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Radionuclide concentrations and excess lifetime cancer risk due to gamma radioactivity in tailing enriched soil around Maiganga coal mine, Northeast Nigeria

M.T. Kolo[1,3], Y.M. Amin[1], M.U. Khandaker[1*], W.H.B. Abdullah[2]

[1]Department of Physics, University of Malaya, 50603 Kuala Lumpur, Malaysia
[2]Department of Geology, University of Malaya, 50603 Kuala Lumpur, Malaysia
[3]Department of Physics, Federal University of Technology, Minna, Nigeria

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Corresponding author:
Dr. Mayeen Uddin Khandaker
Fax: *+603 7967 4146*
E-mail:
mu_khandaker@yahoo.com

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ABSTRACT

Background: Human activities such as mining enhance the radioactivity levels above normal background which can lead to an incremental increase in the radiation risk to the population. ***Materials and Methods***: 20 tailing enriched soil samples collected around Maiganga coal mine, Gombe, Northeast Nigeria were assessed for their ^{226}Ra, ^{232}Th and ^{40}K contents using HPGe gamma-ray detector. ***Results:*** The mean activity values of 11.90±3.0, 17.72±3.6 and 70.44±20.4 Bq kg^{-1} were obtained for ^{226}Ra, ^{232}Th and ^{40}K respectively. These values were below the world average values documented by UNSCEAR. The ratio of ^{232}Th:^{226}Ra obtained was 1.5, which showed that ^{232}Th activity was higher than the activity of ^{226}Ra while ^{40}K recorded the highest activity concentration in the studied samples. Statistical analysis identified strong positive relationships among all radiological parameters and confirmed that ^{226}Ra, ^{232}Th and ^{40}K were the major contributors to radiation dose. Radium equivalent activity (Ra_{eq}), absorbed gamma dose rate (D_R), annual effective dose (AEDE), activity utilization index (AUI), external and internal hazard indices (H_{ex} and H_{in}), gamma representative index ($I_{\gamma r}$), annual gonadal dose (AGDE) and excess lifetime cancer risk (ELCR) were calculated to quantify the radiation risk to the public from exposure to ^{226}Ra, ^{232}Th and ^{40}K in the studied samples. The mean values of these hazard parameters were within the acceptable limits provided for human safety and environmental protection. ***Conclusion:*** The use of the tailing enriched soil samples of Maiganga coal mine for any purpose whatsoever does not therefore pose any immediate radiological risk to the coal workers or the general public.

Keywords: *Maiganga coal mine, tailings, HPGe detector, absorbed dose, excess lifetime cancer risk.*

INTRODUCTION

The presence of contaminants in human environment has attracted serious attention in research community over the years. This is as a result of environmental and human health consequences associated with its exposure, especially at levels above the prescribed safety limits. Natural radioactivity has always been present and broadly distributed in the earth's crust and the atmosphere, either as primordial radionuclides of uranium (^{238}U) and thorium (^{232}Th) decay series and radioactive potassium (^{40}K), or as cosmic radiations that are produced constantly in the atmosphere [1-4]. Primordial radionuclides of ^{238}U and ^{232}Th decay series and ^{40}K which has extremely long half-lives are of great concern in terms of radiation exposure due

to their gamma ray emitting potentials. These radionuclides in their decay chains are assumed to be in radiological equilibrium in any naturally undisturbed environmental medium. Human activities and industrial processes such as mining disturb their secular equilibrium thereby altering their natural state. These alterations result in the enrichment or depletion of the radionuclides in the end products and wastes which can lead to an incremental increase in the radiation risk to the population [5-6].

Mining activities and the processing of natural resources have impacted considerably on human being and the environment [7, 8]. Mining operations are associated with environmental degradation, destruction of ecosystems and general pollution of the environment [7, 9]. Huge amounts of top soils are removed during mining which results in the production of considerable amount of mining wastes (tailings) with enhanced radioactivity [10]. These large quantities of mine tailings are disposed of on the surface in the vicinity of the mine where they are subjected to continuous physical, chemical and biological processes that concentrates radioactivity in the environment, resulting in significant radiation dose to the public [11]. Mine tailings consists of relatively loose non-compacted debris that easily contaminate the surrounding soils through atmospheric dispersion. The dust particles suspended in the air can also be inhaled directly, thus contributing to human radiation exposure [12-13]. Additionally, tailings could be washed with rain and the radionuclides carried away into surface and groundwater bodies. Direct ingestion of such waters or consumption of agricultural products such as vegetation, fish, meat and milk produced from farmlands irrigated by such waters could be the exposure pathways for human to radiation [7, 11, 14].

Series of research works on the radiological implications of mining activities have been conducted in Nigeria. Ibeanu [7] highlighted concerns about the radiological consequences of tin mining and processing in Nigeria. Ademola [15] discussed the exposure to high background radiation level in the tin mining area of Jos Plateau while Ajayi [16] evaluated the equivalent dose due to natural radioactivity in the soil around the consolidated tin mine in Nigeria. Natural radioactivity levels and the radiological health implications of tailing enriched soil and sediment samples around two mining sites in Southwest Nigeria were assessed by Isinkaye [13], while health and ecological hazards due to natural radioactivity in soil from mining areas of Nasarawa State, Nigeria were X-rayed by Aliyu *et al.* [11]. Most of these investigations, however, were centred on the radiological implications of tin mining activities, with little or no attention on the impact of coal mining in Nigeria.

