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RADIOLOGICAL HAZARDS ASSESSMENT IN MAIGANGA COAL MINE AND ENVIRONS, GOMBE STATE NORTH-EAST NIGERIA

Abubakar G. Mathew[1]*, Nzotta C. Christian[2], Chiegwu U. Hycienth[2], Ugwu[1] A.C, Akosile[3] C.O, Nwodo K. Victor[2]. Ezenma I.C[2]

[1]Department of Medical Radiography, Faculty of Allied Health Sciences, University of Maiduguri, Borno state
[2]Department of Radiography and Radiological Sciences, Nnamdi Azikwe University, Nnewi Campus, Nigeria
[3]Department of Medical Rehabilitation, Nnamdi Azikiwe University, Nnewi Campus, Nigeria

***Correspondence:** mattosky@unimaid.edu.ng; +2348066740058

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ABSTRACT

Background
Humans are exposed externally and internally in their environment to natural background radiation from radionuclides such as ^{40}K, ^{238,} U and ^{232}Th. These radionuclides emit gamma, alpha, beta and other forms of radiation through their decay processes. They are found in the soil, food and the water we consume. Also, human activities such as Mining and milling of uranium, phosphate processing, oil exploration, building materials (Cement industry), coal-fired power station can trigger the Naturally Occurring Radioactive Materials

Methodology: A prospective cross sectional survey design was adopted using a purposive sampling technique, fourteen (14) soil samples were collected from Maiganga Coal Mine (Zone 1) and environment (Zone 2) in Gombe state Nigeria with the use of geographical positioning system (GPS). The activity concentrations of these natural radionuclides were measured using a High Purity Germanium detector. All samples were analysed at the Radiation Protection Institute of Ghana Atomic Energy Commission in Accra, Ghana. Data was analyzed using Statistical Package for Social Sciences version 23.0(IBM Corp Armonk, NY, USA, 2015). Descriptive statistics of Mean, Standard deviation and Range was used for the various radionuclides activity concentrations. Inferential statistics such as Pearson correlation was used to determine the degree of association between the natural radionuclides in soil samples.

Findings: The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil samples at Zone 1&2 of Maiganga is 45.33, 28.83, 105.99 Bqkg^{-1} and 68.38, 33.0, 243.33 Bqkg^{-1}respectively. Radiation hazard indices at Zone1&2 of Maiganga shows the mean for External Hazard index, Internal Hazard index, Gamma Index, External Absorbed Dose Rate, Annual Effective Does Rate, External Annual Effective Does Rate, Excess Lifetime Cancer Risk and Annual Gonadal Effective Dose to be 0.26, 0.38, 0.66, 38.80nGyhr^{-1}, 0.26mSvyr^{-1}, 0.48mSvyr^{-1}, 0.16x10^{-3}, 293.89mSvyr^{-1} and 0.36, 0.55, 0.95, 52.54nGyhr^{-1}, 0.38mSvyr^{-1}, 0.064mSvyr^{-1}, 1.23x10^{-3}, 425.63mSvyr^{-1} respectively.

Conclusion: Maiganga Coal Mining activity does not pose any significant radiation risk though the environment shows value higher than world limits in ^{238}U and AGED.

INTRODUCTION

Gamma radiation is electromagnetic radiation of high frequency (very short wavelength), and is produced by decay of high energy state atomic nuclei and also energy sub-atomic particle interactions by natural processes and man-made mechanisms [1]. Radionuclides can be classified according to their origins as: Naturally Occurring Radioactive Materials (NORMs), Technologically Enhanced Natural Occurring Radioactive Materials (TENORMs) and man-made or anthropogenic radionuclides [2]. Sources of manmade radionuclides include nuclear tests, nuclear power plants and reprocessing facilities, sources used for medical, industrial and agricultural applications, and sources used for research purposes. Both NORMs and TENORMs are from the same natural source, but human activities such as mining and milling of uranium and phosphate, tobacco smoking, oil exploration, air transportation, coal-fired power station, and so on trigger the TENORMs [2, 3]. Industries giving rise to TENORM discharges include fossil fuel (e.g. Coal) nuclear power stations, oil and gas exploration, metal processing, phosphate industry, titanium Oxide and pigment production, zirconium and rare earth process and cement production [4]

