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Radioactive Element Distribution in Nigerian Coal Deposits: Implications for Environmental and Health Risks

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ABSTRACT
Coal mining and utilization pose significant environmental and health risks due to the presence of naturally occurring radioactive materials (NORMs). Nigeria, with its vast coal reserves is no exception. This study investigates the distribution of radioactive elements in Nigerian coal deposits using NaI(Tl) based gamma-ray spectroscopy technique. The specific activity concentrations of the radionuclides ranged from 52.56 $\pm$ 3.59 Bq/kg to 117.45 $\pm$ 5.71 Bq/kg for ^{40}K, 16.22 $\pm$ 3.50 Bq/kg to 19.54 $\pm$ 3.87 Bq/kg for ^{226}Ra and 16.88 $\pm$ 1.54 Bq/kg to 51.75 $\pm$ 3.99 Bq/kg for ^{232}Th. The results indicated that thorium concentrations were much higher than the United Nation Scientific Committee on the Effect of Atomic Radiation (UNSCEAR, 2000) permissible limit of 30 Bq/kq. This potent radiological health risk to vital body organs and tissues, hence the need to limit exposure time or use proper shielding equipment by miners and people living around coal fired power plants. Similarly, the results of the annual gonadal dose equivalent were slightly less than the ICRP permissible limit of 300 $\mu S_v y^{-1}$. Hence, the need to reduce exposure time (during work hour) especially by the miners and people around coal fired power plants.

Keywords:
Coal mining,
Environmental health risks,
Nigeria,
NORMs,
Radioactive elements.

INTRODUCTION

Coal, a fossil fuel formed from the remains of ancient plants, has been a primary source of energy globally for centuries (International Energy Agency, 2020). Nigeria, with its vast coal reserves, is no exception (Nigerian Geological Survey Agency, 2019). However, coal deposits, like other geological formations, can contain varying levels of naturally occurring radioactive materials (NORMs) (International Atomic Energy Agency, 2011). The presence of these radioactive elements, such as uranium (U), thorium (Th), and potassium (K), poses significant environmental and health risks (World Health Organization, 2018).

The mining and utilization of coal can lead to the release of these radioactive elements into the environment, contaminating soil, water, and air (United Nations Environment Programme, 2013). Prolonged exposure to radiation from these elements can cause harm to humans and the ecosystem (National Institute for Occupational Safety and Health, 2019). The radiation risks associated with coal mining and utilization are often overlooked, particularly in developing countries like Nigeria, where regulatory frameworks and monitoring mechanisms may be inadequate (Uloko *et al*., 2024). Nigeria's coal deposits are primarily found in the eastern and central regions of the country. The Enugu coal field, one of the most prominent coal deposits in Nigeria, has been mined extensively since the early 20th century. However, there is a paucity of information on the levels and distributions of radioactive elements in Nigerian coal deposits. This knowledge gap necessitates a comprehensive assessment of the radioactive element distribution in Nigerian coal deposits with the aim to understand the potential environmental and health implications. Thus, this study aims to investigate the distribution of radioactive elements in Nigerian coal deposits, with focus on the Maiganga coal, Gboko coal, Onyeama coal, Okobo coal, Opoko-obido coal, Odagbo coal and Ofugo coal. This work seeks to provide valuable insights into the radiation risks associated with the coal mining and utilization in Nigeria, informing policymakers, regulators, and stakeholders on the need for effective radiation safety measures and guidelines.

MATERIALS AND METHODS

Study Area

In Figure 1, we present the locations of the coal deposits studied in this work.

Maiganga is a community located between latitudes 10° 02' and 10° 05' and longitudes 11° 06' and 11° 08' in Akko Local Government Area of Gombe State, Northeast Nigeria (Pandey *et al.,* 2014). The Maiganga coal is situated within the late Cretaceous Gombe Formation in the Gongola sub-basin of the Northern Benue Trough, Nigeria (Kolo *et al.,* 2016). The Maiganga coal deposit is a low-rank, sub-bituminous coal resource identified by the Nigerian government as a key target for future power generation initiatives (Kolo *et al.,* 2016).

The Gboko coal mine is situated in Benue State, Nigeria, within the Gboko Local Government Area. Geographically, it lies at 7.31620°N latitude and 8.90170°E longitude (Uloko *et al.,* 2024). The region is notable for its rich mineral deposits, including limestone, granite, barite, and alluvial clay (Uloko *et al.,* 2024).

