Evaluation of Radiation Hazard Indices in Mining Sites of Nasarawa State, Nigeria

U. Rilwan1*, I. Umar2, G. C. Onuchukwu3, H. A. Abdullahi4 and M. Umar1

1Department of Physics, Nigerian Army University, P.M.B 1500, Biu, Borno State, Nigeria.
2Department of Physics, Nasarawa State University, P.M.B 1022, Keffi, Nasarawa State, Nigeria.
3Vice Chancellor’s Office, Nigerian Army University, P.M.B 1500, Biu, Borno State, Nigeria.
4National Agency for Science and Engineering Infrastructure, IduIndustrial Area, P.M.B 391, Garki, Abuja, Nigeria.

**Authors’ contributions**
This work was carried out in collaboration among all authors. Author UR designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors UR, IU and GCO managed the analyses of the study. Authors UR, HAA and MU managed the literature searches. All authors read and approved the final manuscript.

**Article Information**
DOI: 10.9734/AJR2P/2020/v3i130111

**ABSTRACT**
This work evaluates the radiation hazard indices from some selected mining sites in Nasarawa West, using Sodium Iodide Thallium Gamma Spectrometry. Raeq ranged from 100.39 – 197.40 Bq/Kg with a mean 161.44 Bq/Kg, which is lower than the average of 370 Bq/Kg. The GADR ranged from 44.85 nGy/hr - 90.71 nGy/hr with the mean 73.68 nGy/hr, which is also below the average of 89 nGy/hr for soil. The AGED ranged from 315.77 mSv/yr - 640.91 mSv/yr with the mean 519.19. Which is above the threshold value of 300 mSv/yr. ACI ranged from 0.73 – 1.45 with the mean value 1.18 which is above the standard of unity. The AEDE (outdoor) ranges from 0.055 mSv/yr - 0.111 mSv/yr with the mean 0.090 mSv/yr which is above the 0.07 mSv/yr standard permissible limit. The AEDE (indoor) ranged from 0.220 mSv/yr - 0.445 mSv/yr with the mean value 0.361 mSv/yr. This is below the 0.45 mSv/yr threshold. The ELCR ranged from 0.770 – 1.558 with the mean value 1.265 and

*Corresponding author: E-mail: rilwanusmanloko4@gmail.com;
from 0.193-0.389 with the mean value 0.317 for outdoor and indoor respectively, which exceed the 0.29 X 10^{-3} threshold limit. The External and Internal Hazard indices ranges from 0.271-0.533 and 0.289-0.675 as well as mean values 0.435 and 0.512 respectively, which are below the threshold. Therefore, there may be serious radiological effects to the populace.

Keywords: Radionuclide; radiation; hazard indices; Nasarawa State.

1. INTRODUCTION

The assessment of radioactivity in our environment allows the determination of population radiation exposure. The occurrence of radionuclides in soil depends on the soil formation as well human activities in the area, such as the geology of the area, tin mining and use of fertilizers in agriculture [1,2]. Consumption of ground water with elevated amounts of natural radionuclides may increase the radioloxicity to human and internal exposure [3] to radiation caused by the decay of the natural radionuclides taken into the body through ingestion as well as inhalation. The decay process leads to the release of several alpha and beta particles which are responsible for the total radiation dose received from natural radioactivity as well as artificial [4,5]. The aim of this study was to Evaluation of Radiation Hazard Indices in Mining Sites of Nasarawa State. Nigeria.

2. MATERIALS AND METHODS

2.1 Materials

In the course of the radiometric study, the following items or materials were used as shown in Table 1.

2.2 Study Area

Four villages were chosen in Nasarawa LGA. The villages are Eyenu, OPanda, Okereku and Udegen-Mbeki abbreviated as NW1, NW2, NW3 and NW4 respectively. The villages NW1, NW2, NW3 and NW4 are located at 08°24.38.2’N and 007°52.59.2’E, 08°21.24.9’N and 007°54.29.6’E, 08°24.04.1’N and 007°52.10.6’E and 08°25.56.3’N and 007°53.49.3’E respectively. Columbite was mined in all the four villages as represented in Fig. 1.