Coal mining activities in Maiganga coal mine employs the open cast mining which has resulted in the production of a large volume of mine tailings heaped around the mine. Both coal workers and the immediate local community are eventually exposed externally to radiation from the easily accessible tailings. Internal exposure can also occur from the inhalation of radon (Rn) and its short-lived decay products. Furthermore, the local community uses the tailings as landfills and for agricultural purposes which can enhance their exposure through consumption of food grown on tailing enriched soils [9, 13]. Although the tailings have been used constantly by the locals for agricultural purposes, there have neither been any radiological investigations of Maiganga coal mine tailings nor been any studies on the quantification of radiation levels of the entire mine. Moreover, the tailing enriched soils around Maiganga coal mine have become readily available component of building materials which constitute another possible population exposure route. It is therefore, important to quantify the activities of ^{226}Ra, ^{232}Th and ^{40}K in the tailing enriched soils of Maiganga coal mine and to assess the radiological impact thereof. *"The knowledge of natural radionuclide distribution and natural radioactivity levels in soil environment is important for assessing the radiation exposure to the population and is useful to set the standards and national guidelines in the light of international recommendations"* [17]. This investigation is therefore considered a pilot study with the aim of determining the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in tailing enriched soils from Maiganga coal mine and to

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quantify the radiation dose received by coal workers and the public from continuous radiation exposure. Data from this research will assist regulatory agencies to develop comprehensive radiological framework for human protection and environmental safety. They will also serve as baseline for subsequent radio-monitoring of the coal mine.

MATERIALS AND METHOD

Sample site

Maiganga is a local community located between latitude 10^0 02' to 10^0 05' and longitude 11^0 06' to 11^0 08' in Akko local government area of Gombe state, Northeast Nigeria (figure 1). Extensive coal mining operations of Maiganga coals involve an open cast mining technique which continuously generates huge amounts of mine overburden and waste rock. The mine tailings are dumped indiscriminately within the vicinity of the mine (figure 2), resulting in the radioactive contamination of soils of Maiganga mining site.

Sample collection

20 samples of tailing enriched soils were collected around Maiganga coal mine. The samples were carefully collected to satisfactorily represent the entire mine tailings dumped around the mine. Four sub-samples randomly collected around a sampling point and were thoroughly mixed together to obtain a bulk sample that represents particular sampling point. The samples, each about 1.00 kg were neatly packed in well-labelled polyethylene bags, properly sealed and transported to the radiation laboratory, Physics department, University of Malaya, Malaysia, for analysis.

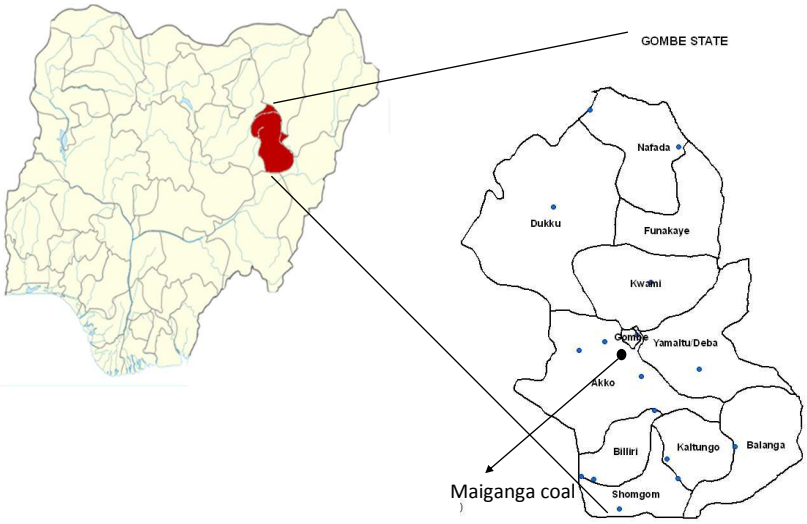

Figure 1. Map of Gombe state, Nigeria, showing the project site.

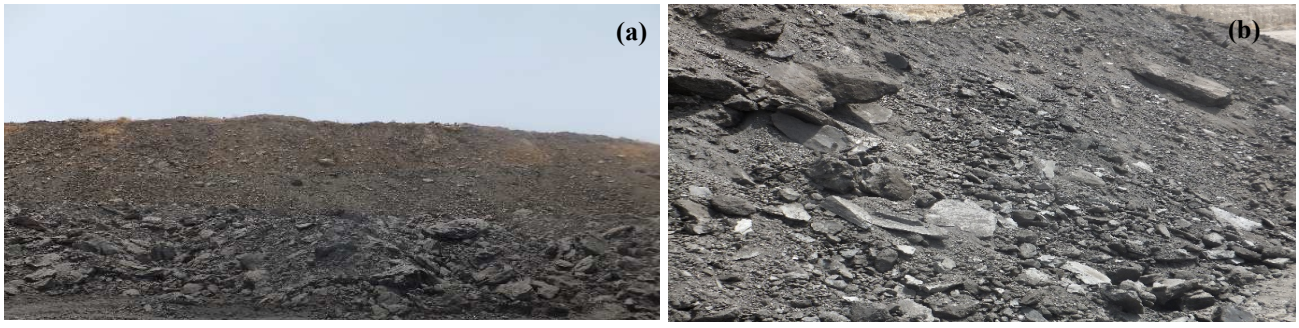

Figure 2. (a) Panoramic view and (b) Close up view of tailing enriched soils from Maiganga coal mine site.

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In the laboratory, the samples were air-dried at ambient temperature for 72 hours to attain constant weight. The dried samples were pulverized, sieved and thoroughly homogenized. 485±1.0 grams (g) of the homogenized samples were carefully packed into well-labelled Marinelli beakers and properly sealed to prevent escape of radon. The sealed samples were stored for 6 weeks to attain radiological equilibrium between the long-lived radionuclides and their respective decay daughters [18-22].