The Onyeama coal mine is geographically situated within the latitudes 60°29' to 60°34' N and longitudes 70°30' E, located within the Enugu coal field, specifically within the catchment area of the Ekulu River (Ozoko, 2015). The Onyeama coal is situated approximately 6.5 kilometres Northwest of Enugu City, in Enugu State, South-eastern Nigeria (Ozoko, 2015). The Onyeama coal mine is an underground mining operation that extracts sub-bituminous coal from the seams 2, 3, and 4 of the Mamu Formation, located at the base of the Enugu Escarpment (Ozoko, 2015).

The Okobo coal mine lies between latitude 7˚22'14" N and longitude 7˚37'31"E in the Enjema district area of Ankpa local government area which is about 200 km North of Enugu having coal reserves amounting to 380 million tonnes (Itodo *et al.,* 2020).

In Igalamela-Odolu local government area of Kogi State, precisely in Egabada community which is surrounded to the East by Enugu State and to the west by the Niger River is the Opoko-Obido coal mine with a longitude of 7^0 1' 15" E and latitude of 7^0 2' 36" N having an abundance of coal deposits covering approximately 26 km^2 (Uloko *et al.,* 2024).

In Okaba district of Ankpa local government area is the Odagbo coal mine which is situated in the North-eastern part of the Anambra Basin with an altitude of about 275 m, longitudes 7^0 43' 30" E to 7^0 44' 00" E and latitudes 7^0 28' 30" N to 7^0 29' 00" N. The mine in this district is approximately 0.8 m thick of bituminous coal, with an overburden of between 3 m and 6 m. The coal is characterised by a dark colour, with a light grey silty shale that overlies it (Uloko *et al*., 2024). Additionally, in the same Ankpa Local Government, there is the Ofugu coal mine. It lies at longitude 7^0 ° 37' 24.7" E, latitude 70 ° 33' 36.9" N, and an altitude of 390 m (Uloko *et al.,* 2024).

Figure 1: Study Area Map of Nigeria, Showing Coal Mining Sites

Sample Collection and Preparation

Seven samples were collected from the active seven (7) coal mines studied in this work, specifically from Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo, and Ofugo coal mines. It was reported that there were cases of indiscriminate mining activities, poor water quality, and continuous acid mine drainage contamination from underground coal mines. It is this report that prompted us to carry out this study.

The coal samples were pulverized into fine powder, sieved with a mesh of diameter 2 mm, and homogenized at the Nigerian Geological Survey Agency (NGSA) laboratory in Kaduna State, Nigeria. Each time a sample was pulverized; the plate inside the machine was washed and dry-cleaned with acetone and tissue paper to avoid cross-contamination of the samples. Then the powdered samples were packed in well-labelled plastic containers and properly sealed to avoid cross-contamination and to prevent the escape of radiogenic gases such as radon gas (Ra-222). These coal samples were then transported to the Centre for Energy Research and Training (CERT), Ahmadu Bello University (ABU), Zaria for the Gamma Spectrometric analysis. The samples were kept for thirty-five (35) days to achieve radioactive secular equilibrium at the environmental laboratory of the Centre for Energy Research and Training (CERT), Ahmadu Bello University (ABU), Zaria.

Sample Analysis

The analysis of the coal samples was carried out using a 76 mm x 76 mm NaI (Tl) detector crystal optically coupled to a photomultiplier tube (PMT). The assembly has a preamplifier incorporated into it and a 1 kilovolt external source. The detector was enclosed in a 6 cm lead shield with cadmium and copper sheets. This arrangement was aimed at minimizing the effects of background and scattered radiation. The data acquisition software used was Maestro by Canberra Nuclear Products. The samples were each measured for a period of 29000 seconds. The peak area of each energy in the spectrum was used to compute the activity concentrations in each sample.

Calibration of the system for energy and efficiency were done with two calibration point 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 the count was taken for 30 minutes.

The standards used to check for the calibration were the IAEA Gamma Spectrometric reference materials RGK-1 for K-40, RGU-1 for Ra-226 (Bi-214 peak) and RTG-1 for Th-232 (Ti-208).

The background count was also done for 29000 seconds.

RESULTS AND DISCUSSION

We shall present the results obtained in this study in Figures 2 to 5 while the data are presented in the respective table. The analysed coal samples from Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo, and Ofugo coal deposits showed the presence ^{40}K, ^{226}Ra and ^{232}Th with their specific activity concentrations in Becquerel per kilogram as presented in Table 1 and Figure 2.

