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NATURAL RADIONUCLIDE CONCENTRATION AND ASSOCIATED HEALTH HAZARD INDICES IN TAILING-ENRICHED AND NON-TAILING ENRICHED SOIL SAMPLES FROM OKOBO COAL MINE, KOGI STATE, NIGERIA.

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ABSTRACT

Background:
Coal mining activities cause indiscriminate deposition and accumulation of mining waste (tailings) on the surface leading to environmental pollution. Relocating naturally occurring radionuclide materials (NORMs) during coal mining operations have the capacity to raise and redistribute radionuclides with associated health hazards.

Material and Methods:
Cross sectional survey design was adopted for this study. A total of fifteen (15) samples were collected from the coal mine: Six (6) tailing enriched soil samples and nine (9) non-tailing enriched soil sample. The samples were analyzed in the laboratory of the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, using high resolution spectrometry technique with high purity germanium detectors (HPGe).

Results: The result revealed that the activity concentration of ^{226}Ra and ^{232}Th in both tailing and non-tailing enriched soil samples recorded mean activity values of 77.93±45.14 and 83.09±31.56 Bq/kg respectively for tailing enriched soil samples and 49.11±32.32 and 61.38±37.67 Bq/kg respectively for non-tailing enriched soil samples. These values were found to be significantly higher than world average of 35 Bq/kg and 30Bq/kg [1] respectively, however the mean activity values of ^{40}K (172.17±90.83 and 55.49±54.26 Bq/kg) fall within global acceptable values of 400 Bq/kg [1]. Radiological hazard indices for tailing enriched soil samples, namely absorbed dose rate (D), annual effective dose equivalents (AEDE) (indoors, outdoors and total), annual gonadal dose equivalent AGDE), representative gamma index (Iγr) and excess lifetime cancer Risk (ELCR) recorded mean values of 93.36 nGy/yr, 0.27 mSv/yr, 0.52, 0.57, 642.16, 1.44 and 0.40×10^{-3} that were higher than the world permissible limit. However, radium equivalent dose (Raeq), internal and external hazard indices recorded mean values that fall within the global acceptable limit. On the other hand, non-tailing enriched soil samples recorded higher values 63.26 nGy/yr, 0.08 and 0.55 mGy/yr than the global permissible limit of 59, nGy/yr, 0.02 and 0.52 mGy/yr respectively [1] for air absorbed dose rate, annual effective dose equivalent (outdoor and total)

Conclusion

The activity concentration of ^{226}Ra and ^{232}Th in both tailing and non-tailing enriched soil sample were found to be higher than the world average values, however, that of ^{40}K fall below world average. The estimated radiological hazard indices for tailing enriched soil sample were found to be higher than the global permissible limit except radium equivalent activity, internal and external hazard indices. Non-tailing enriched soil samples also recorded higher radiological hazard indices for air absorbed dose rate, annual effective dose equivalent outdoor and total, however other calculated radiological hazard indices fall below world acceptable limit.

Introduction

The main source of external irradiation to the human body is represented by gamma radiation emitted by naturally occurring radionuclide materials (NORMs), also called terrestrial environmental radiation [2]. One of the major sources of natural background radiation come from radionuclides of sufficient energy such as ^{40}K and decay products of ^{238}U and ^{232}Th decay chains. They exist in all ground formations including coal and constitute about 80% of the total radiation dose to human population in any given year [3]. Radionuclide concentration in soil and external exposure due to gamma radiation depends largely on geological processes and geographical conditions of the area [1]. However, certain industrial activities such as coal mining have the potential to raise the concentrations of (NORMs) above normal acceptable limits in the environment. These radionuclides are assumed to exist in radiological equilibrium in any natural and undisturbed environmental medium [4]. However, anthropogenic activities such as coal mining disturb the secular equilibrium leading to enrichment or depletion of these radionuclides in the end products and wastes.