2.3 Methods

2.3.1 Sample collection

Four sample locations were visited from all over Nasarawa West, Nigeria, to conduct the radiometry study. Three samples will be collected from each sample area to make twelve samples of soil. The samples were collected at 0.5 m depth level from the surface of the soil. From each area, as stated earlier, three samples were collected as follows. Firstly from the mining spot, secondly from a distance of 100 m away from the mining spot, and thirdly, from the river area within the mining spot. The collected samples were sealed in a labeled polythene bag and enclose into one sack for easiest transportation from the mining or sample point to the house.

Meanwhile, when collecting the sample from the mining spot, Inspector Alert Nuclear Radiation Monitor was set at one meter above the ground to measure the physical activity concentration of the radionuclides present in the soil. In addition, Global Positioning System (GPS) was used to take the altitude of the area.

2.3.2 Sample preparation

The collected wet samples were taken to the laboratory and left open for a minimum of 24 hours to dry under ambient temperature. The samples were grounded using mortar and pestle and allowed to pass through 5 mm-mesh sieve to remove larger object and make it fine powder. The samples were packed to fill 7 cm by 6 cm cylindrical plastic container. Each container accommodated 300 g of sample. They were carefully sealed so as to prevent radon escape and then stored for a minimum of 24 days to allow radium attain equilibrium with the daughters.

2.3.3 Sample analysis

Gamma-ray spectrometry technique was employed in the spectral collection of the prepared sample using the higher energy region of the gamma-lines.

2.4 Data Analysis

The principal primordial radionuclides that was discuss for all the radiological parameters (Radium Equivalent Activity Ra_{eq}, Absorbed Dose Rate, Effective Dose Rate, External Hazard Index H_{(ex)} and Internal Hazard Index H_{(in)}) in this case are \( ^{226}\text{Ra} \), \( ^{232}\text{Th} \) and \( ^{40}\text{K} \).
Table 1. Using items in the radiometric study

| Materials                                      | Specifications                                                                                                                                 |
|-----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Inspector Alert Nuclear Radiation Monitor     | This is a health and safety instrument that is optimized to detect the physical levels of activity concentration of the radionuclides present in the environment. |
| Global Positioning System (G.P.S)             | This is a space-based satellite navigation system that provides location and time information in all weather, anywhere or near the earth. This was used to locate the mining sites. |
| Disposable Hand Glove                         | This is a shielding material used to protect the hands and fingers from contacting any radioactive source.                                    |
| Measuring Tape                                 | This was used to measure the depth of the pit and also to measure the distance between two points.                                             |
| Masking Adhesive Tape                          | This was used to label the samples for easier identification.                                                                                  |
| Marker pen                                     | This was used to mark the masking tape attached to the polythene bag for easy identification of the soil samples.                           |
| Mortar and Pestle                              | This was used to ground the collected samples after being dried at 60°C to 80°C for 24 hours in order to maintain the radioactive equilibrium. |
| 5mm-Mesh Sieve                                 | This was used to sieve the grounded samples in order to remove any larger particles in it and make it a powder.                                |
| Cylindrical Plastic Container                  | The sieved powder was packed into a cylindrical plastic container and the cover will be sealed with a masking tape to prevent it from any external radiation. |
| Electronic Analytical Balance                  | The sealed containers were placed on the electronic analytical balance to measure its weight in grams.                                        |
| Cutlass                                        | This was used for clearing of the mining sites also for shallow digging.                                                                     |
| Sealer                                         | This was used to seal the sieved and labeled samples in their respective container in order to avoid leakage also to prevent the escape of gaseous $^{222}$Rn from the sample. |
| Sodium Iodide-Thalium Gamma Spectroscopic System | This is an instrument set in the laboratory, which was used to analyze the soil samples.                                                     |

2.4.1 Radium Equivalent Activity ($Ra_{eq}$)

This first index can be calculated using [6] relation:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_{K}$$

(1)

Where $A_{Ra}$, $A_{Th}$ and $A_{K}$ are the specific activities of $^{226}$Ra, $^{232}$Th and $^{40}$K in Bq/kg, respectively.