Table 1: Activity Concentrations of Radionuclides in the Coal Samples

Sample ID	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)	^{232}Th (Bq/kg)
S1	102.3639 ± 5.3344	18.1070 ± 4.7071	37.0826 ± 3.6726
S2	85.2146 ± 3.4588	16.2234 ± 3.5009	50.0582 ± 4.6789
S3	110.9020 ± 6.2099	19.5436 ± 3.8462	37.0468 ± 1.2582
S4	117.4448 ± 6.2099	17.1108 ± 2.9541	51.7485 ± 2.2018
S5	81.3530 ± 5.4121	16.6629 ± 2.9696	22.4173 ± 1.7697
S6	52.5599 ± 3.5863	19.5436 ± 1.8744	16.8757 ± 1.5416
S7	117.4479 ± 5.7124	19.5436 ± 3.8693	51.7480 ± 3.9909
Permissible Limits	400.00	35.00	30.00

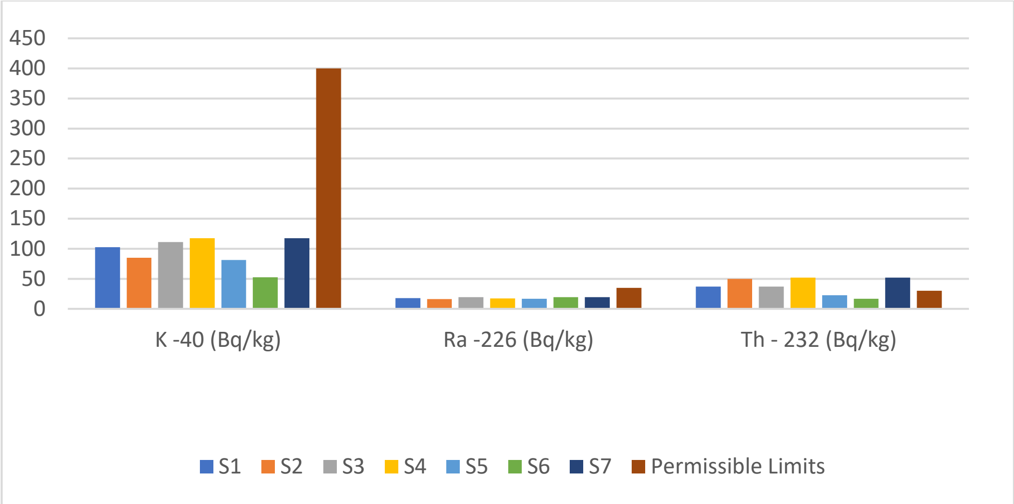

Figure 2: Specific Activity Concentrations of Radionuclides in the Coal Samples

The specific activity concentration in Bq/kg of ^{40}K, ^{226}Ra, and ^{232}Th with their respective uncertainty (± σ) levels in the coal samples from Maiganga, Gboko, Onyeama, Okobo, Opoko-obido, Odabgo, and Ofugo presented in Table 1 and Figure 2 indicated that the potassium concentration in all the coal samples were less than the world average of 400 Bq/kg. Similarly, radium concentration revealed a minimal concentration level lower than the permissible limit of 30 Bq/kg by UNSCEAR, 2020.

The concentration of thorium in the coal samples presented in Table 1 and Figure 2 indicated that samples S1 (Maiganga coal), S2 (Gboko coal), S3 (Oyeama coal), S4 (Okobo coal), and S7 (Ofugo coal) were much higher than the United Nation Scientific Committee on the Effect of Atomic Radiation (UNSCEAR, 2000) and the International Commission on Radiological Protection (ICRP, 2006) permissible limit of 30 Bq/kq. This potent radiological health risk to vital body organs and tissues, hence there is need to limit exposure time, and ensure the proper use shielding equipment by miners and people living around coal fired power plants.

Estimation of Radiological Parameters

Absorbed Dose Rate (D_R)

Absorbed dose rate is the quantity that gives the measure of the energy deposited in matter by ionizing radiation per unit mass (Nwankwo *et al.,* 2015). The absorbed dose rates which were used in the calculation of dose uptake in living tissue were calculated using equation (1) based on the standards and guidelines by UNSCEAR (2000).

$$D_R = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad (1)$$

where: D_R is the absorbed dose rate, A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively in Bq/kg and 0.462, 0.604 and 0.0417 are the conversion factors (Nwankwo *et al.,* 2015; UNSCEAR, 2000).

The evaluated absorbed dose rate presented in Table 2 and Figure 3a, showed that the Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coal samples analysed have absorbed dose rates of 35.0315 ± 4.6154 nGy/h, 41.2789 ± 4.3567 nGy/h, 36.0300 ± 2.7958 nGy/h, 44.0587 ± 2.9537 nGy/h, 24.6307 ± 2.6617 nGy/h, 21.4137 ± 1.9465 nGy/h, and 45.1825 ± 4.4363 nGy/h respectively. The values obtained were below the world recommended permissible limit of 84.00 nGy/h (UNSCEAR, 2000). This showed no immediate radiological health risk regarding exposure level of the public in the study areas.