Coal is one of the nonrenewable sources of energy used by a number of industries in most parts of the world for power generation, transportation and cement production [5]. Coal mining activities commenced in Okobo community in the year 2011 with estimated coal reserve of over 380 million tones [6]. The underlying goal was to contribute to diversification of the country's economy by providing coal as the main source of fuel for energy generation. This is meant to increase electricity generating capacity in Nigeria and support the country's efforts to enhance access to affordable and reliable electricity supply. However, mining processes of coal especially the open cast method produces a lot of wastes (tailings) which accumulates and pollute the environment. These wastes contain radionuclides in altered equilibrium state which has the capacity to raise the concentration of naturally occurring radionuclide materials (NORMs) in the environment. This industrial process involves relocating these radionuclides from normally inaccessible locations to areas where humans are present [7]. Their concentration above certain level increases the natural background radiation and exposes human population to radiations with resultant environmental and human health consequences [1]. Study has shown that exposure to high concentration of uranium (U) and radium (Ra) can trigger some health effects such as lung diseases, acute leucopoenia, anemia and necrosis of the mouth. Bone and nasal tumors can also result from exposure to radium while cancer of the lung, pancreas, liver, bone and kidney including leukemia can result from exposure to high concentration of thorium [8].

The presence of enhanced naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) in mining waste (tailing) has attracted the attention of researchers both in Nigeria and abroad. This is because of possible increased radiation exposure to unsuspecting human population and their associated radiological health hazard. A handful of literatures exist locally on the radiologic impacts of mining wastes but most of them focused mainly on tin mining activities. The radiological impact of coal wastes in Maiganga Coal Mine was evaluated by Kolo et al. [9], and they reported non-hazardous nature of coal wastes (tailings) from the mine. However, the evaluation of background ionizing radiation in Okobo Mining site by Uzuegbu, Avwiri and Ndukwu, [10] reported high mean background radiation dose from the mine. The reported increase in background radiation informed the authors' interest in evaluating coal wastes in the mine in order to identify the source of the emission and the possible radionuclides responsible for such high absorbed dose rate. Itodo et al., [11] also estimated the radiologic impacts of mining on soil, water and plants samples from okobo coal field but with little or no information on the radiologic impact of coal wastes (tailing), which this study is meant to address.

Materials and Method:

Study Area

The coal mining site is located between latitude N07^0 51' and longitude E07^0 70' in Okobo village of Enjema district of Ankpa local government area of Kogi state. It is bordered in the east by Benue State and in the South by Enugu State. The area of study is comprised of alternating sandstones, shales, sandy shales and mudstones, with coal seams or carbonaceous shales at various horizons [12].

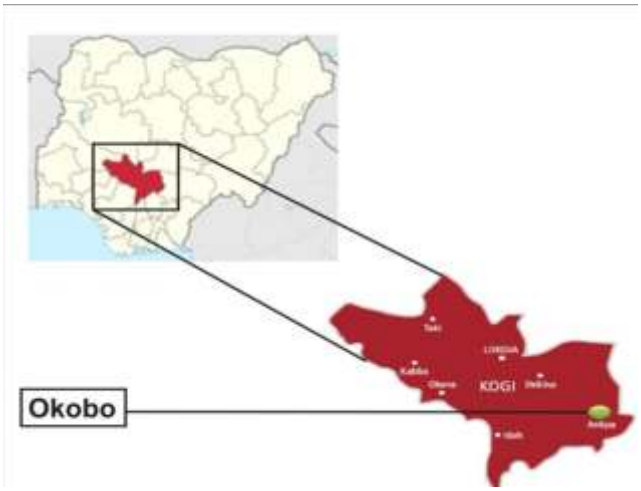

Fig 1: Map of Kogi State showing the study area

Sample collection, preparation

Non tailing enriched Soil sample collection

A total of nine (9) soil samples were collected from the coal mining site. The study area was first divided into nine equal segments. The top layers of the soil which contains wastes that are yet to decompose were removed. At each sampling location soil samples were collected at a depth of (10-15 cm) as a representation of each of the segments of the study area. Grasses and pieces of wood were manually eliminated from the samples. About 1 kg of each sample was packed separately in a clean zip lock plastic bags, properly sealed and labelled for easy identification.

