

Assessment of Radioactivity Concentration in Soil and Plant Samples from Selected Mining Sites in Kaduna State, Nigeria

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Abstract: This study is aimed at determining the radioactivity concentration in soil and plant samples from selected mining sites in the Jema'a area of Kaduna State, Nigeria. A total of fifteen samples of soil and fifteen samples of plants were collected from the selected mining sites and were subjected to Gamma Spectroscopy analysis using NaI(Tl) detector. The activity of ^{238}U , ^{232}Th and ^{40}K for soil ranged from 11.73 ± 2.3 Bq/kg to 1194.8 ± 35.4 Bq/kg with mean value of 84.908 ± 17.2 Bq/kg, 0.53 ± 0.04 Bq/kg to 38.77 ± 2.9 Bq/kg with mean value of 20.255 ± 1.5 Bq/kg, 188.85 ± 11.0 Bq/kg to 5093.31 ± 292.6 Bq/kg with mean value of 2985.31 ± 175.9 Bq/kg respectively. The activity of ^{238}U , ^{232}Th and ^{40}K for plant ranged from 4.30 ± 1.0 Bq/kg to 76.99 ± 17.1 Bq/kg with mean value of 31.429 ± 7.0 Bq/kg, 0.44 ± 0.03 Bq/kg to 11.46 ± 0.9 Bq/kg with mean value of 5.125 ± 0.3 Bq/kg, 27.86 ± 1.7 Bq/kg to 1021.39 ± 73.0 Bq/kg with mean value of 406.143 ± 26.4 Bq/kg respectively. The mean transfer factors for ^{238}U , ^{232}Th , and ^{40}K are 0.922379, 0.55846, and 0.290847, respectively. These indicate the potential for radionuclide uptake by plants, highlighting the need for ongoing monitoring and risk assessment to ensure environmental and public health safety. The mean absorbed dose rate, radium equivalent activity, external hazard indices, annual effective dose equivalent, excess life cancer risk, and annual gonadal dose equivalent are 175.9307 nGy/h, 343.6983 Bq/kg, 0.928216 mSv/y, 0.215761 mSv/y, 0.604671, and 1284.293, respectively. These indicate that the hazards associated with natural radionuclides in the selected mining areas are lower than the worldwide average and UNSCEAR recommended limits, except for absorbed dose rate and excess life cancer risk, which are higher than the worldwide average and UNSCEAR recommended limits. The AEDE calculated values are lower than the ICRP recommended limit for public exposure. It is therefore concluded that the mining activities in the selected mining sites in Kaduna State revealed alarming levels of radioactivity at certain mining sites, characterized by elevated activity concentrations of adsorbed dose rate and excess lifetime cancer risk. These areas require immediate regulatory intervention to mitigate potential radiological hazards to the public. The radiation levels detected pose a significant threat to human health and the environment, necessitating prompt action.

Keywords Radioactivity¹, NaI(Tl) detector², transfer factor³.

1 Introduction

Mining on any scale, whether small or huge, has the potential to devastate the environment by exposing it to dangerous radionuclides [1]. Mining activities have been identified as a major source of NORM exposure. While NORMs are the main sources of both external and internal radiation exposure to humans and are present in air we breathe, the food we eat, and the water we drink, and have resulted in adverse health consequences on the public. The largest contributor to radiation exposure is Radon (^{222}Rn), which is a decay product of ^{238}U commonly found in rocks and soils. However, there are two main mechanisms in which plants become contaminated by radioactivity, either by root uptake from the soil as a result of natural

radionuclides, ^{232}Th and ^{238}U including their decay products present in the soil or directly by aerial deposition of fallout radionuclides such as Cs-137 on plants as a result of some introduction of some activities that gives rise to radiation exposure. Overexposure to radiation can cause health problems like leukemia, chromosomal breakage, bone necrosis, bone cancer, gene mutations, and cataracts in the eye lens, among other things. The high levels of exposure to these radionuclides may be detrimental to the public, as natural background radiation contributes the most to human exposure [2-5]. Several studies on spontaneous radionuclide transfer from soil to plant have been conducted in various parts of the world. However, Jema'a local government area is known for mining activities, and there is a possibility that naturally occurring radionuclides

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may be present in soil and plants around the area, contaminating plants and causing significant radiation exposure to people living in the surrounding area.