2.4.2 Absorbed dose rate

According to UNSCEAR [7], conversion factors to transform specific activities $A_{Ra}$, $A_{Th}$ and $A_{K}$ of $^{226}$Ra, $^{232}$Th and $^{40}$K, respectively, in absorbed dose rate at 1 meter above the ground (in nGy/hr by Bq/kg) are calculated by relation:

$$D(nGy/hr) = 0.0417A_{K} + 0.462A_{Ra} + 0.604A_{Th}$$

(2)

Where $A_{Ra}$, $A_{Th}$ and $A_{K}$ are the activities of $^{226}$Ra, $^{232}$Th and $^{40}$K in Bq/kg, respectively.

2.4.3 Annual Gonadal Equivalent Dose (AGED)

According to Alam, et al. [8], AGED is calculated with given activity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K (in Bq/Kg) using the relation:

$$AGED (mSv/yr) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_{K}$$

(3)

Where, $A_{Ra}$, $A_{Th}$, and $A_{K}$ are the radioactivity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K (in Bq/Kg) in soil samples respectively.

2.4.4 Activity concentration index (Representative gamma index)

According to Alam, et al. [8], the activity concentration index is given by:

$$I_{R} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_{K}}{1500}$$

(4)

Where, $A_{Ra}$, $A_{Th}$, and $A_{K}$ are the radioactivity concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K (in Bq/Kg) in soil samples respectively.
2.4.5 Annual Effective Dose Equivalent (AEDE)

According to UNCEAR [9] Veiga, et al. [10], AEDE is determined by the equations below.

\[
\text{AEDE (Outdoor) (mSv/y)} = D \times 8760 \times 0.7 \times 0.2 \times 10^{-6}
\]

And

\[
\text{AEDE (Indoor) (mSv/y)} = D \times 8760 \times 0.7 \times 0.8 \times 10^{-6}
\]

2.4.6 Excess Lifetime Cancer Risk (ELCR)

According to Taskin, et al. [11], Excess lifetime cancer risk (ELCR) is given by;

\[
\text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF}
\]

Where AEDE is the Annual Effective Dose Equivalent, DL is the average duration of life / life expectancy (estimated as 70 years), and RF is the Risk Factor (Sv\(^{-1}\)), i.e. fatal cancer risk per Sievert.

2.4.7 External hazard index

According to Beretka and Mathew [6], can be calculated using the equation:

\[
H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}
\]

Where \(A_{Ra}\), \(A_{Th}\), and \(A_{K}\) are activity concentrations of \(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K in Bq/kg respectively.

2.4.8 Internal hazard index

According to Beretka and Mathew [6], is given by the formula

\[
H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}
\]

Where \(A_{Ra}\), \(A_{Th}\), and \(A_{K}\) are activity concentrations of \(^{226}\)Ra, \(^{232}\)Th and \(^{40}\)K in Bq/kg respectively.

3. RESULTS AND DISCUSSION

3.1 Results

This shows the experimental results obtained from the spectra of twelve soil samples under investigation. For the effective computation of the experimental data from Count Dose Rate (cpm) to Exposure Dose Rate (\(\mu\text{Sv hr}^{-1}\)), Absorbed Dose Rate (nGyhr\(^{-1}\)), Annual Effective Dose Rate (mSvyr\(^{-1}\)), Annual Gonadal Equivalent Dose Rate (mSv/yr), Activity Concentration Index
(representative gamma index), Excess Lifetime Cancer Risk, External Hazard Index (Bq/Kg) and Internal Hazard Index (Bq/Kg); Equation 1 to 9 was used and the results are presented in the Table 2.

3.2 Result Analysis

The data in Table 2 were used to plot chats (see Figs. 2 to 11) so as to analyze the results and compare them with those of regulatory bodies.

