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Determination of Activity Concentration and Radiotoxicity of Some Radionuclides in Gold Mining Area of Galadima Kogo in Niger State, Nigeria

Saba D. Ibrahim[1], *Samson D. Yusuf*[1], *Ibrahim Umaru*[1], *and Idris M. Mustapha*[1*]

Department of Physics, Nasarawa State University, Keffi Nigeria.

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Abstract: This study is aimed at determining the activity concentration and radiotoxicity of some radionuclides in the Gold mining area of Galadima Kogo in Niger State, Nigeria. A total of thirty soil samples were collected from the gold mining sites and were subjected to Gamma Spectroscopy analysis using a NaI(Tl) detector. The activity of ^{238}U, ^{232}Th, and ^{238}U ranged from 17.3±6.1Bq/kg to 51.4±5.1Bq/kg with mean value of 34.563±6.8 Bq/kg, 11.2±4.1 Bq/kg to 45.0±1.3 Bq/kg with mean value of 28.79±7.2 Bq/kg, 98.3±6.1 Bq/kg to 498.4±7.2 Bq/kg with mean value of 230.4±9.4 Bq/kg respectively. The mean gamma dose rate, radium equivalent activity, external hazard indices, annual effective dose rate, annual gonadal dose rate, excess life cancer risk, and annual gonadal dose equivalent are 43.445 nGy/h, 93.477 Bq/kg, 0.252 mSv/y, 0.053 mSv/y, 0.186, and 299.502 respectively. These indicate that the hazards associated with natural radionuclides in the mining areas are lower than the worldwide average and UNSCEAR recommended limits. The AEDE calculated is lower than the ICRP recommended limit for public exposure. It is therefore concluded that the mining activities in the Galadima Kogo area of Niger State do not pose significant radiological hazard to the host communities.
Keywords: Radioactivity, Gold mining site, NaI(Tl) detector, and Annual effective dose equivalent.

1 Introduction

Gold is one of the major solid minerals Nigeria has over the years attracted the attention of miners, particularly in the North of the country. Niger State is rich in gold. Gold mining in the state is largely carried out by artisans, who deploy their crude skills in extracting the product, thus harming the environment and in the process creating social disorder. In most of the minefields visited in Minna and its environs recently, the lands are inundated and degraded [1, 2]. Although mining activities have been taking place in locations such as Gurmana, Galadiman Kogo, Tashibo, Garafini, Shikira, Zumba, Gwada, Kadaura Zazzaga, Beni, etc. Minna, the capital of Niger State, and its satellite towns are witnessing an increasing surge of mining artisans, who came from as far as Niger Republic in search of the precious commodity.

Regulations regarding uranium soil contamination originate within the Environmental Protection Agency (EPA). The EPA is responsible for calculating the maximum dose, concentration, or environmental release limits. Generally, the EPA seeks to keep the risk of cancer or other deleterious effects to less than 1 event per million populations and focuses on “at risk” individuals. The EPA then issues limits, and the National Radiological Commission converts the limits to rules, regulations, and limits for licensed facilities [2- 4].

Despite the positive values and uses for the production of fertilizer, animal feed supplements, and industrial chemicals have shown that phosphate rocks contain a substantial concentration of uranium, thorium, and their decay products. Mine minerals contain uranium and thorium, and mining activities enhance the concentration of these radionuclides within its vicinity [2, 5, 6]. When phosphate rocks are applied to soil, they raise the radioactivity levels in the soil. The radionuclides in soil may be incorporated into human bodies when contaminated soil is accidentally consumed (hand to mouth) or through inhalation of contaminated soil dust by workers, other site users, or a member of the general public [5, 7]. Leaching of these radioactive nuclides is another source of dissemination and possible transfer to waters and finally to human beings and animals [8, 9]. Gamma radiation from natural radionuclides and cosmic rays constitute external exposure while those derived from inhalation and ingestion through foods and drinking water constitute internal exposure to humans [10]. About 80% of doses contribution to the environment are derived from natural radionuclides while the remaining 20% is from cosmic rays and nuclear