2 Experimental Sections

2.1 Materials

The materials that were used in this study are:

Ludlum micro survey meter, global positioning system (GPS), masking tape, plastic container, pestle, mortar, and a sieve, tissue paper, methylated spirit, polythene bags, shovel.

2.2 Methods

Study Area

Kaduna State is known to have significant mineral resources and mining activities, which are carried out in various locations across the state. Some of the minerals found in Kaduna State include: gold deposits, Columbite, Cassiterite, Molybdenite, Tantalite, Iron Ore, Nickel, and an array of Gemstones such as Aquamarine, Sapphire, Tourmaline, Topaz, and Amethyst.

Jema'a LGA of Kaduna State is located in the Southern part of the state. It shares boundaries with Zango Kataf LGA to the north, Jaba LGA to the west, Sanga LGA to the east, Kaura LGA to the northeast, Riyom LGA of Plateau state to the east, and Karu LGA of Nasarawa state to the south. The exact geographic coordinates of Jema'a LGA are approximately 9.3827°N latitude and 8.2681°E longitude. Jema'a Local Government is well suited for the production of arable crops such as millet, maize, ginger, and cassava because of its favorable climate conditions. They also embark on small and medium livestock production. The major tribes are Fantuwam, Kagoma, Nigzom, Bajju, Kaninkon, e.t.c.

Sampling Techniques

The Sampling technique that was used for sample collection is the 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 March to August 2024.

Method of Sample Collection

Fifteen samples of soil and fifteen samples of plants were collected 100m away from the mining sites in Jema'a, Kaduna state of Nigeria. The plant samples were collected above ground level, excluding the roots. The soil samples were collected by a coring tool to a depth of 5cm. The collected samples were each measured using a beam

balance. The mass of the collected samples was approximately 5kg in wet mass and was 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 Global Positioning System (GPS).

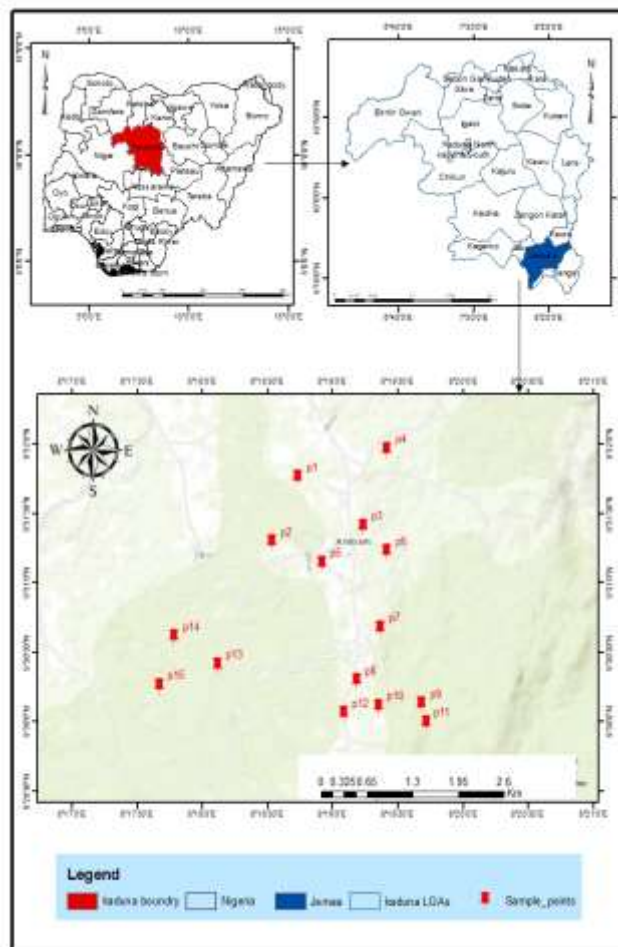


Fig.1: Map of the study Area.