[5] stated that coal, like most material found in nature contains trace quantities of naturally occurring radionuclides NORM (Uranium and thorium families and potassium-40). Therefore, the combustion of coal results in release of radionuclides and non-combustible mineral matter, containing bottom ash and fly ash, which are eventually released into the environment. [5] said that emissions from thermal power stations in gaseous and particulate form contain radioisotopes arising from the uranium and thorium series as well as from Potassium-40. These are discharged into the environment causing changes in the natural radiation background and radiation exposures to the population. The continual release of these materials to environment may result in a buildup in the air, water and soil of radionuclides. says coal is very important in manufacturing steel and it is also an important source of chemicals used in manufacturing medicine, fertilizers, pesticides, and other products. Coal mining has a significant impact on the biophysical environment, some of these impacts can be quantified by estimates while others are hard to estimate. It also has serious social consequences on people's health and the environments they live in. Most literature point to the positive impacts of mining, such as job creation and businesses development and overlook the harmful environmental consequence [6]. Coal mining is a dirty and dangerous activity, in coal mine significant volumes of earth must be displaced to mine coal, coal mines and the resulting rock waste can harm the environment. Surface mining has resulted in a great deal of damage to the landscape [6]. Many surface mines have removed acres of vegetation and altered topographic features, such as hills and valleys, leaving soil exposed for erosion resulting from ecological disturbance to pollution of air, land and water, instability of soil and rock masses, and radiation hazards [6].

Maiganga coal deposit is one of the recently discovered coal fields whose intrinsic characteristics are yet to be understood. Maiganga is a local community in Akko local government of Gombe state in North-eastern Nigeria [7]. This deposit is targeted by the Nigerian government for power generation [7]. Intense exploration is going on presently in this deposit to ascertain the quantity and the quality of the coal. Coal from Maiganga coalfield is mined currently and used for firing the kilns of the largest cement producing factory in the North-eastern Nigeria, the Ashaka Cement Factory, Gombe state. The aim of this work is to assess the radiation impact in Maiganga Coal Mine and their Environment

MATERIALS AND METHODS

Study setting

Maiganga Coal Mine which is the second study area, located in Gombe state, Akko local government area, figure 1 below. It is located between longitude 090 59'24.1"N longitude 110 09' 12.4". The study area which is Maiganga covers a land area of about 20129.47 Acres (48.16 Km2) bounded to the south by Billiri to the west by kumo town, located on longitude 9°59'19.65"N and 9°59'3.03"N, latitude 11° 8'31.29"E and 11° 9'44.63" The study area is characterized by wet and dry season largely determine by the properties and movement of Inter tropical convergence zone (ITCZ) [8]. It is seasonally wet from April to October and dries from October to March. Rainfall ranges from 850 mm to 1000 mm; the rainfall concentration reaches it maximum in July/August. Much of the rainfall especially in July and August are associated with storms of high intensity. The mean maximum monthly temperature is 370 C, occurring in March – October while from December to February the temperature lowers to 21 ^{0}C. Relative humidity has the same pattern being 94 % in August and dropped to less than 10% during harmattan, December/January [8].

The study area is on the complex geologic crystalline bedrocks (figure 2). Although the ancient crystalline basement complex sedimentary rocks underlie much of the area, the complex is formed during the late cretaceous period, which has influence the topography of the area. Subsequently extended to the east and also there is discontinuous escarpment rising in some places particularly along Kumo road to form sand stone and clift with over 150 meters above the surrounding plains. The soil is typically ferruginous; they are dark in color with the pH value of 4-6 pending of the location. The soil is intensively formed because of incomplete weathering activities of the basement complex rock. Traditional management practice such as bush clearing, annual burning and livestock grazing have made the soil in the study area susceptible for erosion and reduce it water-holding capacity.