*Corresponding author e-mail: idrismustapham@nsuk.edu.ng

processes [11, 12]. The natural radionuclides of concern in terrestrial environment are mainly Uranium- 238, Thorium-232, Potassium-40, and the radioactive radon gas produced as a result of the decay of the aforementioned parent nuclides [2, 13, 14]

2 Materials and Methods

2.1 Study Area

Galadima Kogo is a district under Shiroro Local Government Area, Niger State in North-central, Nigeria as shown in Figure 1. The area lies within, longitude 10°4'60" N and latitude 6°52'60" E. It covers an area of under 5,015 square kilometers and a population below 100,000. The study area experiences distinct dry and wet seasons with annual rainfall varying from 1,100 mm in the northern parts to 1,600 mm. The maximum temperature (usually not more than 45^{o}C) is recorded between March and June, while the minimum is usually between December and January. The rainy seasons last between 120 days to 150 days.

2.2 Sampling Techniques

The Sampling technique that was used for sample collection is systematic random sampling. This is a probability sampling method in which sample members from a larger population are selected according to a random starting point but with a fixed, periodic interval. This interval called the sampling interval, is calculated by dividing the population size by the desired sample size. This study was done in the period between July to November 2019.

2.3 Method of Sample Collection

Thirty soil samples were collected from some selected Gold mining areas in Galadima Kogo in Shiroro LGA, Niger state, Nigeria. The samples were collected by the coring tool to a depth of 5 cm or the depth of the plow line. The collected samples each were measured using beam balance and were approximately 4 kg in wet mass and were immediately transferred into a high-density polyethylene zip-lock plastic bag to prevent cross-contamination. Each sample was marked with a unique identification number (sample ID) for traceability and its position coordinates were recorded for reference purposes using GPS.

2.4 Method of Sample Preparation

A total of thirty soil samples were collected from the study area. All samples were dried for 4 to 6 days to ensure that moisture was completely removed. All samples were crushed, homogenized, and sieved through a 200 µm, which was the optimum size enriched in heavy minerals. Samples were placed in a polyethylene beaker, of 250 cm^3 volume each and weighed. The beakers were completely sealed for 4 weeks to reach a secular equilibrium of radium and thorium and their progenies.

In the laboratory, soil samples were each transferred into a separate metal drying pan and dried at a temperature of 105 ^{0}C for 24 h in an oven (Labotech; model number MT 202) to remove all residual moisture and to obtain samples with constant weight. The dried samples were pulverized into fine powder for homogeneity [14,15]. Pulverized homogenized samples were each transferred into separate 500 ml wide-mouth plastic containers for gamma spectroscopy analysis using the Sodium Iodide (NaI) detector.

2.5 Method of Data Analysis

Evaluation of radiological hazard effects depending upon the activity concentration of primordial radioactive elements, various radiological hazards delivered to the surrounding living biota are calculated based on the following hazard parameters;

i. Absorbed Dose Rate (D): The total absorbed dose rate (D) in nGy/h is calculated using the following formula:

$$D\ (nGy/h) = 0.462\ A_U + 0.604\ A_{Th} + 0.0417\ A_K \quad (1)$$

where, A_U, A_{Th}, and A_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in Bqkg^{-1} [16-18].

ii. Radium Equivalent Activity (Ra_{eq}): The Radium Equivalent Activity (Ra_{eq}) was calculated using;

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

where A_{Ra}, A_{Th}, and A_K are the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K (in Bq/kg).

iii. External Hazard Indices (HI_{ex}): The gamma-ray radiation hazards due to the specified radioactive elements in soil samples are assessed by calculating the following two hazard indices using the relationship given by Xinwei *et al*. [19-21]:

$$HI_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (3)$$

where, A_U, A_{Th}, and A_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in Bq kg^{-1}. The recommended value by the UNSCEAR [22-25] report for the hazard indices is less than unity.