Annual Effective Dose (AED)

This is the measure of the total radiation exposure a person receives over a year, taking into account the sensitivity of different organs and tissues to radiation (Nwankwo *et al.,* 2015). It is the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body and it represents the stochastic health risk to the whole body, which is the probability of cancer induction and genetic effects, of low levels of ionizing radiation (ICRP, 2006). The annual effective dose (in mSv/y) evaluation enables the summation of organ doses due to varying levels and types of radiation, both internal and external to produce overall calculated effective dose. It represents a 5.5 % chance of developing cancer (ICRP, 2006). This value was calculated using equation (2) given by UNSCEAR, (2000).

$$E_d = D_R \times O_f \times C_C \times T \quad (2)$$

where: E_d is the annual effective dose in (mSv/y), D_R is the value of absorbed dose rates in (nGy/h), O_f is the outdoor occupancy factor (0.2 which implies that people spend 20% of the time outdoor), C_C is the dose conversion coefficient (0.7×10^{-6} in Sv/Gy i.e. 0.7 is the conversion factor and 10^{-6} is conversion from nano to milli), T is the time of exposure per year, (8760 in hr/y) (Nwankwo *et al.,* 2015; UNSCEAR, 2000).

The evaluated annual effective dose for the coal samples from Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo mines as presented in Table 2 and Figure 3b indicated that the values were 0.0429 ± 0.0057 mSv/y, 0.0506 ± 0.0053 mSv/y, 0.0442 ± 0.0034 mSv/y, 0.0540 ± 0.0036 mSv/y, 0.0302 ± 0.0033 mSv/y, 0.0263 ± 0.0024 mSv/y, and 0.0554 ± 0.0054 mSv/y respectively. These values were below the International Commission on Radiological Protection (ICRP, 2006) and the United Nation Scientific Committee on the Effect of Atomic Radiation (UNSCEAR, 2000) permissible limits of 0.29 mS_v/y and 1.00 mS_v/y respectively.

Radium Equivalent Activity (Ra_{eq})

This is the measure of the radioactivity of a sample (Nwankwo *et al.,* 2015). It is the activity of a sample that would produce the same gamma ray exposure as 1 gram of radium (Ra-226) in equilibrium with its decay products.

The Radium Equivalent Activity is a common radiological index used to compare the specific activities of materials containing ^{238}U, ^{232}Th and ^{40}K by a single quantity which takes into account the radiation hazards associated with them (Nwankwo, *et al.,* 2015). We calculated Ra_{eq} using equation 3 below (Nwankwo *et al.,* 2015).

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \leq 370 \quad (3)$$

where: A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K respectively. The values of the studied samples must be less than 370 Bq/kg for the radiation hazard to be negligible (Nwankwo *et al.,* 2015).

Table 2 and Figure 3c presents the evaluated results of the radium equivalent activity in Bq/kg for the analysed coal samples from Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coal mines. The results were 79.0171 ± 10.3697 Bq/kg, 94.3681 ± 10.4581 Bq/kg, 81.0599 ± 6.1236 Bq/kg, 100.1544 ± 5.9170 Bq/kg, 54.9838 ± 5.9170 Bq/kg, 47.7229 ± 4.3250 Bq/kg, and 102.5867 ± 10.0161 Bq/kg accordingly. These numerical values were less than the United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) permissible limit of 370 Bq/kg.

Table 2: Absorbed Dose Rate, Annual Effective Dose and Radium Equivalent Activity of the Coal

Samples ID	Absorbed Dose Rate ($nGy.h^{-1}$)	Annual Effective Dose ($mS_v y^{-1}$)	Radium Equivalent Activity (Bq/kg)
S1	35.0315 ± 4.6154	0.0430 ± 0.0057	79.0171 ± 10.3697
S2	41.2789 ± 4.3567	0.0506 ± 0.0053	94.3681 ± 10.4581
S3	36.0300 ± 2.7958	0.0442 ± 0.0034	81.0599 ± 6.1236
S4	44.0587 ± 2.9537	0.0540 ± 0.0036	100.1544 ± 5.9170
S5	24.6307 ± 2.6617	0.0302 ± 0.0033	54.9838 ± 5.9170
S6	21.4137 ± 1.9465	0.0263 ± 0.0024	47.7229 ± 4.3250
S7	45.1825 ± 4.4363	0.0554 ± 0.0054	102.5867 ± 10.0161
Permissible Limits	84.00	0.46	370.00