Tailing enriched soil sample collection

A total of 6 tailings samples were collected at random from the three tailings dumps around the coal mine. The samples were carefully collected to satisfactorily represent the entire tailings dumped around the mining site. Each of the tailings dump was divided into two equal sub lots of approximately equal weight by marking imaginary line of demarcation. Four increments of 2 Kg each were drawn from each sub lots into a plastic bucket using a scooper to obtain the gross sample. The gross sample was thoroughly mixed, coned and quartered. In this process the gross sample was poured onto a clean surface, making it to form a cone as it drops and flattened to form a low circular pile. The pile was cut into four quarters along two diameters which intersect at right angles. Retaining one part of opposite quarters and reject the other. Repeat till the size of the retained sample is reduced to the required weight of 1kg. Precaution should be taken to avoid contamination with moisture and foreign matter. The 1kg mass was neatly packed in a well labelled polyethylene bags and properly sealed before being transported to NIRPR University of Ibadan for analysis.

Tailing enriched and non -tailing enriched Soil sample preparation

The samples were air-dried in ambient temperature for 72 hours to attain constant weight in the laboratory [13]. The dried samples were pulverized, sieved using 0.2 mm mesh, and thoroughly homogenized. About 400 g of the homogenized samples were carefully measured and poured into a well-labelled 500 ml Marinelli beaker. The beakers were covered with the beaker lids and properly sealed to ensure there is no room for escape of any radioactive gas like radon. The sealed samples were stored for 28 days to attain secular equilibrium before counting. At secular equilibrium the decay rates of the daughter nuclides and their respective parents become equal, and the activities of all the radionuclides of the series are therefore identical. Thus the measurement of the concentration of any daughter element can be used to estimate the concentration of any other element in the decay series. The samples were then moved to gamma analysis room for counting.

Gamma Spectrometric Measurements

The measurement of radionuclides concentration in the samples was performed using gamma spectrometry technique. The detector is a vertical coaxial cylindrical high purity germanium (HPGe) type, of 172 cm^3 active volume and with 80% relative efficiency, with a resolution of 2.3 keV at 1332 keV of Cobalt-60 gamma-ray line. The detector was coupled to 18 k-channel analyzer. The spectra of all samples were perfectly analyzed using Genie-2000 spectra analysis software (which match various gamma energy peaks to a library of all possible radionuclides) to calculate the concentrations of ^{238}U, ^{232}Th and ^{40}K. The detector is enclosed in a cylindrical shielding container made

of lead and iron with 11.3 cm thickness, 51 cm height and 28 cm internal diameter and having a fixed bottom and moving cover to reduce the external gamma-ray background. All the samples were counted for 18,000s. Prior to the measurement of the samples, the environmental gamma background at laboratory site was determined with an identical empty Marinelli beaker and plastic container to be used in the sample measurement. The activity concentration of ^{226}K, ^{232}Th and ^{40}K in Bq/Kg were calculated using the analytical equation given by:

$$\mathbf{A_{ci} = \frac{NCi}{\varepsilon \times yi \times M \times T}}$$

where A*ci* is the activity concentration of the ith radionuclide in the sample given in Bq/Kg or Bq/L. NCi is the net count rate of *i*th radionuclide under the corresponding peak, which is obtained by subtracting count per second (cps) for the background value from cps for the sample. ε is Detection efficiency. *yi* is gamma ray yield per disintegration of a specific nuclide. M is Mass of the measured sample in kg, and T is the counting time (18000 seconds).

III. RADIOLOGICAL HAZARD ESTIMATION

Based on the measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, from the sampled coal, the radiation health hazard to the exposed community were calculated through the following hazard parameters:

Air-Absorbed Dose Rates

Determination of absorbed dose rate is the first major step for evaluating the radiation exposure to gamma radiation. The exposure to ionizing radiation due to activity concentration of natural radionuclides in soil is given by the absorbed dose rate in the air at 1 metre above the ground surface/ level. Absorbed dose rate available in air is generally calculated using the mean activity concentration of ^{226}Ra (of the ^{238}U series) ^{232}Th, and ^{40}K (Bq/kg) in soil samples by using the conversion factors 0.462, 0.604 and 0.0417 for ^{226}Ra, ^{232}Th and ^{40}K, as provides by the United Nation Scientific Committee on the Effect of Atomic Radiations [1].

$$\mathbf{D(nGy/h) = 0.462}A_{Ra} + \mathbf{0.604}A_{Th} + \mathbf{0.0417}A_k$$

where D is the dose rate (nGy h^{-1}) at 1m above the ground due to ^{226}Ra ^{232}Th and ^{40}K in the soil samples. $A_{Ra,}$ A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. The population weighted values of absorbed dose rate in air outdoor from terrestrial gamma radiation is given a value of 59 nGyh^{-1}.