Method of Sample Preparation

Fifteen soil samples were collected from the study area. The samples collected were transferred into a separate metal drying pan and dried at room temperature (Labotech; model number MT 2002) to remove all residual moisture and to obtain samples with constant weight. The dried samples were pulverized into fine powder for homogeneity [7]. After drying, the samples were pulverized using a ceramic mortar and pestle and were passed through a 5mm-mesh sieve to remove the larger particles and collect the fine powder. The prepared samples were packed in a well-sealed cylindrical plastic container to prevent the escape of radon and were stored for at least 24 days to allow radium to attain equilibrium with the daughters.

Fifteen plant samples were washed with tap water and de-ionized water to remove air pollutants, followed by drying at room temperature to remove moisture for 3 to 4 weeks. The dried samples were pulverized using a pestle and mortar, followed by sieving through a 0.5 mm mesh size sieve to obtain a uniform particle size. Each plant samples were labeled and stored in a dry plastic container for radioactivity concentration analysis [8-10].

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:

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

where: A_U , A_{Th} , and A_K are the activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in Bq kg^{-1} .

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

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

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:** 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 [11-12].

$$H_{ex} = \left(\frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \right) < 1 \quad (3)$$

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 [2] 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 [6] as:

$$AEDE \text{ (mSv/y)} = D \text{ (nGy/h)} \times 8760\text{h} \times 0.2 \times 10^{-6} \text{ Sv/Gy} \times 10^{-6} \quad (4)$$

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 [13].

vi.

$$ELCR = AEDE \times DL \times RF \quad (5)$$

where AEDE, DL, and RF are annual effective dose equivalent, duration of life (56.05s years), and risk factor (0.05 Sv^{-1}), respectively.

- vii. **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 [14].

$$AGDE \text{ (}\mu\text{Sv/y)} = 3.09 A_U + 4.18A_{Th} + 0.314 A_K \quad (6)$$

- viii. **Soil-to-Plant Transfer Factor (TF)**

The soil-to-plant transfer factor (TF) is defined as the ratio of the concentrations of radionuclides in plant (Bq kg^{-1} , dry mass) to that in soil (Bq kg^{-1} , dry mass) and was calculated using the following formula [15-16].

$TF = \text{Activity of radionuclides in plant (BqKg}^{-1}\text{, dry mass)} / \text{Activity of radionuclides in soil (BqKg}^{-1}\text{, dry mass)}$

3 Results and Discussion

The results of activity concentration for ^{238}U , ^{232}Th , and ^{40}K of soil samples collected from the selected mining site in Jema'a, Kaduna State, are presented in Table 1. Sodium Iodide (NaI) detector was used to determine the activity concentration of the soil samples collected.

Radionuclide activity concentrations in the soil samples varied within the study area due to the differences in geological structure or formation of the area (Table 1). The activity of ^{238}U , ^{232}Th and ^{40}K for soil ranged from $11.73 \pm 2.3 \text{ Bq/kg}$ to $1194.8 \pm 35.4 \text{ Bq/kg}$ with mean value of $84.908 \pm 17.2 \text{ Bq/kg}$, $0.53 \pm 0.04 \text{ Bq/kg}$ to $38.77 \pm 2.9 \text{ Bq/kg}$ with mean value of $20.255 \pm 1.5 \text{ Bq/kg}$, $188.85 \pm 11.0 \text{ Bq/kg}$ to $5093.31 \pm 292.6 \text{ Bq/kg}$ with mean value of $2985.31 \pm 175.9 \text{ Bq/kg}$ respectively. The least values from ^{238}U , ^{232}Th , and ^{40}K are found in SS14 ($11.73 \pm 2.39 \text{ Bq/kg}$), SS14 ($0.53 \pm 0.04 \text{ Bq/kg}$), and SS13 ($188.85 \pm 11.02 \text{ Bq/kg}$), respectively. While the highest values from ^{238}U , ^{232}Th , and ^{40}K are found in SS2 ($1194.83 \pm 35.42 \text{ Bq/kg}$), SS2 ($38.77 \pm 2.95 \text{ Bq/kg}$), and SS1 ($5093.31 \pm 292.64 \text{ Bq/kg}$), respectively. Comparison of the results obtained in the mining site with published data from similar investigations in Nigeria and the world average. The activity concentration of ^{238}U estimated in this study is higher than the world average [6]. The average activity concentration of ^{232}Th obtained in this study is lower than that obtained in Nigeria by [17-19]. But higher than what is obtained by [12]. Similar to what was obtained in this study, indicate that concentrations of ^{40}K in soil samples are significantly higher than the concentrations of ^{238}U and ^{232}Th . The average activity concentration of ^{40}K in this study is higher than study obtained by [17-19].