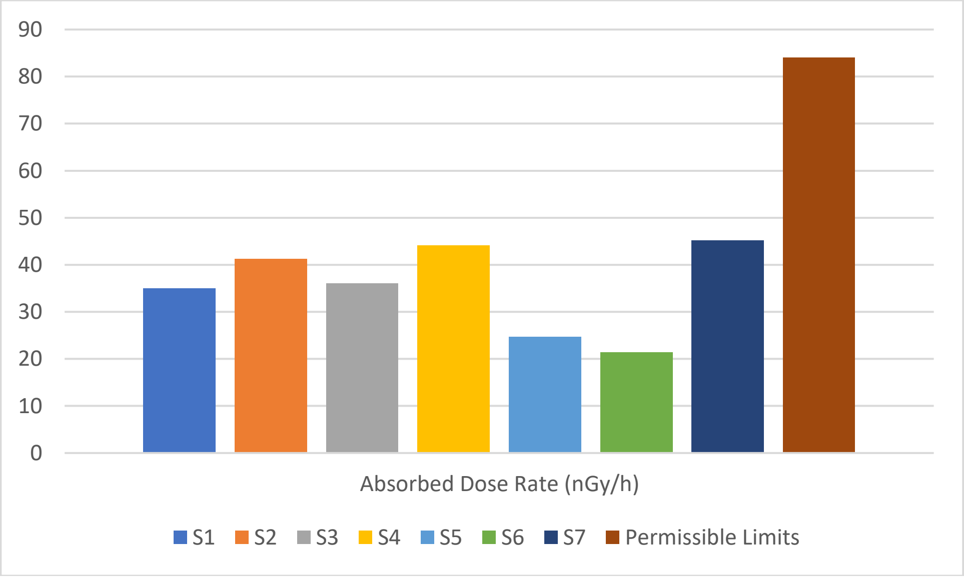

Figure 3a: Absorbed Dose Rate in the Coal Samples

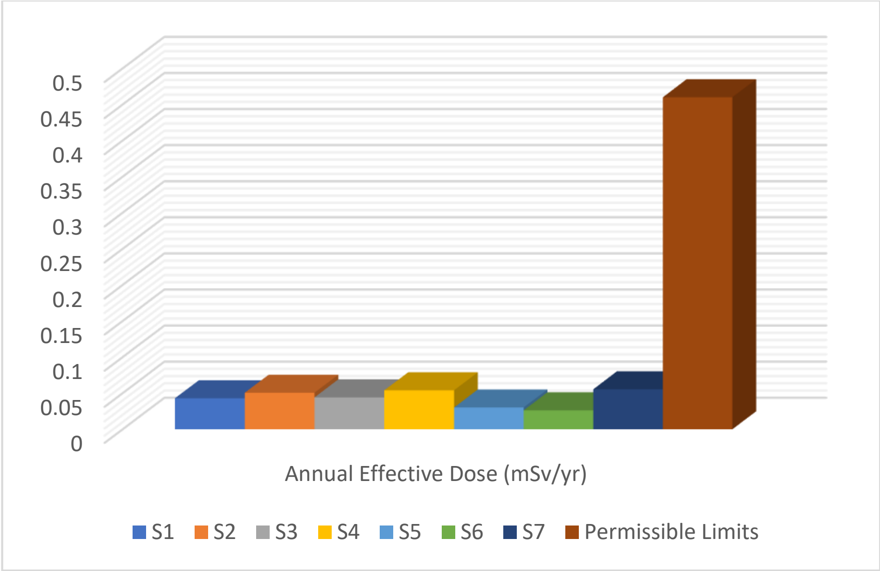

Figure 3b: Annual Effective Dose in the Coal Samples

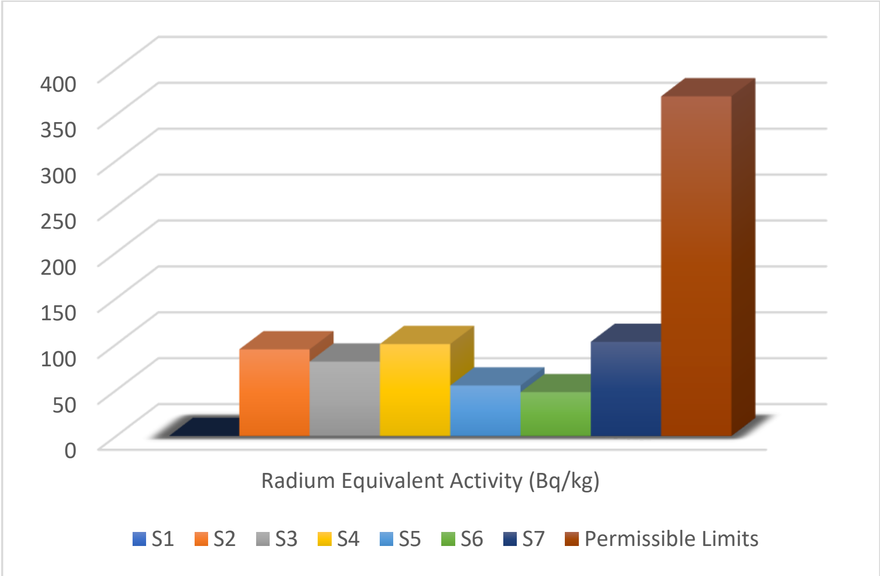

Figure 3c: Radium Equivalent Activity in the Coal Samples

External Hazard Index (H_{ex})