3.3 Discussion

From Table 2 and the charts plotted it is possible to see that, all the locations have their Radium Equivalent Activity ranging between 100.39 Bq/Kg and 197.40 Bq/Kg with a mean value of 161.44 Bq/Kg. The Gamma Absorbed Dose Rates calculated ranged from 44.85 nGy/hr to 90.71 nGy/hr with the mean of 73.68 nGy/hr. Annual Gonadal Equivalent Dose (AGED) obtained ranged from 315.77 mSv/yr to 640.91 mSv/yr with the mean of 519.19 mSv/yr. Activity Concentration Index (ACI) calculated for the locations ranged from 0.73 to 1.45 with the mean value of 1.18. The AEDE (outdoor) value ranges between 0.055 mSv/yr and 0.111 mSv/yr with the mean of 0.090 mSv/yr. On the other hand, the AEDE (indoor) value ranged from 0.220 mSv/yr to 0.445 mSv/yr, with the mean value of 0.361 mSv/yr. Excess Lifetime Cancer Risk Index (ELCR) obtained ranged from 0.770 to 1.558 with the mean value of 1.265 and from 0.193 to 0.389 with the mean value of 0.317 for outdoor and indoor respectively. External and Internal Hazard indices ranged from 0.271 Bq/kg to 0.533 Bq/kg and 0.289 Bq/kg to 0.675 Bq/kg as well as mean values of 0.435 Bq/kg and 0.512 Bq/kg respectively. The results showed trends that are generally high for most radiation hazard indices calculated except for few indices whose values are below the recommended thresholds.
Table 2. Evaluated results for radiation hazard indices

| Sample Code | Ra\(_{eq}\) (Bq/kg) | G.A.D.R (nGy/hr) | A.G.E.D (mSv/yr) | I\(_{yr}\) (Bq/kg) | AEDE Outdoor (mSv/yr) | AEDE Indoor (mSv/yr) | E.L.C.R Indoor (mSv/yr) | E.L.C.R Outdoor (mSv/yr) | H\(_{ex}\) (Bq/kg) | H\(_{ex}\) (Bq/kg) |
|-------------|----------------------|------------------|------------------|------------------|----------------------|----------------------|------------------------|------------------------|----------------|----------------|
| NW1A        | 177.54               | 80.99            | 572.87           | 1.31             | 0.999                | 0.397                | 1.390                  | 0.347                  | 0.479          | 0.532          |
| NW1B        | 162.74               | 74.65            | 527.55           | 1.20             | 0.992                | 0.366                | 1.281                  | 0.322                  | 0.439          | 0.507          |
| NW1C        | 164.62               | 75.73            | 534.00           | 1.21             | 0.993                | 0.372                | 1.302                  | 0.326                  | 0.445          | 0.535          |
| NW2A        | 100.39               | 44.85            | 315.77           | 0.73             | 0.955                | 0.220                | 0.770                  | 0.193                  | 0.271          | 0.289          |
| NW2B        | 102.27               | 46.47            | 326.26           | 0.74             | 0.957                | 0.228                | 0.798                  | 0.200                  | 0.276          | 0.332          |
| NW2C        | 197.40               | 90.71            | 640.40           | 1.45             | 0.111                | 0.445                | 1.558                  | 0.389                  | 0.533          | 0.529          |
| NW3A        | 153.54               | 67.08            | 480.64           | 1.07             | 0.082                | 0.329                | 1.152                  | 0.287                  | 0.415          | 0.536          |
| NW3B        | 170.95               | 78.70            | 556.02           | 1.26             | 0.097                | 0.386                | 1.351                  | 0.340                  | 0.462          | 0.552          |
| NW3C        | 189.00               | 89.13            | 640.91           | 1.43             | 0.109                | 0.437                | 1.530                  | 0.382                  | 0.505          | 0.554          |
| NW4A        | 181.35               | 83.03            | 584.22           | 1.32             | 0.102                | 0.407                | 1.425                  | 0.357                  | 0.489          | 0.592          |
| NW4B        | 195.30               | 87.27            | 605.22           | 1.38             | 0.107                | 0.428                | 1.498                  | 0.375                  | 0.527          | 0.675          |
| NW4C        | 142.16               | 65.55            | 466.44           | 1.06             | 0.080                | 0.322                | 1.127                  | 0.280                  | 0.384          | 0.415          |
| Range       | 100.39-197.40        | 44.85-90.71      | 315.77-640.91    | 0.73-1.45        | 0.055-0.111          | 0.220-0.445          | 0.770-1.558            | 0.193-0.389            | 0.271-0.533    | 0.289-0.675    |
| Mean        | 161.44               | 73.68            | 519.19           | 1.18             | 0.090                | 0.361                | 1.268                  | 0.317                  | 0.435          | 0.512          |
Fig. 5. Activity Concentration Index (ACI) compared with the threshold