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

Sample Code	Geopoint		Activity Concentration (Bq/kg)		
	Longitude	Latitude	U-238	Th-232	K-40
SS1	8°18'44" E	9°31'45" N	132.15 ± 23.96	19.86 ± 1.56	5093.31 ± 292.64
SS2	8°18'32" E	9°31'17" N	1194.83 ± 35.42	38.77 ± 2.95	3830.38 ± 232.21
SS3	8°19'14" E	9°31'24" N	78.11 ± 17.65	37.58 ± 2.79	2673.42 ± 166.96
SS4	8°19'25" E	9°31'57" N	24.67 ± 5.08	16.82 ± 1.17	1660.74 ± 95.20
SS5	8°18'55" E	9°31'08" N	143.54 ± 25.18	25.59 ± 1.92	3277.78 ± 193.37
SS6	8°19'25" E	9°31'13" N	93.87 ± 19.07	15.71 ± 1.31	3951.95 ± 233.46
SS7	8°19'22" E	9°30'40" N	122.53 ± 24.66	30.15 ± 2.23	3319.99 ± 197.86
SS8	8°19'11" E	9°30'17" N	112.07 ± 21.29	21.58 ± 1.71	4135.01 ± 240.99
SS9	8°19'41" E	9°30'07" N	91.67 ± 19.98	14.53 ± 1.17	4563.17 ± 262.03
SS10	8°19'21" E	9°30'06" N	58.03 ± 13.28	17.04 ± 1.35	2729.95 ± 166.48
SS11	8°19'43" E	9°29'59" N	95.95 ± 16.37	21.94 ± 1.52	2846.97 ± 160.46
SS12	8°19'05" E	9°30'03" N	80.06 ± 13.96	26.15 ± 1.81	3008.22 ± 168.84
SS13	8°18'07" E	9°30'24" N	14.25 ± 2.70	BDL	188.85 ± 11.02
SS14	8°17'47" E	9°30'36" N	11.73 ± 2.39	0.53 ± 0.04	1539.32 ± 96.59
SS15	8°17'40" E	9°30'15" N	95.16 ± 17.84	17.12 ± 1.35	1960.62 ± 121.87
Mean			84.908 ± 17.255	20.255 ± 1.525	2985.31 ± 175.999

Table 2: Activity concentration of ^{238}U , ^{232}Th , and ^{40}K of the plant sample collected from the study area.

Sample Code	Geopoints		Activity concentration (Bq/kg)		
	Longitude	Latitude	U-238	Th-232	K-40
PS1	8°18'44" E	9°31'45" N	4.30 ± 1.01	5.04 ± 0.37	27.86 ± 1.75
PS2	8°18'32" E	9°31'17" N	19.60 ± 4.77	7.28 ± 0.54	56.49 ± 3.60
PS3	8°19'14" E	9°31'24" N	20.31 ± 4.86	6.87 ± 0.51	416.09 ± 24.33
PS4	8°19'25" E	9°31'57" N	40.38 ± 7.79	5.45 ± 0.40	208.04 ± 12.81
PS5	8°18'55" E	9°31'08" N	60.69 ± 14.13	11.46 ± 0.95	502.18 ± 37.83
PS6	8°19'25" E	9°31'13" N	4.72 ± 1.14	3.64 ± 0.28	138.99 ± 8.69
PS7	8°19'22" E	9°30'40" N	15.82 ± 3.67	6.98 ± 0.52	588.26 ± 36.45
PS8	8°19'11" E	9°30'17" N	29.99 ± 6.19	BDL	590.95 ± 36.42
PS9	8°19'41" E	9°30'07" N	13.22 ± 3.18	5.59 ± 0.43	615.17 ± 37.91
PS10	8°19'21" E	9°30'06" N	26.92 ± 6.02	0.44 ± 0.03	686.91 ± 41.89
PS11	8°19'43" E	9°29'59" N	16.77 ± 3.76	8.43 ± 0.63	333.59 ± 21.19
PS12	8°19'05" E	9°30'03" N	76.99 ± 17.14	3.11 ± 0.29	1021.39 ± 73.04
PS13	8°18'07" E	9°30'24" N	75.33 ± 18.81	9.62 ± 0.81	460.93 ± 33.88
PS14	8°17'47" E	9°30'36" N	42.07 ± 8.86	2.97 ± 0.23	301.81 ± 18.77
PS15	8°17'40" E	9°30'15" N	24.32 ± 5.05	BDL	143.48 ± 8.90
Mean			31.429 ± 7.0923	5.125 ± 0.399	406.143 ± 26.497