Activity concentration measurement

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the tailing enriched soil samples were measured using a P-type coaxial ORTEC, GEM-25 HPGe gamma-ray spectrometer. The detector which has relative efficiency of 28.2 % and energy resolution of 1.67 keV (FWHM) at 1.33 MeV peak of ^{60}Co was coupled to ADCM data acquisition system with PCAII multi-channel analyser. The detector was properly shielded in a good cylindrical lead shield to suppress any external background radiation from the surrounding environment [9, 19, 21-23]. A cylindrical multi-nuclide gamma ray source with density similar to the sample to be analysed was used to calibrate (energy and efficiency) the detector prior to analysis. The calibration source which has an initial activity of 5.109 µCi contain the following radionuclides with their respective energies: ^{241}Am (59.541 keV), ^{109}Cd (88.040 keV), ^{57}Co (122.061 keV, 136.474 keV), ^{203}Hg (279.195 keV), ^{113}Sn (391.698 keV), ^{85}Sr (514.007 keV), ^{137}Cs (661.657 keV), ^{88}Y (898.042 keV, 1836.063 keV), and ^{60}Co (1173.22 keV, 1332.492 keV). The source was supplied by the Isotope products laboratories, Valencia, CA, 91355, USA. The background radiation in the surrounding environment of the detector was obtained by counting an empty sealed beaker with the same geometry as the samples for 86,400 seconds. Each sample was then counted for the same period (86,400 seconds) from which the background count was subtracted to obtain the net activity of the measured radionuclides [6, 20]. The characteristic gamma lines used to obtain the net activities of the respective nuclides are presented in table 1. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were computed using the equation [19, 22]:

$$A(Bq/kg) = \frac{CPS \times 1000}{\varepsilon_\gamma \times I_\gamma \times W} \quad (1)$$

where A (Bq kg^{-1}) is the specific activity, CPS is the net counts per second for each sample investigated, ε_γ (E) is the detector photo-peak efficiency at respective gamma-ray peak, I_γ is the corresponding gamma-ray intensity, W is the sample mass in g and 1000 is the mass conversion factor from gram (g) to kilogram (kg).

Radiation hazard indices

Numerous assessment criteria have been published in literature to help in quantifying radiological burden on human population from exposure to radiation in various environmental matrix [6, 23-25].

Table 1. Homogeneous and inhomogeneous Houndsfield Unit (H.U) and relative electron density applied in treatment planning contour

Nuclides of interest	Detected nuclides	Half-life	Decay mode (%)	γ-ray energy, E_γ (keV)	γ-ray intensity, I_γ (%)	Sources/origin
^{238}U (^{226}Ra)	^{214}Pb	26.80 m	β^- (100)	295.22	18.42	^{238}U (^{226}Ra) series
				351.93	35.6	^{238}U (^{226}Ra) series
	^{214}Bi	19.90 m	α (0.02); β^- (99.98)	609.32	45.49	^{238}U (^{226}Ra) series
^{232}Th	^{228}Ac	6.15 h	α+β^- (100)	911.21	29	^{232}Th series
				968.97	17.4	
	^{208}Tl	3.053 m	β^- (100)	583.187	85	^{232}Th (^{228}Ra) series
^{40}K	^{40}K	1.248 x 10^9 y	EC (10.72); β^- (89.28)	1460.822	10.66	Primordial/ terrestrial

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Radium Equivalent Actvity (Ra_{eq})

Due to non-uniformity in the distribution of ^{226}Ra, ^{232}Th and ^{40}K in environmental sample, a common index of radiation, the radium equivalent activity (Ra_{eq}) was introduced to account cumulatively for the hazard associated with individual radionuclides [26-27]. Ra_{eq} is expressed as a weighted sum of activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, based on the assumption that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce the same gamma dose rate [22, 28]. Ra_{eq} was estimated by the equation:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively in Bq kg^{-1}.

Air-Absorbed Dose Rate (D_R)

The absorbed dose rate represents the dose received in an open air by the gamma radiation emitted from the radionuclides available in the environmental media. The conversion factors of 0.462, 0.604 and 0.0417 Bq kg^{-1} respectively for ^{226}Ra, ^{232}Th and ^{40}K provided by UNSCEAR [29], were used to estimate the absorbed dose rate in air (D_R) at 1 m above ground level due to gamma -ray emissions from ^{226}Ra, ^{232}Th and ^{40}K in soils. D_R was calculated from the equation [27]:

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

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively in Bq kg^{-1}.

Annual Effective Dose Equivalent (AEDE)

Exposure risk to any individual due to absorbed dose rate is estimated in term of the annual effective dose equivalent (AEDE). AEDE was calculated by applying the conversion factors of 0.70 Sv Gy^{-1}, which converts absorbed dose rate in the air to effective dose and the outdoor occupancy factor of 0.2, assuming that an individual spends average of 80 % of his time indoors [27]. AEDE in outdoor air, measured in mSv y^{-1} was evaluated using the equation:

$$AEDE\ (mSv\ y^{-1}) = D_R(nGy\ h^{-1}) \times 8760(h\ y^{-1}) \times 0.7(Sv\ Gy^{-1}) \times 0.2 \times 10^{-6}(mSv\ y^{-1})$$

$$AEDE\ (mSv\ y^{-1}) = D_R \times 1.21 \times 10^{-3} \quad (4)$$

Annual Gonadal Dose Equivalent (AGDE)

Annual gonadal dose equivalent (AGDE) represents the dose received by those organs which include the reproductive organs (gonads), bone marrows and bone cells [30]. AGDE due to activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the tailing enriched soil samples was calculated from the formula [22, 28, 30-31]:

$$AGDE\ (\mu Sv\ y^{-1}) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (5)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively in Bq kg^{-1}. 3.09, 4.18 and 0.314 are the respective conversion factors that transform the specific activities of ^{226}Ra, ^{232}Th and ^{40}K into total dose received by the organs of interest.