iv. Annual Effective Dose Equivalent (AEDE): The annual effective dose equivalent (AEDE) in outdoor air is determined following UNSCEAR [16] as:

AEDE (mSv/y) = D (nGy/h) x 8760h x 0.2 x 0.7 Sv/Gy x 10^{-6} 4

where 8760 is the time in hours for one year, and 10^{-6} is the factor converting from nano to milli.

v. Excess Lifetime Cancer Risk (ELCR): Excess lifetime cancer risk (ELCR) is calculated using the formula explained by Idris *et al*. [2] as:

ELCR = AEDE x DL x RF 5

where, AEDE, DL, and RF are annual effective dose equivalent, duration of life (70 years), and risk factor (0.05 Sv^{-1}), respectively.

vi. Annual Gonadal Dose Equivalent (AGDE): Annual gonadal dose equivalent (AGDE) due to the specific activities of ^{238}U, ^{232}Th, and ^{40}K is calculated using the formula explained by Xinwei, et al. [26] as:

AGDE (μSv/y) = 3.09 A_U +4.18A_{Th} + 0.314 A_K 6

3 Results and Discussion

The results of activity concentration for ^{238}U, ^{232}Th, and ^{40}K of soil samples collected from Gold Mining areas in Galadima Kogo, Niger State are presented in Table 1. Sodium Iodide (NaI) detector was used to determine the activity concentration of the soil sample collected.

Radionuclide activity concentrations in the soil samples varied within the study area due to the differences in the geological structure or formation of the area (Table 1). The activity of ^{238}U, ^{232}Th and ^{238}U ranged from 17.3 ± 6.1Bq/kg to 51.4 ± 5.1Bq/kg with average value of 34.563 ± 6.8 Bq/kg, 11.2 ± 4.1 Bq/kg to 45.0 ± 1.3 Bq/kg with mean value of 28.79 ± 7.2 Bq/kg, 98.3 ± 6.1 Bq/kg to 498.4 ± 7.2 Bq/kg with mean value of 230.4 ± 9.4 Bq/kg respectively. SM8 was found to have the highest activity concentration of 51.4 ± 5.1Bq/kg for ^{238}U, while SM19 had the highest activity concentration of 45.0 ± 1.3 Bq/kg for ^{232}Th, while SM26 was found to have the highest concentration of 498.4 ± 7.2 Bq/kg for ^{40}K. The lowest values from ^{238}U, ^{232}Th, and ^{40}K are found in SM12 (17.3 ± 6.1 Bq/kg), SM2 (11.2 ± 4.1 Bq/kg), SM2 and SM4 (98.3 ± 6.1 Bq/kg) respectively. A comparison of the results obtained in the mining site with published data from similar investigations in Nigeria, Ghana, and the world average were presented in Table 2. Higher activity concentration was determined by Ademola and Ademonehin [8], while lower activity concentration was determined by Ademola and Obed [8] and Innocent *et al*. [1]; in Nigeria' and Idris et al. [2] in Nigeria for ^{238}U compared to this study. The activity concentration of ^{238}U estimated in this study is lower than the world average (UNSCEAR, 2000). The average activity concentration of ^{232}Th obtained in this study is higher than that obtained in Nigeria by Ademola and Ademonehin (2010) and Idris *et al.,* [2]. ^{232}Th concentration in the study site is also lower than which is obtained by Innocent *et al*. [1]. The average activity concentration of ^{232}Th is lower than the world average (UNSCEAR, 2000). Similar to what was obtained in this study, other studies as can be seen in Table 2 also indicated that concentrations of ^{40}K in soil samples are significantly higher than the concentration of ^{238}U and ^{232}Th. The average activity concentration of ^{40}K in this study is lower than the world average.