Radionuclide activity concentrations in the soil samples varied within the study area due to the differences in geological structure or formation of the area (Table 2). The activity of ^{238}U , ^{232}Th and ^{40}K for plant ranged from 4.30 ± 1.0 Bq/kg to 76.99 ± 17.1 Bq/kg with mean value of 31.429 ± 7.0 Bq/kg, 0.44 ± 0.03 Bq/kg to 11.46 ± 0.9 Bq/kg with mean value of 5.125 ± 0.3 Bq/kg, 27.86 ± 1.7 Bq/kg to 1021.39 ± 73.0 Bq/kg with mean value of 406.143 ± 26.4 Bq/kg respectively. The least values from ^{238}U , ^{232}Th , and ^{40}K are found in PS1 (4.30 ± 1.01 Bq/kg), PS10 (0.44 ± 0.03 Bq/kg), and PS1 (27.86 ± 1.75 Bq/kg), respectively.

While the highest values from ^{238}U , ^{232}Th , and ^{40}K are found in PS12 (76.99 ± 17.14 Bq/kg), PS5 (11.46 ± 0.95 Bq/kg), and PS12 (1021.39 ± 73.04 Bq/kg), respectively. The activity concentration of ^{238}U and ^{232}Th estimated in this study is lower than the world average [6]. While the activity concentration of ^{40}K is higher than the world average [6].

Transfer Factor

The results of the transfer factor for ^{238}U , ^{232}Th , and ^{40}K of soil-to-plant samples collected from the selected mining site in Jema'a, Kaduna State, are presented in Table 3.

Table 3: Calculated soil to plant transfer factor.

TF	U-238	Th-232	K-40
TF1	0.032539	0.253776	0.00547
TF2	0.163565	0.187774	0.014748
TF3	0.260018	0.18281	0.15564
TF4	1.636806	0.324019	0.125269
TF5	0.422809	0.447831	0.153207
TF6	0.050282	0.2317	0.03517
TF7	0.129111	0.231509	0.177187
TF8	0.267601	NA	0.142914
TF9	0.144213	0.384721	0.134812
TF10	0.463898	0.025822	0.25162
TF11	0.174779	0.38423	0.117174
TF12	0.961654	0.118929	0.339533
TF13	5.286316	#DIV/0!	2.44072
TF14	3.58653	5.603774	0.196067
TF15	0.25557	NA	0.073181
MEAN	0.922379	0.55846	0.290847
MIN	0.032539	NA	0.00547
MAX	5.286316	5.603774	2.44072

The transfer factor values for the Jema'a area of Kaduna state were also calculated as shown in Table 3. For ^{238}U , ^{232}Th , and ^{40}K ranged from 0.032 to 5.286, with a mean value of 0.922; from NA to 5.603, with a mean value of 0.55; 0.005 to 2.440, with a mean value of 0.290, respectively. These transfer factors indicate the potential for radionuclide uptake by plants, highlighting the need for ongoing monitoring and risk assessment to ensure environmental and public health safety.