Activity Utilization Index (AUI)

Activity utilization index defines the dose rate in air due to different combinations of ^{226}Ra, ^{232}Th and ^{40}K in the tailing enriched soil samples. Using the activity concentrations of the radionuclides along with their respective conversion factors, AUI was calculated from the relation [22, 28]:

$$AUI = \left(\frac{A_{Ra}}{50\ Bq\ kg^{-1}}\right)f_U + \left(\frac{A_{Th}}{50\ Bq\ kg^{-1}}\right)f_{Th} + \left(\frac{A_K}{500\ Bq\ kg^{-1}}\right)f_K \quad (6)$$

Where A_{Ra}, A_{Th} and A_K are the measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively. The fractional contributions, f_U, f_{Th} and f_K to the total gamma radiation dose rate in the air from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K are 0.462, 0.604 and 0.041 respectively [31]. According to NEA-OECD [32], typical activities per unit mass of ^{40}K, ^{232}Th and ^{226}Ra in soils are 500, 50 and 50 Bq kg^{-1} respectively.

Hazard Indices (H_{ex} and H_{in})

Other additional criteria for assessing the radiological burden on a given population are the external hazard index (H_{ex}) and the internal

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hazard index (H_{in}). The external hazard index (H_{ex}) is derived from the same expression of Raeq with the supposition that its maximum value corresponds to the upper limit of Raeq, 370 Bq kg^{-1}. It represents the hazard incurred due to external exposure to radiation from ^{226}Ra, ^{232}Th and ^{40}K in the studied soil samples. It was calculated from the equation [27]:

$$H_{ex} = \frac{A_{Ra}}{370\ (Bq\ kg^{-1})} + \frac{A_{Th}}{259\ (Bq\ kg^{-1})} + \frac{A_K}{4810\ (Bq\ kg^{-1})} \quad (7)$$

Similarly, the risk to respiratory organs from internal exposure to radon and its short-lived daughter nuclei was quantified in terms of the internal hazard index, H_{in} [27]:

$$H_{in} = \frac{A_{Ra}}{185\ (Bq\ kg^{-1})} + \frac{A_{Th}}{259\ (Bq\ kg^{-1})} + \frac{A_K}{4810\ (Bq\ kg^{-1})} \quad (8)$$

where A_{Ra}, A_{Th}, and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. UNSCEAR [27] provided a precautionary safety limit of unity for above indices.

Representative Gamma Index ($I_{\gamma r}$)

Representative gamma index ($I_{\gamma r}$) is a screening index that confirms the conformity of environmental samples to dose standards set for building materials [23]. $I_{\gamma r}$ for the studied soil samples was computed from the equation [23, 32-33]:

$$I_{\gamma r} = \frac{A_{Ra}}{150\ (Bq\ kg^{-1})} + \frac{A_{Th}}{100\ (Bq\ kg^{-1})} + \frac{A_K}{1500\ (Bq\ kg^{-1})} \quad (9)$$

Where A_{Ra}, A_{Th} and A_K are the specific activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively in Bq kg^{-1}. $I_{\gamma r}$ must be ≤ 1 which corresponds to an annual effective dose of ≤ 1mSv in order to satisfy the given dose criteria [28, 34].

Excess Lifetime Cancer Risk (ELCR)

The probability of cancer risk to any population from exposure to radiation in the studied soils is a measure of the ELCR. It was calculated based on the estimated AEDE using the equation [28, 35]:

$$ELCR = AEDE \times DL \times RF \quad (10)$$

Where AEDE is as defined in equation (4), DL is the life duration of 70 years and RF is risk factor given to be $0.05Sv^{-1}$ for stochastic effects in any given population [35, 36]. Data obtained from this study were subjected to Pearson's correlation analysis using a statistical software: statistical package for social sciences (SPSS 22.0). This was necessary to understand and establish interdependency and mutual relationships that may exist among the measured radiological variables.

RESULTS AND DISCUSSION

The statistical description of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, comprising the minimum and maximum values, the mean and standard deviation (SD) together with their respective concentration ratios are presented in table 2. The activity concentration of ^{226}Ra ranged between 4.58 and 16.32 Bq kg^{-1} with a mean concentration value of 11.90±3.0 Bq kg^{-1}. For ^{232}Th, the activity concentration varied from 8.48 to 23.21 Bq kg^{-1} with an average concentration of 17.72±3.6 Bq kg^{-1}. ^{40}K however, showed a high mean concentration value within the SD compared to those of ^{226}Ra and ^{232}Th. The mean activity of ^{40}K was found to be 70.44±20.4 Bq kg^{-1}. The primordial radionuclides showed an even distribution in the tailing enriched soils around the coal mine as demonstrated in the normal (Bell-shaped) frequency distribution histograms shown in figure 3. The mean activities of ^{226}Ra, ^{232}Th and ^{40}K in the tailing enriched soils around Maiganga coal mine were found to be lower than their respective world averages of 32, 45 and 412 Bq kg^{-1}. Furthermore, the degree of soil contamination by radioactivity can be measured by the activity ratios. The calculated mean $^{232}Th/^{226}Ra$ ratio was 1.53. This value was found to be higher than the factor 1.2 reported for normal soils by Eisenbud and Gesell [37], indicating a slight enhancement of ^{232}Th above ^{226}Ra in the studied soil samples. Additionally, the mean values for activity ratios $^{226}Ra/^{40}K$ (=0.18) and $^{232}Th/^{40}K$ (=0.26) were less than