This is a measure used in radiation protection to access the external radiation exposure hazard posed by a radioactive source or a contaminated area. In this case, we are interested in the external radiation hazard from radionuclides present in the coal sample (Nwankwo *et al.,* 2015). It was used to evaluate the potential radiation exposure to humans from external sources around the coal-mining region. In order to determine the susceptibility of individuals exposure to dose delivered externally due to gamma ray emission in the coal, the external hazard index was evaluated using equation 4. The implication of this is that the activity concentrations of ^{238}U, ^{232}Th and ^{40}K were assumed to possess the same gamma radiation dose of 370, 259 and 4810 Bq/Kg of uranium, thorium and potassium (Usikalu *et al.,* 2018).

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \qquad (4)$$

where: A_U, A_{Th}, and A_K are the activity concentrations of uranium, thorium and potassium respectively (Usikalu *et al.,* 2018).

The external hazard index evaluated are presented in Table 3 and Figure 4, the results showed numeral values less than unity. These values were 0.2134, 0.2548, 0.2189, 0.2704, 0.1485, 0.1289 and 0.277 for the analysed coal samples from the Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo mine sites respectively.

Internal Hazard Index (H_{in})

This is a measure used to assess the internal radiation hazard from radionuclides present in the coal sample, which are ingested or inhaled (Nwankwo *et al.,* 2015). It was used to evaluate the potential radiation exposure to humans from internal sources from the coal mining operation and utilization processes. The internal hazard index was used for approximating relative radiological risks to respiratory organs due to inhalation of radon and its short-lived daughters and applied to the safe use of certain building materials in the construction of dwellings (Usikalu *et al.,* 2018). The H_{in} was calculated using equation 5.

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

where: A_U, A_{Th} and A_K are the activity concentrations of uranium, thorium and potassium respectively and were assumed to possess the gamma radiation dose of 185, 259 and 4810 Bq/kg (Usikalu 2018 *et al.,* 2018). The estimated value must be less that unity in order to keep the radiation hazard insignificant (Usikalu *et al.,* 2018).

The internal hazard index presented in Table 3 and Figure 4 indicated that the results are below unity. This implies that the radiation hazard is almost insignificant but caution must be exercised against prolonged exposure to the radiation emission from the coal deposits investigated. The evaluated internal hazard index values were 0.2624, 0.2987, 0.2717, 0.3167, 0.1936, 0.1817, and 0.3298 for Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coal respectively.

Gamma Level Index ($I\gamma r$)

The extent of gamma concentration in the coal was computed using the radiological parameter known as the gamma level index. The Gamma Level Index is a measure used to assess the gamma radiation levels in the coal mining environment (Nwankwo *et al.,* 2015). It was used to quantify the gamma radiation exposure and radiation safety. The gamma radiation hazards associated with the activity of natural radionuclide in the investigated coal samples (Jegede *et al.,* 2019) was estimated using equation 6.

$$I\gamma r = \frac{A_U}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \leq 1 \quad (6)$$

where: A_U, A_{Th} and A_K are the activity concentrations of uranium, thorium and potassium respectively (Jegede *et al.,* 2019).

Table 3 and Figure 4 shows the gamma level index for the coal samples from Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coal mines. The estimated gamma level index were 0.2799, 0.3328, 0.2872, 0.3548, 0.1947, 0.1670, and 0.3629 respectively.