Radiological Hazard Assessment

The radiological hazard assessment has been carried out by evaluating the absorbed dose rate, Radium equivalent activity, External hazard indices, Annual effective dose rate, Annual gonadal dose rate, and Excess life cancer risk were calculated. The activity concentrations of ^{238}U , ^{232}Th , and ^{40}K measured from the soil sample are presented in Table 4.

From the calculations in Table 4, the average absorbed dose rate from terrestrial gamma rays ranged from 14.458 nGy/h to 285.439 nGy/h, with a mean value of 175.930 nGy/h. This is much higher than the worldwide average of 59 nGy/h [6].

The Radium equivalent in the study area is presented in Table 3. The values for the radium equivalent ranged from 28.791 Bq/kg to 552.734 Bq/kg, with a mean value of 343.698 Bq/kg, which shows that the average values obtained from around the selected mining sites of the Jema'a area of Kaduna State were lower than the suggested maximal permissible value of 370 Bq/kg [20--22].

Calculated values of external hazard indices for soil samples from Jema'a of Kaduna State ranged from 0.077 to 1.492, with an average of 0.928. 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 Jema'a area of Kaduna state were also calculated as shown in Table 3. They were found to be in the range 0.017 to 0.350 mSv/y with an average of 0.215 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 Jema'a were considered safe for the population [23-27].

The calculated values of excess lifetime cancer risk for soil samples from Jema'a of Kaduna State ranged from 0.049 to 0.981 $\mu\text{Sv/yr}$, with an average of 0.604 $\mu\text{Sv/yr}$, which shows that the average values for ELCR were higher than the average value of 0.29 $\mu\text{Sv/yr}$, posing a radiological threat to the population in the area.

Table 4: Calculated radiological hazard parameters for soil.

Sample Code	D (nGy/h)	Raeq (Bq/kg)	Hex (mSv/yr)	AEDE (mSv/yr)	ELCR (μ Sv/yr)	AGDE
SS1	285.439767	552.73467	1.492741907	0.35006333	0.981052483	2090.65764
SS2	238.505386	470.21036	1.269892783	0.292503005	0.819739673	1735.07262
SS3	170.266754	337.70274	0.912009207	0.208815147	0.58520445	1237.89818
SS4	90.809678	176.59958	0.476885952	0.111368989	0.312111592	668.01026
SS5	218.455266	432.52276	1.168200178	0.267913538	0.750827691	1579.72772
SS6	217.653095	420.63545	1.1359703	0.266929756	0.74807064	1596.6384
SS7	213.263043	421.28373	1.13779804	0.261545796	0.732982093	1547.12156
SS8	237.240577	461.32517	1.245881794	0.290951844	0.815392542	1734.89384
SS9	241.411849	463.81199	1.252541135	0.296067492	0.829729145	1776.83108
SS10	150.940935	292.60335	0.790186516	0.185113963	0.51878188	1107.7442
SS11	176.299309	346.54089	0.935920404	0.216213473	0.605938257	1282.14328
SS12	178.225094	349.08744	0.942753193	0.218575255	0.612557153	1301.27348
SS13	14.458545	28.79145	0.077775468	0.01773196	0.049693817	103.3314
SS14	69.929024	131.01554	0.353773983	0.085760955	0.240345076	521.80758
SS15	136.062254	270.60934	0.730902881	0.166866748	0.467644062	981.24068
MEAN	175.9307	343.6983	0.928216	0.215761	0.604671	1284.293

4 Conclusions

The activity concentrations of ^{238}U , ^{232}Th , and ^{40}K in soil samples from the Jema'a area of Kaduna State have been studied using NaI (Tl) gamma ray spectrometry. The results obtained showed that this radiometric investigation revealed alarming levels of radioactivity at certain mining sites, characterized by elevated activity concentrations of ^{40}K and excess lifetime cancer risk. These areas require immediate regulatory intervention to mitigate potential radiological hazards to the public. The radiation levels detected pose a significant threat to human health and the environment, necessitating prompt action. Furthermore, the moderate transfer factor of radionuclides from soil to plants signals a potential risk to the food chain and ecosystem. Although the levels are not exceedingly high, consistent monitoring and surveillance are crucial to prevent further contamination and ensure the safety of the food chain. Proactive measures, such as soil remediation and radiation protection strategies, are essential to minimize exposure and safeguard public health and the environment.