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unity, showing that the specific activity of ^{40}K in the studied soil samples was higher than those for ^{226}Ra and ^{232}Th. A plot of the respective calculation ratios is shown in figure 4. These results agree with the earlier reports [13]. Ra_{eq}, D_R, AEDE, AGDE, ELCR and other radiation hazard indices were estimated using equations (2) to (10) and their results presented in table 3. The results obtained for Ra_{eq} varied from 18.77 to 54.98 Bq kg^{-1} with a mean value of 42.67 Bq kg^{-1}. The mean value was lower than the safe precautionary limit of 370 Bq kg^{-1} set by the Organization of Economic Cooperation and Development [32]. Thus, the usage of the tailing enriched soils of Maiganga coal mine, either for landfills, agricultural purposes or as aggregates of building material does not pose any radiological threat to the general public. The gamma absorbed dose rate in air at 1 m above ground level estimated for the studied soils ranged between 8.35 and 26.67 nGy h^{-1} with an average value of 19.14 nGy h^{-1}. This mean value was below the world average value of 58 nGy h^{-1} provided by [29]. Similarly, the estimated mean annual effective dose equivalent of 0.02mSv y^{-1} was recorded for the studied samples which was also lower than the mean worldwide outdoor effective dose of 0.07 mSv reported by UNSCEAR [27]. The average values calculated for AUI, H_{ex}, H_{in}, and $I_{\gamma r}$ were 0.33, 0.12, 0.15 and 0.30 respectively. All the values were below the safety limit of unity set by UNSCEAR [27] for radiation protection. This indicates that the radiation hazard to the general public due to exposure to natural radionuclides in the studied samples is insignificant. In the same context, the

Table 2. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, radiation dose and radiation hazard indices of tailing enriched soils from Maiganga coal mine site

	Activity concentrations (Bq kg^{-1})				Radiation dose			Radiation hazard indices (≤ 1)				
Sample_ID	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}	D_R (nGy h^{-1})	AEDE (mSv y^{-1})	AGDE (μSv y^{-1})	AUI	H_{ex}	H_{in}	$I_{\gamma r}$	ELCR (x 10^{-3})
CMW 01	13.26±0.6	18.63±0.9	87.44±4.1	46.64	21.03	0.03	146.32	0.36	0.13	0.16	0.33	0.09
CMW 02	12.93±0.6	21.45±1.0	69.44±3.3	48.94	21.82	0.03	151.40	0.38	0.13	0.17	0.35	0.09
CMW 03	11.05±0.5	19.48±1.0	65.96±3.1	43.99	19.62	0.02	136.29	0.34	0.12	0.15	0.31	0.08
CMW 04	9.98±0.5	12.98±0.6	64.97±3.1	33.54	15.16	0.02	105.48	0.25	0.09	0.12	0.24	0.06
CMW 05	15.09±0.7	19.78±1.0	84.80±4.0	49.89	22.45	0.03	155.90	0.39	0.13	0.18	0.35	0.10
CMW 06	10.83±0.5	18.88±1.0	64.07±3.1	42.77	19.08	0.02	132.53	0.33	0.12	0.14	0.30	0.08
CMW 07	13.52±0.6	17.93±0.9	70.88±3.3	44.62	20.03	0.02	138.98	0.35	0.12	0.16	0.32	0.08
CMW 08	10.68±0.5	18.21±0.9	53.60±2.6	40.85	18.17	0.02	125.97	0.32	0.11	0.14	0.29	0.08
CMW 09	4.58±0.2	8.48±0.4	26.74±1.3	18.77	8.35	0.01	58.00	0.15	0.05	0.06	0.13	0.04
CMW 10	10.73±0.5	17.65±0.9	45.79±2.2	39.49	17.52	0.02	121.29	0.32	0.11	0.14	0.28	0.07
CMW 11	14.35±0.7	23.21±1.1	96.47±4.5	54.98	24.67	0.03	171.67	0.42	0.15	0.19	0.39	0.10
CMW 12	6.51±0.3	12.44±0.6	54.34±2.6	28.48	12.79	0.02	89.17	0.22	0.08	0.09	0.20	0.05
CMW 13	12.29±0.6	19.64±1.0	81.08±3.8	46.62	20.92	0.03	145.53	0.36	0.13	0.16	0.33	0.09
CMW 14	13.68±0.7	20.29±1.0	97.97±4.6	50.24	22.66	0.03	157.85	0.38	0.14	0.17	0.36	0.10
CMW 15	14.34±0.7	20.08±1.0	66.47±3.2	48.17	21.52	0.03	149.11	0.38	0.13	0.17	0.34	0.09
CMW 16	12.17±0.6	18.44±0.9	114.07±5.3	47.32	21.52	0.03	150.51	0.34	0.13	0.16	0.34	0.09
CMW 17	13.67±0.7	20.41±1.0	81.52±3.8	49.14	22.05	0.03	153.17	0.38	0.13	0.17	0.35	0.09
CMW 18	16.32±0.8	15.82±0.8	46.05±2.2	42.49	19.02	0.02	131.02	0.35	0.11	0.16	0.30	0.08
CMW 19	7.45±0.4	12.62±0.6	75.73±3.5	31.33	14.22	0.02	99.55	0.23	0.08	0.10	0.23	0.06
CMW 20	14.59±0.7	18.03±0.9	61.46±2.9	45.10	20.19	0.02	139.74	0.36	0.12	0.16	0.32	0.09
Minimum	4.58	8.48	26.74	18.77	8.35	0.01	58.00	0.15	0.05	0.06	0.13	0.04
Maximum	16.32	23.21	114.07	54.98	24.67	0.03	171.67	0.42	0.15	0.19	0.39	0.10
Mean	11.90	17.72	70.44	42.67	19.14	0.02	132.97	0.33	0.12	0.15	0.30	0.08
SD	3.0	3.6	20.4	8.7	3.9	0.01	27.1	0.07	0.02	0.03	0.06	0.02
± values represent counting error for individual measurements												
SD is the standard deviation for average values												