Fig. 6. Annual Effective Dose Equivalent, AEDE (Outdoor) compared with the threshold

Fig. 7. Annual Effective Dose Equivalent, AEDE (Indoor) compared with the threshold

Fig. 8. Excess lifetime cancer risk (Outdoor), compared with the threshold
Fig. 9. Excess lifetime cancer risk (Indoor) compared with the threshold

Fig. 10. External Hazard Index (H_{ex}) compared with the threshold

Fig. 11. Internal Hazard Index (H_{in}) compared with the threshold

4. CONCLUSION

Therefore, it can be concluded that, there may be serious immediate radiological effects to the populace and the environment in these areas except for few locations where the risk due to radiation is less significant even though, it can be recommended that, all the locations may need further investigation and monitoring using the High Purity Germanium (HPGe) detector for the locations.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Pujol L, Sanechez-Cebeza JA. Natural and artificial radioactivity in surface waters of the Ebro River Basin (Northeast Spain). Journal of Environ, Radioactivity. 2000;51:181–210.
2. Solomon AO. A study of natural radiation levels and distribution of dose rates within the younger granites province of Nigeria. A Ph.D Thesis, University of Jos, Nigeria. 2005;1:12.
3. Dinh Chau N, Dulinski M, Jodłowski P, Nowak J, Rozanski K, Slezia M, Wachniew P. Natural radioactivity in
groundwater—A review. Isotopes in Environmental and Health Studies. 2011; 47(4):415-437.

4. Karahan G, Ozturk N, Ahmed B. Natural radioactivity in various surface waters in Istanbul, Turkey. Water Resources. 2000; 24:4367–70.

5. Nguelem EJM, Darko EO, Ndontchueng MM, Schandorf C, Akiti TT, Muhulo AP, Bam EKP. The natural radioactivity in groundwater from selected areas in greater accra region of Ghana by gross alpha and gross beta measurements. Radiation Protection and Environment. 2013;36(1): 14.

6. Beretka J, Mathew PJ. Natural radioactivity of australian building materials, industrial wastes and byproducts. Health Physics. 1985;48.

7. UNSCEAR. Exposure of public and workers from various sources of radiation. United Nation Scientific Committee on Effect of Atomic Radiation UNSCEAR Report. 1988;1:12.

8. Alam MN, Miah MMH, Chowdhury MI, Kamal M, Ghose S, Islam MN, Mustafa MN, Miah MSR. Radiation dose estimation from radioactivity analysis of lime and cement used in Bangladesh. Journal of Environmental Radioactivity. 1999;4: 21.

9. UNCEAR. Radiological Protection Bulletin. United Nations Scientific Committee on the effect of Atomic Radiation No. 20000. 2000:224:21. New York.

10. Veiga RG, Sanches N, Anjos RM, Macario K, Bastos J, Iguatemy M, Auiar JG, Santos AM, Mosquera B, Carvalho C, Baptista Filho M, Umisedo NK. Measurement of natural radioactivity in Brazilian beach sands. Journal of Radiation Measurement. 2006;41:189.

11. Taskin H, Karavus M, Ay P, Topozoglu A, Hindiroglu S, Karahan G. Radionuclide concentrations in soil and life time cancer risk due to gamma radioactivity in Kirkkareli, Turkey. Journal of Environmental Radioactivity. 2009;35:53.

© 2020 Rilwan et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/53523