Radium Equivalent Activity (Ra_{eq})

Radium equivalent activity (Ra_{eq}) is a radiation hazard index used on a large scale to describe the gamma output from different mixtures of ^{238}U (^{226}Ra), ^{232}Th and ^{40}K in the samples. This allows comparison of the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K to be calculated through the relation according to Beretka and Mathew [14] and UNCEAR [1] as follows; $\boldsymbol{Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K}$

where,$A_{Ra,}$ A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Bqkg-1.This will be calculated based on the estimation that 370B q/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K are all producing the same gamma ray dose rate [14]. The maximum value of radium equivalent activity (Raeq) must be equal to or less than 370 Bq/kg in order to keep the external dose less than 1.5mSv.

Annual Effective Dose Equivalent (AEDE)

The absorbed dose in the air at 1 meter above the ground surface does not directly provide any idea about the radiation hazard to which an individual is exposed. The annual effective dose equivalent was estimated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv/Gy as recommended by UNSCEAR [15] with outdoor occupancy factor of 0.2 and indoor occupancy factor of 0.8. The annual effective dose due to natural activity in the soil and coal samples will be determined using the following equations:

AEDE (Outdoor) (mSv/y) = (D) nGy/h × 8760h × 0.7 Sv/Gy × 0.2×10^{-6}

AEDE (Indoor) (mSv/y) = (D) nGy/h × 8760h × 0.7 Sv/Gy × 0.8×10^{-6}

where D = Dose rate (nGy h^{-1}), 8760h = Number of hours in one year and 10^{-6} = Conversion factor of nano to milli, 0.2 = Outdoor occupancy factor, 0.7 (Sv/Gy) = Conversion factor from the absorbed dose in air to the effective dose received by an adult person. The average background outdoor effective dose rate from soil for an adult person is 0.07mSV [1].

Total annual effective dose (D_{tot}) , was calculated according to the following equation (16);

$$\boldsymbol{D_{tot}\,(mSvy^{-1}) = D_{out} + D_{in}}$$

Where D_{out} =the annual effective outdoor dose and, D_{in} = the annual effective indoor dose.

These indices measure the risk of stochastic and deterministic effects of irradiated individuals. The corresponding worldwide values for D_{out}, D_{in} and D_{tot} are 0.08, 0.04 and 0.50 mSv/year respectively [1]. The recommended value of the annual effective dose equivalent is 0.48mSvyr^{-1} and the criterion of the total annual effective dose equivalent (indoor + outdoor) should be less than 1mSvyr^{-1} [1]

External Hazard index (H_{ex})

The decay of radioactive materials occurs naturally and when these happen they produce external radiation field which expose humans. External hazard index represents the hazard incurred due to these external exposures to radiation from ^{226}Ra, ^{232}Th and ^{40}K in the studied soil coal and water samples. It is derived from the same expression of Ra_{eq} with the supposition that its maximum value corresponds to the upper limit of Ra_{eq} , 370 Bq/kg. It will be calculated from the equation bellow [14, 1];

$$H_{ex} = \frac{ARa}{370} + \frac{ATh}{259} + \frac{AK}{4810} \leq 1$$

where H_{ex} is the external hazard index and ARa, ATh and AK are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The value of this index must be less than unity in order to keep the radiation hazard insignificant. The prime objective of this index is to limit the radiation dose to the accepted dose limit of 1mSv/yr.

Internal Hazard Index (H_{in})

Radon and its short-lived daughter nuclei are hazardous to the respiratory organs such as the lungs. So internal exposure to radon and its short lived products is quantified by an internal hazard index and expressed mathematically by UNSCEAR [1] and Beretka and Mathew [14] as:

$$H_{in} = \frac{ARa}{185} + \frac{ATh}{259} + \frac{AK}{4810} \leq 1$$

where H_{in} is the internal hazard index and ARa, ATh and AK are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively. For the safe use of a certain building materials in the construction of dwellings, the index (H_{in}) must be less than unity for radiation hazard to be negligible.