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computed average AGDE was 132.97 μSv y^{-1} with a corresponding mean ELCR of 0.08 × 10^{-3}. This value was found to be lower than the world average ELCR value of 0.29 × 10^{-3} contained in UNSCEAR [27] and also below 0.05, the low-level radiation limit set by the International Commission on Radiation Protection. Thus, the probability of cancer effects in the general public from the use of tailing enriched soils of ganga coal mine in negligible.

Pearson's correlation matrix

Mutual relationships and the level of association that may exist among the calculated radiological variables were assessed through the calculation of Pearson's correlation coefficients. The results of correlation matrix among the radiological variables for the tailing enriched soil samples are presented in table 2. The results showed a very high positive relationship (r^2=0.78) between ^{226}Ra and ^{232}Th. This relationship is expected owing to the fact that radium and thorium decay series have a common origin and existence in nature [28, 38]. Furthermore, all the measured radiological variables showed very strong positive correlation with one another and with the primordial radionuclides. It can therefore, be inferred that ^{226}Ra, ^{232}Th and ^{40}K are the major contributors to radiation emissions in the tailing enriched soil samples of Maiganga coal mine.

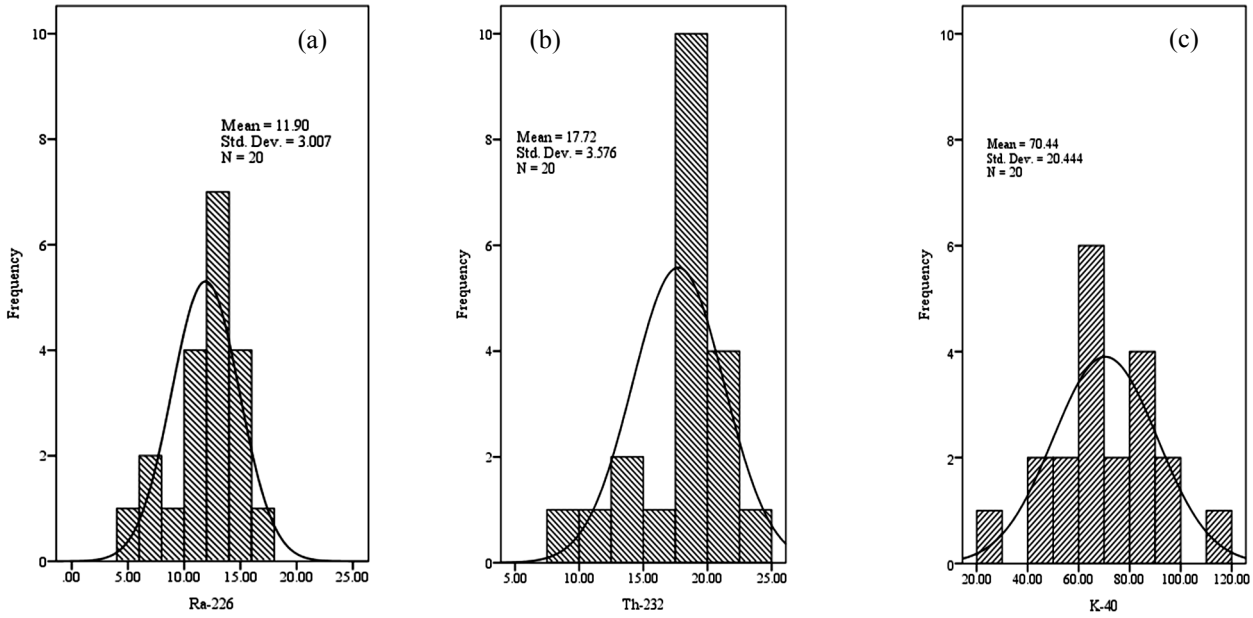

Figure 3. Frequency distribution histograms of (a) ^{226}Ra, (b) ^{232}Th and (c) ^{40}K in tailing enriched soils from Maiganga coal mine site.

Table 3. Pearson's Correlation matrix of radioactive parameters of tailing enriched soils from Mainganga coal mine site

	^{226}Ra	^{232}Th	^{40}K	Ra_{eq}	D_R	AEDE	AGDE	AUI	H_{ex}	H_{in}	I_{yr}	ELCR
^{226}Ra	1.00											
^{232}Th	0.78	1.00										
^{40}K	0.45	0.60	1.00									
Ra_{eq}	0.88	0.97	0.69	1.00								
D_R	0.88	0.96	0.71	1.00	1.00							
AEDE	0.64	0.78	0.81	0.83	0.84	1.00						
AGDE	0.88	0.96	0.72	1.00	1.00	0.84	1.00					
AUI	0.92	0.96	0.58	0.99	0.98	0.78	0.98	1.00				
H_{ex}	0.85	0.97	0.71	0.99	0.99	0.83	0.99	0.98	1.00			
H_{in}	0.94	0.94	0.62	0.99	0.99	0.79	0.98	0.99	0.97	1.00		
I_{yr}	0.88	0.96	0.71	1.00	1.00	0.83	1.00	0.98	0.99	0.98	1.00	
ELCR	0.88	0.93	0.70	0.98	0.98	0.82	0.98	0.97	0.97	0.97	0.98	1.00