The population of Maiganga according to the Nigeria Population Commission census 2006 is about 3,520 people. Their main economic activities are Agriculture which include cultivation of different types of crops such as maize, beans, soya beans, guinea corn groundnut, rice, millet and sorghum.

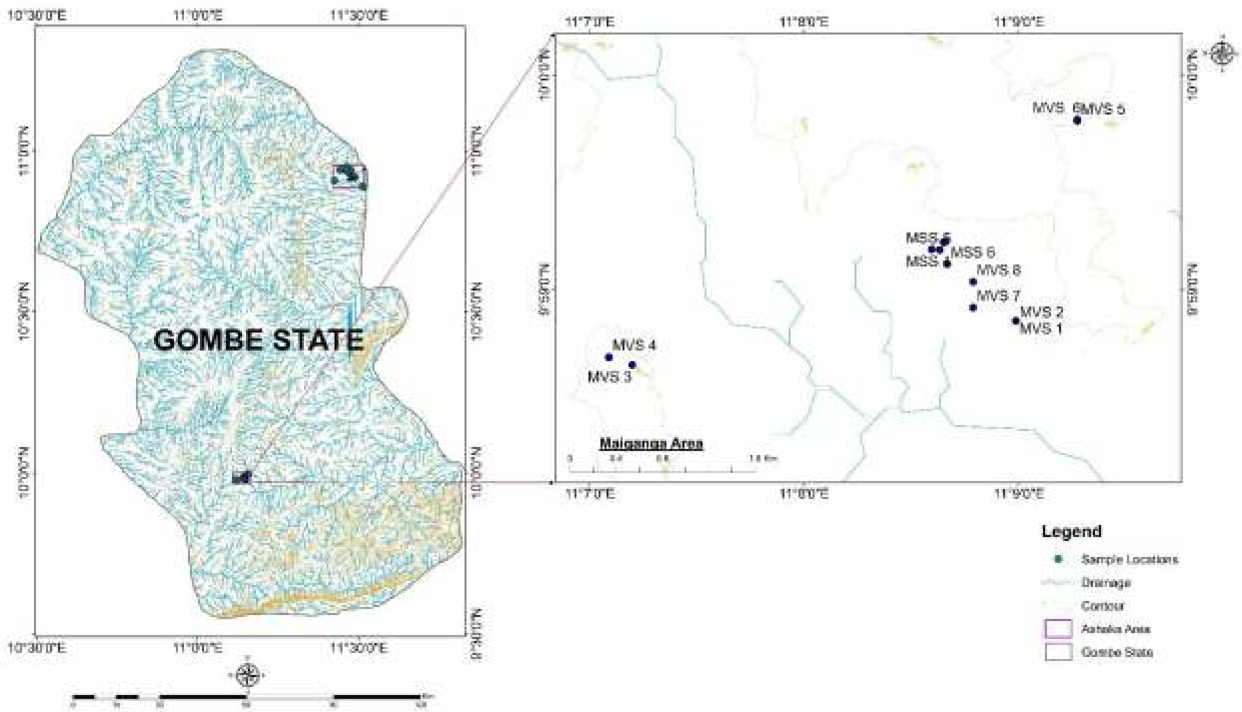

Figure 1: Location Map of the study areas (Maiganga Coal Mine). The GPS coordinates of sampling points were used to produce a Location map of the study areas as shown above

Sample Collection, preparation and analysis

These samples were collected and prepared following the IAEA Technical Report series 295 No 95 procedures. Permanent marker, masking tape, Polyethene bags, Geometric Positioning System device, cutlass and Hoe were used for soil collection. Samples were collected randomly in three points at each of the locations, at the depth of 10cm from the surface of the soil. Each soil sample was collected into a non-radioactive polythene bag, sealed and labeled to avoid mixing and contamination of samples. The samples were collected randomly to satisfactorily represent the entire Coal Mine and its environment. The soil samples were transported to Radiation Protection Institute of Ghana Atomic Energy