Representative gamma index

Representative gamma index (Iγr) is used to estimate the radiation hazard associated with the natural radionuclide in a specific investigated samples. It is also used as a screening index that confirms the conformity of environmental samples to dose standards set for building materials [17]. According to the European Commission (EC), gamma activity concentration index (Iγr) helps to identify whether a dose standard is met [18] and this was estimated using the formula:

$$I\gamma r = \frac{ARa}{150} + \frac{ATh}{100} + \frac{AK}{1500} \leq 1$$

Where ARa, ATh and AK are the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively in Bq/kg. Representative gamma index (Iγr) must be less than or equal to unity which corresponds to an annual effective dose of ≤ 1mSv in order to satisfy the given dose criteria [19, 14].

Annual Gonadal Dose Equivalent

According to UNSCEAR (20), the reproductive organs and bone marrows are considered as organs of interest. Therefore, the Annual Gonadal Equivalent Dose (AGDE) for the workers/residents of the study area due to exposure to ^{226}Ra, ^{232}Th and ^{40}K was estimated using the equation given by Arafa [21] as:

$$AGDE = 3.09ARa + 4.18ATh + 0.314AK$$

Where ARa, = Activity concentration of ^{226}Ra, ATh = Activity concentration of ^{232}Th and AK = Activity concentration of ^{40}K.

Excess life time cancer risk (ELCR)

The possibility of developing cancer by any of the mine workers or residents of the study area who will probably spend majority or all their life time in the study environment can be evaluated using the excess life time cancer risk (ELCR). The calculated annual effective dose (AEDE) is used to estimate the excess lifetime cancer risk (ELCR) using 70 years as the average duration of life for human beings according to the equation [14, 22]:

$$ELCR = AEDE \times DL \times RF$$

where AEDE = The annual effective dose equivalent in mSv/year , DL = Average duration of life (Estimated to be 70 years average), and RF = Risk factor Sv^{-1}, i.e fatal cancer risk per Sievert. For low dose background radiations which are considered to produce stochastic effects, ICRP uses 0.05 threshold value for the public [22].

Results and Discussion

Activity concentration in tailing enriched soil samples

The statistical description of activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in tailing enriched soil samples, comprising the minimum and maximum values, the mean and standard deviation are presented in table 1 below. The values showed that there were variations of ^{226}Ra, ^{232}Th, and ^{40}K concentration from one sample to another. The minimum recorded activities for ^{226}Ra, ^{232}Th, and ^{40}K were 48.83±2, 59.23±3.20, and 60.60±3.39 whereas the maximum activity concentration values were 165.12±8.50, 143.54±7.55 and 330.62±17.49 with average values of 77.93±45.14, 83.09±31.56 and 172.17±90.83 respectively. These values were found to be significantly higher than the worldwide average of 35 Bq/kg and 30Bq/kg for ^{226}Ra and ^{232}Th respectively [1]. However, the activity concentration of ^{40}K was found to be lower than the global permissible value of 400 Bq/kg [1]. The activity concentration of ^{226}Ra and ^{232}Th exceed the world recommended average values and also higher than the values (3.0 Bq/Kg, 3.6 Bq/Kg and 20.4 Bq/Kg) reported by Kolo et al [4] in northern Nigeria. This increased concentration poses significant radiological threat of cancer to both staff and residents of the community if prolonged and cumulative exposure is allowed.