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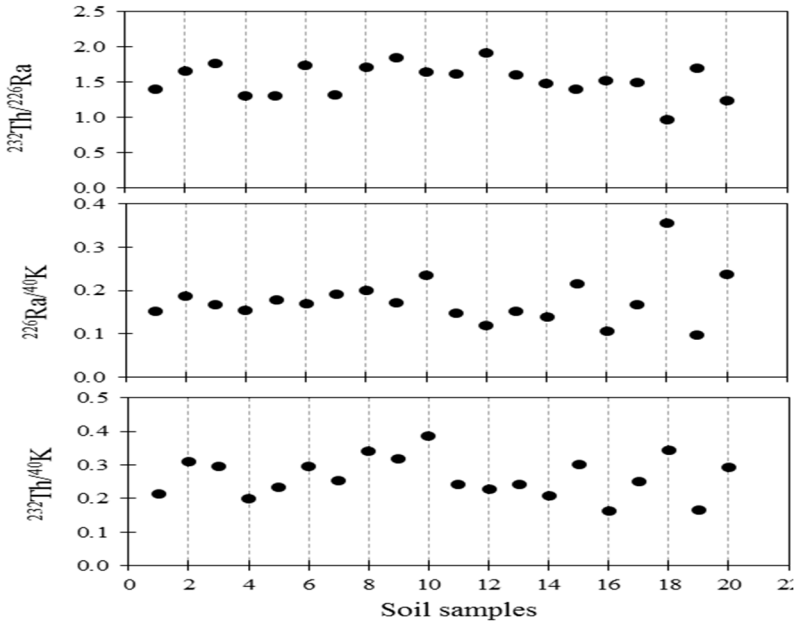

Figure 4. Activity ratios $^{232}Th/^{226}Ra$, $^{226}Ra/^{40}K$, and $^{232}Th/^{40}K$ for tailing enriched soils from Maiganga coal mine site

CONCLUSION

Tailing enriched soils around Maiganga coal mine Northeast Nigeria were assessed for their natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) contents using gamma-ray spectrometric technique. The results show that mean activity concentrations of the radionuclides are lower than the world average values for normal soils. Radiation hazard indices which were calculated from the measured activity concentrations were below precautionary limits set for human and environmental protection. The use of tailing enriched soils for any purpose whatsoever is therefore, radiologically safe for the general public. Constant radiological screening of the tailings is however recommended to keep the possible radiation hazards as low as reasonably achievable (ALARA). The results of this study can serve as baseline for further radiological studies of Maiganga coal mine.

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REFERENCES

1. Samad MA, Haydar MA, Ali MI, Paul D, Bhuiyan MMR, Islam SMA (2012) A Study on the Radioactivity Level in Raw Materials, Final Products and Wastes of the Phosphate Fertilizer Industries in Bangladesh. *Journal of Environmental Protection, **3(10):** 1393.*
2. Hasan MM, Ali M, Paul D, Haydar M, Islam S (2013) Measurement of Natural Radioactivity in Coal, Soil and Water Samples Collected from Barapukuria Coal Mine in Dinajpur District of Bangladesh. *Journal of Nuclear and Particle Physics, **3(4):** 63-71.*
3. Ferdous J, Begum A, Islam A (2015) Radioactivity of soil at proposed Rooppur Nuclear Power Plant site in Bangladesh. *Int. J Radiat Res,* **13(2):** 135-142.
4. Manjunatha S, Jayasheelan A, Venkataramanaiah P (2013) Study of distribution of ^{226}Ra, ^{232}Th and ^{40}K in different rock formations and their dose estimation in and around Chickmagalur, India. *Int. J Radiat Res, **11(3):** 183-187.*
5. Michalik B, Brown J, ,Krajewski P (2013) The fate and behaviour of enhanced natural radioactivity with respect to environmental protection. *Environmental Impact Assessment Review, **38:** 163-171.*
6. Kolo, MT (2014) Natural radioactivity and environmental risk assessment of Sokoto phosphate rock, Northwest

[DOI: 10.18869/acadpub.ijrr.15.1.71]