Table 3: External Hazard Index, Internal Hazard Index and Gamma Level Index of the Coal

Samples ID	(H_{ex}) < 1	(H_{in}) < 1	($I\gamma r$) < 1
S1	0.2134	0.2624	0.2799
S2	0.2548	0.2987	0.3328
S3	0.2189	0.2717	0.2872
S4	0.2704	0.3167	0.3548
S5	0.1485	0.1936	0.1947
S6	0.1289	0.1817	0.1670
S7	0.2770	0.3298	0.3629

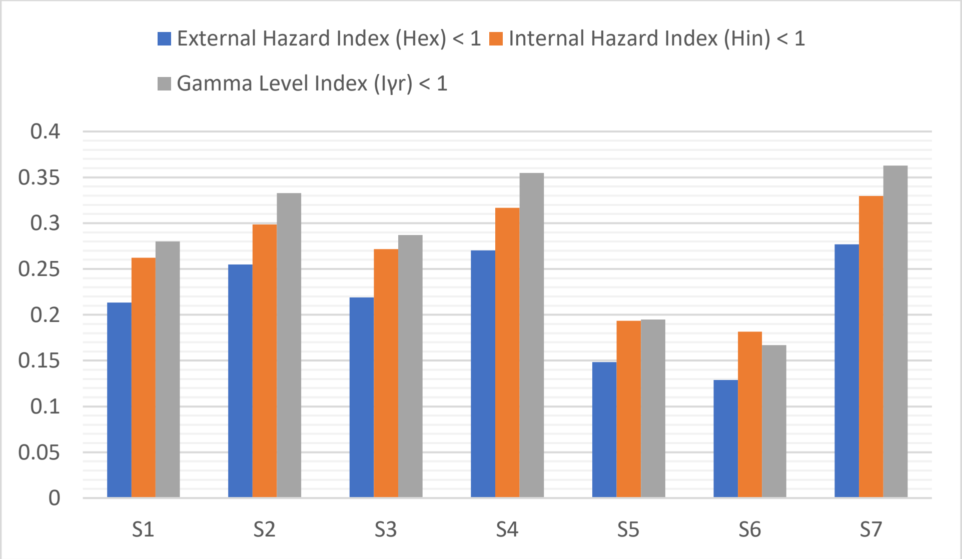

Figure 4: Hazard Indices in the Coal Samples

Excess Life Cancer Risks (ELCR)

This is a measure of the increased risk of developing cancer due to exposure to a carcinogen, such as ionizing radiation (Jegede *et al.,* 2019). It represents the additional risk of cancer above the background risk. The excess life cancer risks showed the probability of an individual developing a cancerous cell due to prolonged exposure to cancer inducing substances over a period (Jegede *et al.,* 2019). Radioactivity in coal are known to produce carcinogenic effects due to accumulation in air such that there is probability of developing cancer, especially lungs cancer, due to the exposure of an individual to gaseous radionuclides over the lifetime. This radiological health parameter was calculated using equation 7 (Jegede *et al.,* 2019).

$$\mathrm{ELCR} = \mathrm{AED_{External}} \times \mathrm{DL} \times \mathrm{RF} \qquad (7)$$

where: ELCR is the Excess Lifetime Cancer Risk per 100/000 people, AED is the Annual Effective Dose in mSv, DL is the duration of lifetime or average lifespan (assumed to be 70 per years) and RF is the fatal cancer risk per Sievert, i.e. risk factor (0.05 S_vy^{-1}) (Jegede *et al.,* 2019).

Table 4 and Figure 5 shows the excess life cancer risk of the analysed coal samples from Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coal mining sites. The values were observed to be homogeneous (0.0701$\times 10^{-3}$) and less than the global mean average of 0.29×10^{-3}.

Annual Gonadal Dose Equivalent (AGDE)

This is a measure of the radiation dose received by the gonads (reproductive organs) over a year. (Jegede *et al.,* 2019). It was used to assess the potential genetic risks associated with radiation exposure. This radioactive parameter predicted whether the gonad, bone cells and marrow of humans are safe after exposure to gamma radiation emanating from the coal mining operation and utilization. The annual gonadal dose equivalent (AGDE) is a measure of the genetic significance of three yearly dose received by the population in reproductive organs (Jegede *et al.,* 2019). Organs with rapidly dividing tissues such as gonads, the bone marrow and bone surface cells were considered as organs of interest as stated in UNSCEAR, 2000 report. This implies that not all living cells are actively sensitive to radiation. A direct interaction of radiation with reproductive cells could result in death or genetic mutation of the cell, whereas a direct interaction with DNA of a dominant cell could have less effect (Jegede *et al.,* 2019). Hence the need to evaluate the annual gonadal dose equivalent (AGDE) due to the specific activity of ^{238}U, ^{232}Th and ^{40}K in the Nigerian coal deposits. This radiological health parameter was evaluated using equation 8 (Jegede *et al.,* 2019).