Commission(GAEC) laboratory for Sample analysis. The soil samples were analyzed for their radioactivity contents using high purity germanium detector (HPGe) gamma-ray spectrometer. For radiological Analysis, soil samples were air-dried at ambient temperature in the laboratory for 72 hours to ensure completely moisture free samples. This becomes necessary because moisture content constitutes error in the desired spectrum. The samples were further oven dried in the laboratory to attain constant weight. Before further processing, foreign materials such as wood, roots and so on, were removed, then they were separately grounded to a degree that they could pass through a 2 mm-mesh sieve. The dried samples were thoroughly pulverized, sieved, and homogenized 375±1.0 g. The grinder was cleaned with distilled water and dried after each sample was grounded to prevent cross-contamination. The meshed raw samples were transferred to a count container. The homogenized samples were carefully packed into well-labelled marinelli beakers, and properly sealed to prevent escape of radon. The sealed samples were then stored for six weeks to attain secular equilibrium, where the decay rates of the daughter nuclides and their respective long-lived parents become equal [9, 7]. Counting of the radionuclide was done by a gamma spectrometric system which involved the use of a high purity germanium detector. All samples and the background was counted for 36000s.

Radiation Hazard Indices

Hazard index is a term used to describe the sum of more than one hazard quotient for multiple substance and multiple exposure pathways. The hazard index is calculated separately for chronic, sub chronic, and shorter duration exposures. Potential non-carcinogenic effects are characterized by comparing projected doses to reference doses. The hazard quotient estimates that result is a ratio. The ratio of the intake to the reference dose (hazard index) is compared to unity (1.0). If the quotient is less than one, then the effects are assumed not to be of concern. If the hazard quotient is greater than one, then the effects are assumed to be of concern. The hazard index is the sum of hazard quotients [10]

External Hazard Index

This is represented by the equation [10].

$H_{ex}=Ra_{eq}/370=A_k/4810+A_{Ra}/370+A_{Th}/259$…..(1)

Where A_k, A_{Ra} and A_{Th} represent the specific activities in $BqKg^{-1}$ respectively of K-40, Ra-226 and Th-232 in the equation.

Internal Hazard index

This is represented by the equation [10]

$H_{in}=A_k/4810+A_{Ra}/185+A_{Th}/259$ ……………(2)

A_k, A_{Ra} and A_{Th} is the activity concentration of K-40, U-238, and Th-232 respectively

Also, $H_{in}\leq 1$

Representative gamma index (I_γ)

This is another radiation hazard index introduced by the European commission (EC, 1999). It is calculated by the following formula

$\mathbf{I_\gamma}= A_k/3000+A_{Th}/200+A_{Ra}/300$………………..(3)

A_k, A_{Ra} and A_{Th} is the activity concentration of K-40, U-238, and Th-232 respectively

For a safe material; $I_\gamma\leq 1$. This corresponds to annual effective dose equal or less than 1 mSv while $I_\gamma\leq 0.5$ corresponds to an annual effective dose equal or less than 0.3mSv

External dose rate

The external dose delivered by radionuclide to the general public at a distance of 1m above the surface can be estimated from the measured specific activities of these nuclides by the following relationships [11].

$D^*=0.0417_{AK}+0.462_{ARa}+0.604_{ATh}$……………(4)

Where D^*= Dose rate in $nGyh^{-1}$ at 1m above the ground surface. A_k, A_{Ra}, and A_{Th} are the specific activities in $BqKg^{-1}$ of K-40, Ra-226 and Th-232 respectively. The other radionuclides eg. ^{137}C, ^{90}Sr and those present in the ^{235}U decay series, can be neglected as they contribute very little to the total dose from the environmental background (Singh *et al,* 2005). The average value of background dose rate from soil is $59nGyh^{-1}$ [11]

Effective dose rate

The absorbed dose rate in air due to measured specific activities of these primary radionuclides in the sample has been converted to effective dose rate by the following relationship [11,12]

$E= D^* \times O \times C \times 8760 \times 10^{-6}$……………………(5)

Where:

E= Effective dose rate ($mSvy^{-1}$)

D^*= Absorbed dose rate in air ($nGyh^{-1}$) at 1m above the sample surface

O= 0.2 (Outdoor occupying factor)
C= 0.7 $SvGy^{-1}$ (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 [11].