3.1 Radiological Hazard Assessment

The radiological hazard assessment has been carried out by evaluating the Gamma dose rate, Radium equivalent activity, External hazard indices, Annual effective dose rate, Annual gonadal dose rate, and Excess life cancer risk for the soil samples, and are presented in Table 2.

The Gamma dose rate, Radium equivalent activity, External hazard indices, Representative level index, Activity utilization index, Annual effective dose rate, Annual gonadal dose rate, and Excess life cancer risk were calculated from the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K measured from soil sample are presented in Table 2. The value of gamma dose rate ranged from 26.33 nGy/h to 57.22 nGy/h, with a mean value of 43.445 nGy/h. The values for the radium equivalent ranged from 56.983 Bq/kg to 125.149 Bq/kg, with a mean value of 93.477 Bq/kg. The estimated external hazard index ranged from 0.154 mSv/y to 0.338 mSv/y, with a mean value of 0.252 mSv/y. The Annual effective dose rate was computed for the measured activity concentration of ^{238}U, ^{323}Th, and ^{40}K, and the values ranged from 32.302 mSv/y to 70.176 mSv/y, with a mean value of 53.280 mSv/y. The value of excess life cancer risk ranged from 113.056 to 245.616, with a mean value of 186.482. The value of the annual gonadal dose equivalent ranged from 180.009 to 390.293, with a mean value of 299.502.

From the calculations in Table 2, the outdoor average dose rate from terrestrial gamma rays ranged from 26.33 nGy/h to 57.22 nGy/h, with a mean value of 43.445 nGy/h. This is much lower than the worldwide average of 59 nGy/h (UNSCEAR, 2000).

The Radium equivalent in the study area is presented in Table 2. The values for the radium equivalent ranged from 56.983 Bq/kg to 125.149 Bq/kg, with a mean value of 93.477 Bq/kg which shows that the average values obtained from around the mining areas of the Galadima Kogo area of Niger State were lower than the suggested maximal permissible value of 370 Bq/kg (UNSCEAR, 1993)

Calculated values of external hazard indices for soil samples from Galadima Kogo of Niger State ranged from 0.154 to 0.338 with an average of 0.252. This shows that the average values for HI_{ex} were lower than unity, posing no significant radiological threat to the population in the area.

The AEDE values for the Galadima Kogo area of Niger state were also calculated as shown in Table 2. They were found to be in the range 0.032 to 0.070 mSv/y with an average of 0.053 mSv/y. Although some AEDE values were below the worldwide average of 0.48 mSv. The International Commission on Radiation Protection (ICRP) recommends the AEDE limit of 1 mSv/y for individual members of the public and 20 mSv/y for radiation workers. In South Africa, the dose constraint applicable to the average member of a critical group from a single source within the exposed population is 0.25 mSv per annum. This means that the AEDE average values from Galadima Kogo were considered safe to the population.