$$\mathrm{AGED}\ (\mu S_v y^{-1}) = (A_U \times 3.09) + (A_{Th} \times 4.18) + (A_K \times 0.077) \qquad (8)$$

where: A_U, A_{Th} and A_K are the activity concentrations of uranium, thorium and potassium respectively. Similarly, the values 3.09, 4.18, and 0.077 are the conversion factors for uranium, thorium and potassium respectively. The results of the annual gonadal dose obtained from the Maiganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coals were 218.8379 $\pm$ 30.3070 $\mu S_v y^{-1}$, 265.9351 $\pm$ 30.6419 $\mu S_v y^{-1}$, 223.7848 $\pm$ 17.6221 $\mu S_v y^{-1}$, 278.2243 $\pm$ 18.8099 $\mu S_v y^{-1}$, 151.4569 $\pm$ 16.9901 $\mu S_v y^{-1}$, 134.9772 $\pm$ 12.5119 $\mu S_v y^{-1}$, and 285.7398 $\pm$ 29.0778 $\mu S_v y^{-1}$ respectively. These results presented in Table 4 and Figure 5, were slightly lower than the ICRP permissible limit of 300 $\mu S_v y^{-1}$. Hence, the need to reduce exposure time (work hour) especially by the miners and people around coal fired power plants. This is to ensure that the gonad, bone cells and marrow are kept safe from ionizing radiation.

Table 4: Excess Life Cancer Risk and Annual Gonadal Dose Equivalent in the Coal Samples

Samples ID	ELCR (10^{-3})	AGDE ($\mu S_v y^{-1}$)
S1	0.0701	218.8397
S2	0.0701	265.1303
S3	0.0701	223.7848
S4	0.0701	278.2243
S5	0.0701	151.4569
S6	0.0701	134.9772
S7	0.0701	285.7398
Permissible Limits	0.29	300.00

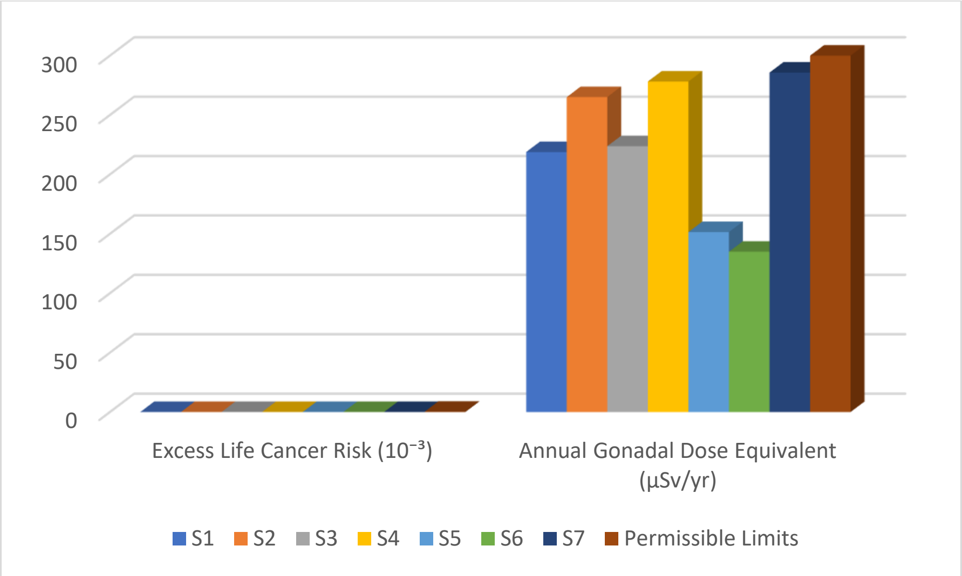

Figure 5: Health Risk Parameters in the Coal Samples

CONCLUSION

The radioactive element distribution in Seven (7) Nigerian coal deposits (Maganga, Gboko, Onyeama, Okobo, Opoko-Obido, Odagbo and Ofugo coal mines) have been determined by measuring the activity concentrations of uranium, thorium and potassium in the coal samples using sodium iodide spectrometric system at the Centre for Energy Research and Training (CERT), Ahmadu Bello University (ABU), Zaria, Nigeria. The specific activity concentration of thorium in samples S1 (Maiganga coal), S2 (Gboko coal), S3 (Oyeama coal), S4 (Okobo coal), and S7 (Ofugo coal) were much higher than the United Nation Scientific Committee on the Effect of Atomic Radiation and the International Commission on Radiological Protection permissible limit of 30 Bq/kq. This potent radiological health risk to vital body organs and tissues, hence there is need to limit exposure time, and to use proper shielding equipment by miners and people living around coal fired power plants. On the other hand, the results of the annual gonadal dose equivalent were slightly less than the ICRP permissible limit of 300 $\mu S_v y^{-1}$. Hence, the need to reduce exposure time (work hour) especially for the miners and people around coal fired power plants. This is to ensure that the gonad, bone cells and marrow are kept safe from ionizing radiation.

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