Activity concentration in non-tailing enriched soil samples

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in non-tailing enriched soil samples were recorded in table 1 below. The values show variations in ^{226}Ra, ^{232}Th, and ^{40}K concentration from one sample to another. The minimum activities for ^{226}Ra, ^{232}Th, and ^{40}K were 13.15±0.75, 13.13±1.76 and 1.36±0.16 whereas the maximum activities were 98.71±5.08, 115.45±5.89 and 208.86±11.05 respectively. The average values obtained for ^{226}Ra, ^{232}Th, and ^{40}K, were 49.11±32.32, 61.38±37.67, and 55.49±54.26 respectively. The activity concentrations of ^{226}Ra and ^{232}Th were found to be significantly higher than the worldwide average values of 35 Bq/kg and 30 Bq/kg respectively [1], however that of ^{40}K was found to be lower than the worldwide average value of 400 Bq/kg [1]. When compared with other published studies, the concentration of ^{226}Ra as obtained in this study was higher than the values published by Isinkaye et al, [23], Rajesh et al, [24], and Popoola et al, [25], conducted in Southwest Nigeria, Kanartaka Egypt, and Edo State Nigeria respectively, but less than the values obtained by Fares et al, [26]. The activity concentration of ^{232}Th was also found to be comparable to the value recorded by Rajesh et al but higher than the rest of other studies [23, 25, 27, 26]. The value of ^{40}K concentration, on the other hand was found to be higher than the values obtained from studies done in South west Nigeria [23] and Edo state Nigeria [25], but less than the values from Kanartaka India [24], Saudi Arabia [27] and Egypt [26].

The increased activity concentration of both ^{226}Ra and ^{232}Th in tailing enriched soil and non-tailing enriched soil samples confirms the fact that radium and thorium decay series has a common origin and exist together in nature [2]). This increase provides possible explanations to the high outdoor ambient radiation dose noted by Uzuegbu et al. [10].

Table 1: Showing Activity Concentration of Tailings Enriched Soil Sample in Bq/kg

Sampling code	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bqkg)
TS1	48.83±2.60	62.15±3.36	181.74±9.73
TS2	52.40±2.76	59.23±3.20	141.26±7.59
TS3	53.56±2.82	66.07±3.56	193.47±10.36
TS4	88.99±4.69	87.40±4.71	60.60±3.39
TS5	58.66±3.09	80.12±4.32	125.32±6.73
TS6	165.12±8.50	143.54±7.55	330.62±17.49
Minimum	48.83±2.60	59.23±3.20	60.60±3.39
Maximum	165.12±8.50	143.54±7.55	330.62±17.49
Average	77.93±45.14	83.09±31.56	172.17±90.83
WA	35	30	400

Table 2: Showing Activity Concentration of non-tailing Enriched Soil Samples in Bq/k

Sampling code	Ra-226 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg
SS1	98.71±5.08	115.45±6.08	65.21±3.48
SS2	52.36±2.76	76.03±4.15	87.24±4.72
SS3	95.16±4.90	111.74±5.89	208.86±11.05
SS4	51.58±2.74	73.51±3.93	29.33±1.92
SS5	24.09±1.24	30.49±1.61	30.82±1.68
SS6	23.63±1.22	13.13±1.76	15.11±0.90
SS7	18.43±1.00	22.65±1.21	5.45±0.44
SS8	13.15±0.75	21.27±1.20	1.36±0.16
SS9	64.86±3.35	88.14±5.01	47.89±2.57
Minimum	13.15±0.75	13.13±1.76	1..36±0.16
Maximum	98.71±5.08	115.45±5.89	208.86±11.05
Average	49.11±32.32	61,38.±37.67	55.59±54.26
WA	35	30	400

The radiological hazard indices for the sampled tailing enriched soils were recorded in table 3 below. The results show that the Absorbed Dose rate in air (D), Annual Effective Dose Equivalents (AEDE) (indoors, outdoors and Total), Annual Gonadal Dose Equivalent AGDE), Representative gamma index (Iγr) and Excess Lifetime Cancer Risk (ELCR) recorded higher mean values of 93.36 nG/h, 0.27 mSv/yr, 0.52 mSv/yr, 0.57 mSv/yr, 642.16, 1.44, 0.40×10^{-3} than the world acceptable limit of 59nGy/h, 0.07 mSv/yr, 0.45mSv/yr, 0.52mSv/yr, 300 mSv/yr, 1.0 and 0.29×10^{-3} respectively as prescribed by UNSCEAR [1]. However, radium equivalent activity, External (Hex) and internal Hazard indices (H_{in}) recorded mean values of 209.70 Bq/Kg, 0.49 and 0.78 respectively, which was found to be lower than the world precautionary value of 370 Bq/Kg 1 and 1 respectively as stipulated by UNSCEAR [1]. The absorbed dose rate in air ranged between 65.92 and 196.78 nG/h, with mean value of 93.36 nGy/h. This value was found to be significantly higher than the world precautionary value of 59 nGy/h as prescribed by UNSCEAR [1]. The high D values in tailing enriched soil samples may likely be explain by increased ^{226}Ra and ^{232}Th concentration which agrees with Al Kaabi [29] that if the concentration of radionuclide in a sample is high, the absorbed dose will also tend to be high. This poses a significant radiological threat to both staff and residents of the local community if prolonged and cumulative exposure is not disallowed.