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References

- [1]. Ahijjo, Y.M. & Umar, S. (2015). A Theoretical Model of Health Implications due to Potassium-40 Prevalence in Sokoto Basin: A Case Study of Dange-SHuni. *Journal of Multidisciplinary Engineering Science Studies (JMESS)*, 1(1), 2912-1309.
- [2]. Arafin, SAK., El-Taher, A., Hoque, AKMF., Hoque, MA., Ferdous, J., Abedin, MJ., (2020) Natural gamma radiation level detection in agricultural soil after Aila disaster and comparison with deep soil gamma activity in a specific area of Sundarban region, Satkhira, Bangladesh. *International Journal of Radiation Research* 18 (3), 397-404.
- [3]. Wael M Badawy, Andrey Yu Dmitriev, Hussein El Samman, Atef El-Taher, Maksim G Blokhin, Yasser S Rammah, Hashem A Madkour, Safwat Salama, Sergey Yu Budnitskiy. (2024) Elemental composition and metal pollution in Egyptian Red Sea mangrove sediments: characterization and origin. *Marine Pollution Bulletin* 198, 115830.
- [4]. Mohamed M Ghoneim, Elena G Panova, Ahmed E Abdel Gawad, Hamdy A Awad, Hesham MH Zakaly,

- Atef El-Taher. (2023) Analytical methodology for geochemical features and radioactive elements for intrusive rocks in El Sela area, Eastern Desert, Egypt. *International Journal of Environmental Analytical Chemistry* 103 (6), 1272-1291.
- [5]. Massoud, E., El-Taher, A., Najam, L.A., Elsaman, R. (2023) Ecological impacts of Assuit fertiliser factory in Upper Egypt: Environmental implications and spatial distribution of natural radionuclides. *International Journal of Environmental Analytical Chemistry* 103 (5), 1039-1052
- [6]. UNSCEAR (2000). United Nations Scientific Committee on the Effects of Ionizing Radiation. Report to the General Assembly, United Nations, 1, 223. New York.
- [7]. Masok, F. B., Masiteng, P. L., Mavunda, R. D. & Maleka, P. P. (2017). An Integrated Health Risk Evaluation of Toxic Heavy Metals in Water from Richards Bay, South Africa. *Journal of Environmental and Analytical Toxicology*, 7(4), 1-7. DOI: <http://dx.doi.org/10.4172/2161-0525.1000487>.
- [8]. Elsaman, R., Seleem, EMM., Salman, SA., Ella, EMAE., El-Taher, A. (2022). Evaluation of natural radioactivity levels and associated radiological risk in soil from Siwa Oasis, Egypt. *Radiochemistry* 64 (3), 409-415.
- [9]. Alashrah, S., El-Taher, A. (2017) Elemental analysis and radiation hazards parameters of bauxite located in Saudi Arabia. *Journal of Physics: Conference Series* 817 (1), 012061.
- [10]. El-Taher, A., Abdelhalim, M.K. (2013) Elemental analysis of phosphate fertilizer consumed in Saudi Arabia. *Life Science Journal* 10 (4), 701-708.
- [11]. Xinwei, I., Lingqing, W. & Xiaodan, J. (2006). Radiometric analysis of Chinese commercial granites. *Journal of Radioanalytical and Nuclear Chemistry*, 267(3), 669-673.
- [12]. Oraby, AH., Saleh, GM., Hassan, EM., Eldabour, SE., El Tohamy, AM., Kamar, MS., El Feky, MG., El Taher, A. (2022) Natural radioactivity and radioelement potentiality of mylonite rocks in Nugrus Area, Southeastern Desert, Egypt. *Radiochemistry* 64 (5), 645-655.
- [13]. Idris, M. M., Sadiq, R.T., Musa, M., Kana, M.A., Isah, S. H., Bello, A. & Umar, S. A. (2021). Outdoor Background Radiation Level and Radiological Hazards Assessment in Lafia Metropolis, Nasarawa State, Nigeria. *ASEANA Journal of Science and Education*, 1(1), 27 – 35.