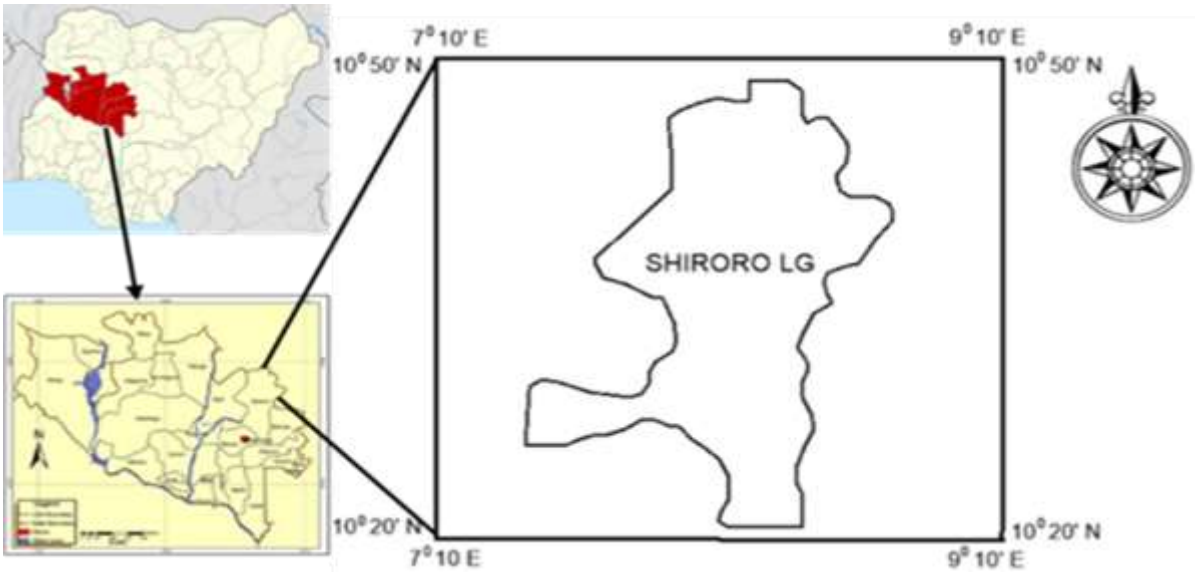

Fig.1: Map of Study Area.

Table 1: Activity concentration of ^{238}U, ^{232}Th, and ^{40}K of the soil sample collected from the study area.

S/N	Sample code	Sampling points		Activity concentration in Bq/kg		
		Latitude	Longitude	^{238}U	^{232}Th	^{40}K
1	SM1	6.75108	9.0003	26.7±3.1	18.0±4.2	198.4±2.8
2	SM2	6.75222	9.0003	37.3±2.5	11.2±4.1	98.3±6.1
3	SM3	6.75336	9.0003	28.2±1.9	21.2±1.8	344.8±2.6
4	SM4	6.7545	9.0003	39.8±4.1	23.0±3.5	198.3±5.3
5	SM5	6.75564	9.0003	20.4±2.8	22.2±4.8	176.6±7.1
6	SM6	6.75678	9.0003	28.1±3.0	19.9±2.6	98.4±4.8
7	SM7	6.75792	9.0003	37.2±2.4	28.9±4.6	228.3±5.9
8	SM8	6.75906	9.0003	51.4±5.1	37.2±3.4	208.4±3.8
9	SM9	6.7602	9.0003	23.3±3.4	35.0±2.9	398.3±2.7
10	SM10	6.76134	9.0003	22.3±2.8	30.8±3.7	91.4±8.1
11	SM11	6.76248	9.0003	34.8±4.2	22.0±5.1	298.7±6.2
12	SM12	6.76362	9.0003	17.3±6.1	35.2±3.3	168.3±5.3
13	SM13	6.76476	9.0003	38.2±3.7	21.7±4.7	244.8±4.5
14	SM14	6.7659	9.0003	49.4±1.8	33.0±6.1	268.3±3.6
15	SM15	6.76704	9.0003	34.4±3.9	22.2±3.3	176.6±6.8
16	SM16	6.76818	9.0003	28.1±4.2	14.9±5.2	98.4±4.9
17	SM17	6.76932	9.0003	47.2±1.3	29.9±3.2	190.3±5.2