The radium equivalent activity for ^{226}Ra, ^{232}Th and ^{40}K from different non-tailing enriched soil samples were recorded in table 4 below. The values range from 51.24 to 268.82 Bq/Kg with an average value of 144.26 Bq/Kg which were found to be lower than the world permissible value of 370Bq/Kg as set by UNSCEAR [1]. However, the absorbed dose rate in air at 1 meter above the ground, range between 22.21 nGy/h and 118.05 nGy/h with a mean value of 63.26 nGy/h which is significantly higher than the world average value of 59 nGy/h [1]. Similarly, the mean values of annual effective dose equivalent (outdoors, and total) recorded values of 0.08 mSv/yr and 0.55 mSv/yr, which were found to be slightly higher than the global permissible value of 0.07 mSv/yr and 0.52 mSv/yr respectively. However, the annual effective dose equivalent indoors and annual gonadal dose equivalent recorded values of 0.16 mSv/yr and 122.59 mSv/yr which were found to be lower than the global mean value of 0.45 mSv/yr and 300mSv/yr respectively, [1]. The increase in the calculated values of absorbed dose rate in air and the annual effective dose equivalent (outdoors and total) indicates high radiological hazard and could pose health issues such as cancer or respiratory diseases if prolonged and cumulative exposure is not checked. Representative gamma index, external and internal hazard indices and the excess lifetime cancer risk recorded minimum to maximum values of 0.23 to 0.35, 0.11 to 0.14, 0.09 to 0.22, and 0.04×10^{-3} to 0.32×10^{-3}, with average values of 0.26 mSv/yr, 0.13, 0.16, and 0.17×10^{-3} respectively, which were all within the world average value of unity for representative gamma index, internal and external gamma indices and 0.29×10^{-3} for excess lifetime cancer risk [1].

Table 3: Showing Radiation Hazard indices for Tailing Enriched Soil Samples

Sampling code	(Ra_{eq})	D	AEDE (Out)	AEDE (Ind)	AEDE (Tot)	AGDE	$I_{\gamma r}$	(H_{ex})	(H_{in})	ECLR ($\times 10^{-3}$)
TS1	**151.89**	**67.68**	**0.08**	**0.33**	**0.41**	**467.76**	**1.06**	**0.41**	**0.54**	**0.29**
TS2	**147.98**	**65.92**	**0.08**	**0.32**	**0.40**	**453.85**	**1.04**	**0.40**	**0.54**	**0.28**
TS3	**162.94**	**72.63**	**0.09**	**0.36**	**0.45**	**502.42**	**1.15**	**0.44**	**0.59**	**0.31**
TS4	**218.64**	**96.43**	**0.12**	**0.47**	**0.60**	**659.34**	**1.51**	**0.59**	**0.83**	**0.41**
TS5	**182.88**	**80.72**	**1.00**	**0.40**	**0.50**	**555.51**	**1.26**	**0.49**	**0.65**	**0.35**
TS6	**393.84**	**176.78**	**0.22**	**0.87**	**1.08**	**1214.03**	**2.62**	**1.07**	**1.52**	**0.76**
Min.	**147.98**	**65.92**	**0.08**	**0.32**	**0.40**	**453.85**	**1.04**	**0.40**	**0.54**	**0.28**
Max.	**393.84**	**196.78**	**0.22**	**0.87**	**1.08**	**1214.03**	**2.62**	**1.07**	**1.52**	**0.76**
Mean	**209.70**	**93.36**	**0.27**	**0.52**	**0.57**	**642.16**	**1.44**	**0.49**	**0.78**	**0.40**
W A	...	**59**	**0.07**	**0.45**	**0.52**	**300**	**1.0**	**≤1**	**≤1**	**0.29**

Key: Raeq: Radium Equivalent Activity, D: Absorbed Dose rate, AEDE: Annual Effective Dose Equivalents AGDE: Annual Gonadal Dose Equivalent, $I_{\gamma r}$ Representative Gamma Index, H_{ex} External Hazard Indices, and H_{in} Internal Hazard Indices, ECLR: Excess Life Time Cancer Risk for Coal Sample, WA World average, Min Minimum, Max Maximum

Table 4: Showing Radiation Hazard Indices for non-tailing Enriched Soil Samples.

