 2020, 9(1): 71-84.
14. Tettey-Larbi L, Darko EO, Schandorf C, Appiah AA, Sam F, Faanu A, Okoh DK, Lawlubi H, Ahyeman BK, Kansaana C, Amoah PA, Osei RK, Agalga R, Osei S. Gross alpha and beta activity and annual committed effective dose due to natural radionuclides in some medicinal plants community used in Ghana. *Int. J. Sci. Technol.* 2013, 3(4): 217–229.
15. Faanu A, Adukpo OK, Tettey-Larbi L, Lawlubi H, Kpeglo DO, Darko EO, Emi-Reynolds G, Awudu RA, Kansaana C, Amoah PA., Efa AO, Ibrahim AD, Agyeman B, Kpodzro R, Agyeman L. Natural radioactivity levels in soils, rocks and water at a mining concession of Perseus gold mine and surrounding towns in Central region of Ghana. *Springer Plus*. 2016, 5: 98, 1-16.
16. Ajayi OS, Ajayi IR. A survey of environmental gamma radiation levels of some areas of Ekiti and Ondo State, Southwestern Nigeria. *Niger. J. Phys.* 1999, 11 (15), 17-21.
17. Orosun MM, Lawal TO, Akinyose FC. Natural radionuclide concentrations and radiological impact assessment of soil and water in Tanke- Ilorin, Nigeria. *Zimbabwe Journal of science and Technology*. 2016, 11, 158-17.
18. Orosun MM, Lawal TO, Ezike SC, Salawu NB, Atolagbe BM, Akinyose FC, Ige SO, Martins G. Natural radionuclide concentration and radiological impact assessment of soil and water from Dadinkowa Dam Northeast Nigeria. *Journal of the Nigeria Association of Mathematical Physics*. 2017, 42 (1) 307-316.
19. Akinyose FC, Tchokossa P, Orosun MM, Oluyide SO, Umakha M, Ochommadu KK, Olaniyan TA, Ajibade OA. Radiological impacts of natural radioactivity in locally produced tobacco products in Ibadan, Oyo State, Nigeria. *Momona Ethiopai Journal of Science (MEJS)*. 2018, 10 (1), 59-75.
20. Dandona I. The impact of air pollution in deaths, disease burden and life expectancy across the states of India: the global burden of disease study. *Lancet planet Health*. 2019, 3, 26-29.
21. NPC Report(National Population Commission),Nigeria,2006, <https://nationpopulation.gov.ng>
22. Jacobson R, Webb JS. "The Pegmatite of Central Nigeria", *Geological Survey of Nigeria Bulletin*, 1946, Vol 17, 61 pp.
23. Wright JB. Controls of mineralization in the Older and Younger Tin Fields of Nigeria. *Econ. Geol.* 1970, 65:945-951.
24. Kinnard JA. Contrasting styles of Sn- Nb-Ta-Zn mineralization in Nigeria. *Journal of African and Earth Sciences*, 1984, 2(2), 81-90
25. Hassan NM, Mansour NA, Fayez-Hassan M, Fares S. Assessment of radiation hazards due to exposure to radionuclides in marble and ceramic commonly used as decorative building materials in Egypt. *Indoor and Built Environment*, 2017, 26(3), 317–326.
26. Larijani C. Destructive and nondestructive measurements of NORM in monazite-rich sands of Brazil. *Radiat. Phys. and Chem.* 2017, 140, 180–185.
27. Ibrahim N. Natural activity of ²³⁸U, ²³²Th and ⁴⁰K in building materials. *Journal of Environmental Radioactivity*, 1999, 43(3), 255-258.

28. Jibiri N, Isinkaye M, Momoh H. Assessment of radiation exposure levels at Alaba e-waste dumpsite in comparison with municipal waste dumpsites in southwest Nigeria. *Journal of Radiation Research and Applied Sciences*. 2014, 7(4): 536-541
29. Beretka J, Mathew PJ. Natural radioactivity of Australian building materials and industrial wastes and byproducts,. *Health Physics*, 1985, 48, 87-95.
30. Augustine KA, Israel A, Babalola OF, Alabi DO, Onuah EE, Enyenihi. Assessment of Natural Radioactivity and Determination of Heavy Metals in Soil around Industrial Dumpsites in Sango-Ota, Ogun State, Nigeria. *J. Medical Physics*, 2014, 39(2): 106-111.
31. Ononugbo CP, Awiri GO, Tutumeni G. Measurement of Natural Radioactivity and Evaluation of Radiation Hazards In Soil Of Abua/Odual Districts Using Multivariate Statistical Approach. *British Journal of Environmental Sciences*, 2016, 4(1):.35-48.
32. Ibrahim U, Akpa TC, Daniel IH. Assessment of Radioactivity Concentration in Soil of some mining areas in central Nasarawa state, Nigeria *Science World Journal*, 2013. 8 (2): 7-12.
33. Kolo MT, Amin YM, Khandaker MU, Abdulla WH. Radionuclide concentrations and excess lifetime cancer risk due to gamma radioactivity in tailing enriched soil around Maiganga coal mine, Northeast Nigeria. *Int. J. Radiat. Res.*, 2017, Vol 15(1): 71-80.
34. Oluyide SO, Tchokossa P, Akinyose FC, Orosun MM. Assessment of radioactivity levels and transfer factor of natural radionuclides around iron and steel smelting company located in Fashina village, Ile-Ife, Osun State, Nigeria. *Working and Living Environmental Protection*, 2018, Vol. 15, No 3, 2018, pp. 241 – 256.
35. Ayse D, Meryem Y. Determination of radioactivity concentrations in soil samples and dose assessment for Rize Province, Turkey. *Journal of radiation research and applied sciences*, 2017, 1-5.
36. Kumari R, Kant K and Garg M. Natural radioactivity in rock samples of Aravali hills in India. *Int. J. Radiat. Res.*, 2016; 15(4): 391-398.