Excess lifetime cancer risk (ELCR)
The ELCR was evaluated using the AEDE values as shown in equation according to [7].

$$ELCR = AEDE\ (mSvy{-}1)\ x\ DL\ x\ RF \quad \ldots\ldots\ldots(6)$$

where DL is average duration of life (70 years) and RF is the fatal cancer risk factor per Sievert (Sv^{-1}). For low dose background radiation, which is considered to produce stochastic effects,

Annual Gonadal Effective Does
It is essential to estimate the annual gonadal equivalent dose (AG), because it is the parameter that predicts whether the gonad, bone cells and marrow of humans are safe after exposure to γ-radiation or not (Usikalu *et al*, 2018). The AG as a result of contributions from the activity concentrations of uranium, thorium and potassium was determined using Equation.

$$AGED\ (\mu SV\ y\text{-}1) = (A_U \times 3.09) + (A_{Th} \times 4.18) + (A_K \times 0.314) \quad \ldots\ldots\ldots(7)$$

A_k, A_{Ra} and A_{Th} is the activity concentration of K-40, U-238, and Th-232 respectively

Table 1: Natural Radionuclides and their activity concentration for soil within Maiganga Coal Mine (Zone 1)

S/N	Code	U-238 (Bq/kg)	Th-232 (Bq/kg)	K-40 (Bq/kg)
1.	MSS 1	8	22	0.57
2.	MSS 2	7	5	75.6
3.	MSS 3	75	49	244.4
4.	MSS 4	52	27	107.6
5.	MSS 5	61	36	153.2
6.	MSS 6	69	34	54.6
	Mean	**45.3±30.31**	**28.83±14.85**	**105.99±84.93**

KEY; Maiganga Soil Sample(MSS)

Table 2: Radiation hazard indices from soil within Maiganga Coal Mine (Zone 1)

S/N	Code	H_{ex} (External Hazard Indices)	H_{in} (Internal Hazard Indices)	Representative gamma index (Iyr)	Ext Absorbed Dose Rate (DE)	Annual Effective Dose Rate (E)	Ext Annual Effective Dose (AEDE)	Excess Lifetime Cancer Risk (ELCR)	Annual Gonadal Equivalent Dose(AG)
1	MSS1	0.11	0.13	0.27	16.99	0.10	0.021	0.07	116.86
2	MSS2	0.05	0.07	0.15	6.57	0.06	0.008	0.03	66.27
3	MSS3	0.44	0.65	1.15	65.27	0.46	0.080	0.28	513.31
4	MSS4	0.27	0.41	0.69	40.78	0.28	0.050	0.18	307.33
5	MSS5	0.34	0.50	0.87	50.57	0.35	0.062	0.22	387.08
6	MSS6	0.33	0.52	0.84	52.64	0.34	0.065	0.23	372.47
		0.26±0.15	**0.38±0.23**	**0.66±0.38**	**38.80±22.58**	**0.26±0.15**	**0.048±0.028**	**0.16±0.07**	**293.89±171**

Table 3: Natural radionuclides and their activity concentration for soil in Maiganga Coal Mine (Zone2)

S/N	CODE	U-238(Bq/kg)	Th-232(Bq/kg)	K-40(Bq/kg)
1	MVS 1	42	30	465.7
2	MVS 2	66	40	249.8
3	MVS 3	117	39	203.2
4	MVS 4	67	30	214.5
5	MVS 5	74	38	221.9
6	MVS 6	57	31	233.1
7	MVS 7	61	35	212
8	MVS 8	63	21	146.5
	Mean	**68.38±21.7**	**33.0±6.33**	**243.3±94.8**

KEY; Mine Village Sample

Table 4: Radiation hazard indices from soil in Maiganga Coal Mine (Zone 2)