- [14]. Xinwei, L. (2004). Natural radioactivity in some building materials and by-products of Shaanxi, China. *Journal of Radioanalytical and Nuclear Chemistry*, 262(3), 777.
- [15]. Karou, S. D., Nadembega, W. M., Ilboudo, D. P., Ouermi, D., Gbeassor, M., De Souza, C. & Simpore, J. (2007). *Sida acuta* Burm. f.: a medicinal plant with numerous potencies. *African Journal of Biotechnology*, 6(25)
- [16]. Patra, A. K., Jaison, T. J., Baburajan, A. & Hegde, A. G. (2008). Assessment of radiological significance of naturally occurring radionuclides in soil and rock matrices around the Kakrapa environment. *Radiation Protection Dosimetry*, 131(1), 487-494.
- [17]. Jibiri, N. N. & Amakom, C. M. (2011). Radiological Assessment of Radionuclide Contents in Soil Waste Streams from an Oil Production Well of a Petroleum Development Company in Warri, Niger Delta, Nigeria. *Indoor and Built Environment*, 20(2), 246–252
- [18]. Samuel, O.O., Pascal, T.F., Cornelus, A. & Muiyiwa, M.O. (2018). Assessment of Radioactivity Levels and Transfer Factor of Natural Radionuclides Around Iron and Steel Smelting Company Located In Fashina Village, Ile-Ife, Osun State, Nigeria. *Working and Living Environmental Protection*, 15(3), 241 – 256
- [19]. Osimobi, J. C., Avwiri, G. O. & Agbalagba, E. O. (2018). Radiometric and Radiogenic Heat Evaluation of Natural Radioactivity in Soil Around Solid Minerals Mining Environment in South-Eastern Nigeria. *Environmental Processes*, 5(4), 859-877.
- [20]. Yehuwdah, E., Umoren, C. & Umoh, I. J. (2014). Baseline radionuclide distribution patterns in soil and radiation hazard indices for Abak, Nigeria. *Advances in Physics Theories and Applications*, 32(1), www.iiste.org, ISSN 2224-719X (Paper) ISSN 2225-0638 (Online).
- [21]. El-Taher, A., Abojassim, AA., Najam, LA., Mraity, HAAB. (2020) Assessment of annual effective dose for different age groups based on radon concentrations in the groundwater of Qassim, Saudi Arabia. *Iranian Journal of Medical Physics* 17 (1), 15-20.
- [22]. UNSCEAR (1993). *Sources and Effects of Ionizing Radiation*. United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations, New York.
- [23]. El-Taher, A., Badawy, WM., Khater, AEM., Madkour, HA., (2019) Distribution patterns of natural radionuclides and rare earth elements in marine sediments from the Red Sea, Egypt. *Applied Radiation and Isotopes* 151, 171-181.
- [24]. Elsaman, R., Omer, MAA., Seleem, EMM El-Taher, A., (2018) Natural radioactivity levels and radiological hazards in soil samples around Abu Karkas Sugar Factory. *Journal of environmental science and technology*, 11, 1, 28-38.
- [25]. Madkour, H., Mansour, AM., Ahmed, AEHN., El-Taher, A., (2014) Environmental texture and geochemistry of the sediments of a subtropical mangrove ecosystem and surrounding areas, Red Sea Coast, Egypt. *Arabian Journal of Geosciences* 7 (9), 3427-3440.

- [26]. Abdel Gawad, AE., Ghoneim, MM., El-Taher, A., an, AA., (2021) Mineral chemistry aspects of U-, Th-, REE-, Cu-bearing minerals at El-Regeita shear zone, South Central Sinai, Egypt. *Arabian Journal of Geosciences* 14 (14), 1356.
- [27]. Abojassim, AA., Mohammed, HAU., Najam, LA., El-A., (2019) Uranium isotopes concentrations in surface water samples for Al-Manathera and Al-Heerra regions of An-Najaf, Iraq *Environmental earth sciences* 78 (5), 132.