Nigeria. *African Journal of Environmental Science and Technology,* ***8(9):*** *532-538.*
7. Ibeanu IGE (2002) Tin mining and processing in Nigeria: cause for concern? *Journal of environmental radioactivity,* ***64(1):*** *59-66.*
8. Ajayi O and Ibikunle S (2013) Radioactivity of surface soil from Oyo state, South-western Nigeria. *Int. J Radiat Res,* ***11,*** 271-278.
9. Usikalu MR, Anoka OC, Balogun FA (2011) Radioactivity Measurements of the Jos Tin Mine Tailing in Northern Nigeria. *Archives of Physics Research,* ***2(2):*** *80-86.*
10. Pontedeiro EM, Heilbron PFL, Cotta RM (2007) Assessement of the mineral industry NORM/TENORM disposal in hazardous landfills. *Journal of Hazardous Materials,* ***B139:*** *563-568.*
11. Aliyu AS, Ibrahim U, Akpa CT, Garba NN, Ramli AT (2015) Health and ecological hazards due to natural radioactivity in soil from mining areas of Nasarawa State, Nigeria. *Isotopes in environmental and health studies (ahead-of-print): 1-21.*
12. Skubacz K, Michalik B , Wysocka M (2011) Occupational radiation risk caused by NORM in coal mining industry. *Radioprotection,* ***46(6):*** *S669-S674.*
13. Isinkaye MO (2013) Natural radioactivity levels and the radiological health implications of tailing enriched soil and sediment samples around two mining sites in Southwest Nigeria. *Radiation Protection and Environment,* ***36(3):*** *122*.
14. Demir I and Kursun H (2012) Investigation of radioactive content of Manisa-Soma and Istanbul-Agacli coals (Turkey). *Physicochemical Problems of Mineral Processing,* ***48(2):*** *341-353.*
15. Ademola J (2008) Exposure to high background radiation level in the tin mining area of Jos Plateau, Nigeria. *Journal of Radiological Protection,* ***28(1):*** *93.*
16. Ajayi IR (2009) An evaluation of the equivalent dose due to natural radioactivity in the soil around the consolidated tin mine in Bukuru-Jos, plateau state of Nigeria.
17. Lu X, Li X, Yun P, Luo D, Wang L, Ren C and Chen C (2012) Measurement of natural radioactivity and assessment of associated radiation hazards in soil around Baoji second coal-fired thermal power plant, China. *Radiation Protection Dosimetry,* ***48(2):*** *219-226.*
18. Dołhańczuk-Śródka A, Wróbel Ł, Kłos A , Wacławek M (2013) Assessment of Gamma Dose Rate at Mine Waste Dump. *Ecological Chemistry and Engineering S,* ***20(3):*** *555-565.*
19. Khandaker MU, Jojo PJ, Kassim HA, Amin YM (2012) Radiometric analysis of construction materials using HPGe gamma-ray spectrometry. *Radiation protection dosimetry,* ***152 (1-3):*** *33-37.*
20. Amin Y, Uddin Khandaker M, Shyen A, Mahat R, Nor R, Bradley D (2013) Radionuclide emissions from a coal-fired power plant. *Applied Radiation and Isotopes,* ***80:*** *109-116.*
21. Asaduzzaman K, Khandaker MU, Amin YM, Bradley DA, Mahat RH, Nor RM (2014) Soil-to-root vegetable transfer factors for 226Ra, 232Th, 40K, and 88Y in Malaysia. *Journal of Environmental Radioactivity,* ***135(0):*** *120-127.*
22. Kolo M, Aziz S, Khandaker M, Asaduzzaman K, Amin Y (2015) Evaluation of radiological risks due to natural radioactivity around Lynas Advanced Material Plant environment, Kuantan, Pahang, Malaysia. *Environmental Science and Pollution Research,* ***22(17):*** *13127-13136.*
23. Jibiri N, Isinkaye M, , Momoh H (2014) 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,* ***7(4):*** *536-541*.
24. Sabiha-Javied M, Tufail M, Asghar M (2010) Hazard of NORM from phosphorite of Pakistan. *Journal of Hazardous Materials,* ***176(1/3):*** *426-433*.
25. Tufail M (2012) Radium equivalent activity in the light of UNSCEAR report. *Environmental monitoring and assessment,* ***184(9):*** *5663-5667.*
26. Beretka J and Mathew P (1985) Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health physics,* ***48(1):*** *87-95*.
27. UNSCEAR (2000) Sources and Effects of Ionizing Radiation. Report to General Assembly, with Scientific Annexes. United Nations, New York.
28. Ravisankar R, Vanasundari K, Suganya M, Raghu Y, Rajalakshmi A, Chandrasekaran A, Sivakumar S, Chandramohan J, Vijayagopal P, Venkatraman B (2014) Multivariate statistical analysis of radiological data of building materials used in Tiruvannamalai, Tamilnadu, India. *Applied Radiation and Isotopes,* ***85(0):*** *114-127.*
29. UNSCEAR (2008) Effects of ionizing radiation: report to the General Assembly, with scientific annexes. Vol. 1. United Nations Publications.
30. Morsy Z, El-Wahab MA, El-Faramawy N (2012) Determination of natural radioactive elements in Abo Zaabal, Egypt by means of gamma spectroscopy. *Annals of Nuclear Energy,* ***44****: 8-11.*
31. Chandrasekaran A, Ravisankar R, Senthilkumar G, Thillaivelavan K, Dhinakaran B, Vijayagopal P, Bramha SN, Venkatraman, B (2014) Spatial distribution and lifetime cancer risk due to gamma radioactivity in Yelagiri Hills, Tamilnadu, India. *Egyptian Journal of Basic and Applied Sciences,* ***1(1):*** *38-48.*
32. NEA-OECD (1979) Exposure to Radiation from Natural Radioactivity in Building Materials. Report by NEA Group of Experts. OECD, Paris.
33. El-Gamal A, Nasr S, El-Taher A (2007) Study of the spatial distribution of natural radioactivity in the upper Egypt Nile River sediments. *Radiation measurements,* ***42(3):*** *457-465.*
34. Manigandan P and Chandar Shekar B (2014) Evaluation of radionuclides in the terrestrial environment of Western Ghats. *Journal of Radiation Research and Applied Sciences*
35. Taskin H, Karavus M, Ay P, Topuzoglu A, Hidiroglu S, Karahan G (2009) Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. *Journal of Environmental Radioactivity,* ***100(1):*** *49-53.*
36. ICRP (1991) Publication 60: 1990 Recommendations of the International Commission on Radiological Protection. *Elsevier Health Sciences*.
37. Eisenbud M and Gesell TF (1997) Environmental Radioactivity from Natural, Industrial & Military Sources: From Natural, Industrial and Military Sources. Access Online via Elsevier.
38. Tanaskovi, I, Golobocanin D, Miljević N (2012) Multivariate statistical analysis of hydrochemical and radiological data of Serbian spa waters. *Journal of Geochemical Exploration,* ***112****: 226-234.*

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