Sampling code	(Raeq)	D	AEDE (Out)	AEDE (Ind)	AEDE (tot.)	AGDE	$I_{\gamma r}$	(H_{ex})	(H_{in})	ECLR ($\times 10^{-3}$)
SS1	**268.82**	**118.05**	**0.15**	**0.07**	**0.72**	**56.55**	**0.13**	**0.09**	**0.09**	**0.04**
SS2	**167.80**	**73.76**	**0.09**	**0.11**	**0.45**	**97.14**	**0.23**	**0.14**	**0.13**	**0.06**
SS3	**271.03**	**117.16**	**0.14**	**0.09**	**0.72**	**156.87**	**0.35**	**0.14**	**0.22**	**0.10**
SS4	**158.96**	**69.45**	**0.09**	**0.10**	**0.43**	**127.49**	**0.28**	**0.14**	**0.19**	**0.32**
SS5	**70.06**	**30.84**	**0.04**	**0.09**	**0.19**	**137.93**	**0.31**	**0.12**	**0.17**	**0.34**
SS6	**72.17**	**31.56**	**0.04**	**0.11**	**0.54**	**124.56**	**0.29**	**0.11**	**0.16**	**0.31**
SS7	**51.24**	**22.21**	**0.03**	**0.10**	**0.14**	**149.32**	**0.34**	**0.11**	**0.18**	**0.37**
SS8	**43.69**	**18.99**	**0.03**	**0.09**	**1.21**	**141.08**	**0.32**	**0.13**	**0.17**	**0.35**
SS9	**194.59**	**86.92**	**0.11**	**0.02**	**0.53**	**139.33**	**0.32**	**0.12**	**0.18**	**0.32**
Min	**43.69**	**18.99**	**0.03**	**0.02**	**0.14**	**56.55**	**0.23**	**0.11**	**0.09**	**0,04**
Max.	**268.82**	**118.05**	**0.15**	**0.11**	**0.72**	**156.87**	**0.35**	**0.14**	**0.22**	**0.32**
Mean	**144.26**	**63.26**	**0.08**	**0.16**	**0.55**	**125.59**	**0.26**	**0.13**	**0.16**	**0.17**
WA	**≤370**	**59**	**0.07**	**0.45**	**0.52**	**300**	**1.0**	**≤1**	**≤1**	**0.29**

Key: Raeq: Radium Equivalent Activity, D: Absorbed Dose rate, AEDE: Annual Effective Dose Equivalents AGDE: Annual Gonadal Dose Equivalent, $I_{\gamma r}$ Representative Gamma Index, H_{ex} External Hazard Indices, and H_{in} Internal Hazard Indices, ECLR: Excess Life Time Cancer Risk for Coal Sample, WA World average, Min Minimum, Max Maximum

Conclusion

The activity concentration of ^{226}Ra and ^{232}Th in both tailing and non-tailing enriched soil sample were found to be higher than the world average values, however, that of ^{40}K fall below world average. The estimated radiological hazard indices such as

absorbed dose rate in air (D), annual effective dose equivalents (AEDE) (indoors, outdoors and Total), annual gonadal dose equivalent AGDE), representative gamma index (Iγr) and excess lifetime cancer risk (ELCR) for tailing enriched soil sample were found to be higher than the global permissible limit except radium equivalent activity, internal and external hazard indices. Non-tailing enriched soil samples also recorded higher radiological hazard indices for air absorbed dose rate, annual effective dose equivalent outdoor and total, however other calculated radiological hazard indices fall below world acceptable limit. These results show that there is significant radiological threat to both staff and residents of the local community.

Recommendation

Therefore, there is probability of both staff and residents of the community developing radiation related illness overtime. And the researcher hereby recommended that appropriate waste (tailing) disposal and management system be developed by the mining company in order to eliminate indiscriminate disposal of mining wastes.

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