18	SM18	6.77046	9.0003	21.4±4.2	37.2±1.6	268.4±2.8
19	SM19	6.7716	9.0003	46.3±5.0	45.0±1.3	188.3±6.9
20	SM20	6.77274	9.0003	32.3±3.7	30.8±4.8	261.4±4.8
21	SM21	6.77388	9.0003	30.8±4.3	38.0±3.9	298.4±6.1
22	SM22	6.77502	9.0003	27.3±5.7	36.2±2.7	308.3±5.5
23	SM23	6.77616	9.0003	48.2±2.9	26.2±3.7	114.8±3.5
24	SM24	6.7773	9.0003	49.8±5.2	29.0±4.8	128.3±3.8
25	SM25	6.77844	9.0003	50.4±1.7	32.2±2.8	206.1±3.6
26	SM26	6.77958	9.0003	28.1±3.6	24.9±6.1	498.4±7.2
27	SM27	6.78072	9.0003	47.2±3.1	28.9±3.3	248.3±3.8
28	SM28	6.78186	9.0003	21.4±6.2	37.2±3.7	278.4±7.6
29	SM29	6.783	9.0003	43.3±2.6	37.0±4.7	318.3±8.3
30	SM30	6.78414	9.0003	26.3±4.2	34.8±2.8	309.3±5.7
	Mean			**34.563±2.8**	**28.79±3.2**	**230.4±2.4**

Table 2: Calculated radiological hazard parameters.

S/N	Sample code	D (nGy/h)	Ra_{eq} (Bq/kg)	HI(ex) (mSv/yr)	AEDE (mSv/yr)	ELCR (μSv/y)	AGDE
1	SM1	31.763	67.716	0.183	0.038	0.136	220.040
2	SM2	28.279	60.885	0.164	0.034	0.121	192.939
3	SM3	40.510	85.065	0.229	0.049	0.174	284.021
4	SM4	40.926	87.959	0.238	0.050	0.175	281.388
5	SM5	30.567	65.744	0.178	0.037	0.131	211.284
6	SM6	29.453	64.133	0.173	0.036	0.126	200.908
7	SM7	44.642	96.106	0.259	0.054	0.192	307.436
8	SM8	55.550	120.643	0.326	0.068	0.238	379.759
9	SM9	49.059	104.019	0.281	0.060	0.210	343.363
10	SM10	33.274	73.382	0.198	0.040	0.142	226.350
11	SM11	42.149	89.259	0.241	0.052	0.180	293.283
12	SM12	36.889	80.595	0.218	0.045	0.158	253.439
13	SM13	41.302	88.080	0.238	0.050	0.177	285.611
14	SM14	54.489	117.249	0.317	0.066	0.233	374.832
15	SM15	37.034	79.744	0.215	0.045	0.158	254.544
16	SM16	26.338	56.984	0.154	0.032	0.113	180.008
17	SM17	48.312	104.610	0.283	0.059	0.207	330.584
18	SM18	44.174	95.263	0.257	0.057	0.189	305.899
19	SM19	57.221	125.149	0.338	0.070	0.245	390.293
20	SM20	44.932	96.472	0.260	0.055	0.192	310.630
21	SM21	50.257	108.112	0.292	0.061	0.215	347.709
22	SM22	47.928	102.805	0.278	0.058	0.205	332.479
23	SM23	43.343	94.506	0.255	0.053	0.186	294.501
24	SM24	46.386	101.149	0.273	0.056	0.199	315.388
25	SM25	51.877	112.316	0.303	0.063	0.222	355.047
26	SM26	49.128	102.084	0.276	0.060	0.211	347.408
27	SM27	50.091	107.646	0.291	0.061	0.215	344.616
28	SM28	44.588	96.033	0.259	0.054	0.191	309.039
29	SM29	56.233	120.719	0.326	0.068	0.241	388.403
30	SM30	46.636	99.880	0.269	0.057	0.200	323.851
	Mean	**43.445**	**93.4772**	**0.252**	**0.053**	**0.186**	**299.502**

4 Conclusions

The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil samples from the Galadima Kogo area of Niger State have been studied using NaI (Tl) gamma-ray spectrometry. The results obtained showed that the distribution of natural radionuclides in the soil samples was not uniform and artificial radionuclide was not detected in any sample measured. The mean activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in the soil samples from the study area were estimated and were found to be lower than the world average. The results of this study area show that there are lower levels of natural radionuclides in the areas than the worldwide average. Therefore, mining activities in the Galadima Kogo area of Niger State pose no significant radiological hazard to the host communities.

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