S/N	Code	H_{ex} (Ext Hazard Indices)	H_{in} (Internal Hazard Indices)	Representative level index (Ir)	Ext Absorbed Dose Rate (DE)	Annual Effective Dose Rate (E)	Ext Annual Effective Dose	Excess Lifetime Cancer Risk	Annual Gonadal Equivalent Dose (AG)
1	MVS 1	0.33	0.44	0.89	39.47	0.35	0.048	0.17	401.41
2	MVS 2	0.39	0.56	1.01	55.69	0.40	0.068	0.24	449.58
3	MVS 3	0.51	0.83	1.31	78.46	0.53	0.096	0.34	588.36
4	MVS 4	0.34	0.52	0.89	49.97	0.36	0.061	0.21	399.78
5	MVS 5	0.39	0.59	1.02	58.07	0.41	0.071	0.25	457.18
6	MVS 6	0.32	0.48	0.84	46.03	0.34	0.056	0.20	378.90
7	MVS 7	0.34	0.51	0.90	50.21	0.36	0.062	0.22	401.36
8	MVS 8	0.28	0.45	0.73	42.40	0.29	0.052	0.18	328.45
		0.36±0.07	**0.55±0.12**	**0.95±0.17**	**52.54±12.19**	**0.38±0.07**	**0.064±0.015**	**1.23±0.05**	**425.63±77.01**

RESULTS AND DISCUSSION

The mean concentration of ^{238}U at Maiganga Zone 1 and 2 are higher than the world average value while that of ^{232}Th and ^{40}K are less than the world average value. The high mean value for ^{238}U in the soil is in agreement with a research by [13, 14] and contrary to [15, 16] where all their values were less than the world average value.

The calculated values of external hazard index, Internal Hazard index and representative Gamma index are all below the permissible limits. This implies that the environment is safe and the coal mining activity does not in any way expose the workers to any radiation hazard. This is in agreement with [17,18,19 ,20]. The result is contrary to the findings of the research of [21,22] reported higher findings. There higher findings may be attributed to the instrument of measurement, they employed portable survey meters, such as Radalert 100 and Digilert 200 nuclear radiation monitors for the insitu measurement. The External absorbed dose(DE) rate, annual External Effective Dose Rate and Annual Effective Dose Rate range values are all below the world permissible limit. The implication is that mining within Maiganga does not pose any danger to the staffs or workers.The Excess Lifetime Cancer Risk and Annual Gonadal Equivalent Dose shows value less than the world average. All hazard indices and radiological parameters are within world permissible limit in Zone 1 of Maiganga. But Annual Gonadal Equivalent Dose is beyond the permissible limit in zone 2. The low values is in agreement with the research conducted by[7] in Coal and Tailings enriched soil in Maiganga where all the radiological risk indices were below world average value.

Strong positive relationship was found to exist between ^{238}U and ^{232}Th, while weak degree of association existed between ^{40}K and ^{232}Th, ^{40}K and ^{238}U. The very strong positive correlation existing between ^{238}U and ^{232}Th may not be unconnected with the fact that radium and thorium decay series have a common origin, and exists together in nature (Kolo *et al.*, 2017). Furthermore, all the estimated radioactive variables were strongly correlated with one another positively, and also with ^{238}U and ^{232}Th. On the other hand, ^{40}K exhibited weaker relationship comparatively with all the radiological variables. This indicated that the emission of gamma radiation is principally due to ^{238}U and ^{232}Th contents in soil samples from within Maiganga Coal Mine and environment

CONCLUSION

The natural radionuclides present are ^{238}U, ^{232}Th and ^{40}K with higher activity concentration of ^{238}U exceeding the world permissible limits of 33 Bq/kg in all zones of Maiganga Coal Mine and their environs. All Radiation Hazard indices are within world permissible limits except the Annual Gonadal effective dose with values which is higher than the world limits of 300mSvyr^{-1} in Maiganga Zone 1. Finally, the results of the research have shown that Maiganga Coal Mine and Environs even with the exploitation and utilization of Maiganga coal, either for power generation or other industrial uses does not pose any significant radiological impact to the workers and the general environment. It is also affirmed from this study that there might be a long term effect of over exposure to γ-radiation to dwellers as a result of contributions from Annual Gonadal equivalent dose.

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