Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/100306

Assessment of background ionizing Radiation from some selected mining sites in Anka, Bagega, and Abare in Anka local government of Zamfara State, Nigeria

Musa Mohammed[1,2*] *Idris M. Mustapha*[2],*Aliyu Zaharadeen*[2], *Ibrahim Kefas Gyurison*[2] , *Ogbu Pius*[2]

[1]Department of Physics, Modibbo Adama University, Yola, PMB 2076, Yola, Adamawa State, Nigeria.
[2]Department of Physics, Nasarawa State University, Keffi, Nigeria.

Received: 22 April. 2025, Revised: 15 June 2025, Accepted: 2 July 2025.

Published online: 1 Sep 2025.

Abstract: This study examines the levels of background ionizing radiation and associated radiological health risks in selected mining communities, Anka, Bagega, and Abare in Anka Local Government Area of Zamfara State, Nigeria. An inspector's Alert nuclear radiation meter was used to conduct radiation measurements, with readings taken at 15 mining spots and corresponding control points located 100 meters away. Radiological hazard indices such as absorbed dose rate (ADR), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR) were determined to evaluate potential health impacts. Results show that mean absorbed dose rates at mining sites were 3984.6 nGy/h (Anka), 2575.2 nGy/h (Bagega), and 4628.4 nGy/h (Abare), notably exceeding the global outdoor average of 59 nGy/h and the safety threshold of 84 nGy/h recommended by UNSCEAR. The corresponding AEDE values in mining areas were 4.886 mSv/yr, 3.158 mSv/yr, and 5.676 mSv/yr, exceeding the public exposure limit of 1.0 mSv/yr set by the ICRP. The calculated ELCR values in all locations also surpass the global average of 0.29×10^{-3}, with mean values of 17.103 (Anka), 11.053 (Bagega), and 19.866 (Abare), indicating substantial lifetime cancer risks. These elevated radiological indices point to significant environmental contamination, with possible long-term health implications for both miners and residents. While no immediate radiological symptoms may be visible, the findings highlight the urgent need for regulatory intervention, public health monitoring, and sustainable mining practices to mitigate future health crises in the region.

Keywords: Radiological health risk, Absorbed dose rate (ADR), Annual effective dose equivalent (AEDE).

1 Introduction

Artisanal and small-scale mining (ASM) has emerged as a significant source of livelihood in sub-Saharan Africa, including Nigeria, particularly due to its low entry cost and high returns. However, these operations often occur without formal regulatory oversight and are carried out with limited regard for radiological, environmental, or safety standards [1-3]. In areas where naturally occurring radioactive materials (NORMs) or uranium-rich minerals are present, such unregulated mining practices can elevate background levels of ionizing radiation in the surrounding environment, posing long-term health risks to miners and local populations. In Nigeria's northwestern region, Zamfara State has gained international attention due to the scale and intensity of gold mining activities. Towns like Anka, Bagega, and Abare have witnessed both artisanal and commercial gold extraction processes that have resulted in significant environmental contamination, especially with heavy metals and particulate matter [4-6]. Although previous studies have explored heavy metal exposure and dust inhalation risks, there remains a lack of comprehensive, up-to-date data on the radiological impacts of these mining operations, particularly about external gamma radiation exposure. Ionizing radiation exposure, especially at elevated levels, has both deterministic and stochastic health effects, including potential carcinogenesis and long-term genetic damage [7-9]. On a Global scale, the average background ionizing radiation is estimated at approximately 59 nGy/h, but this value can vary considerably depending on local geology and anthropogenic activities [10-12]. Studies conducted in other Nigerian mining regions have reported background dose rates far above this global average, suggesting significant radiation exposure in those areas [13-14]. The International Commission on Radiological Protection (ICRP)

*Corresponding author e-mail: musamohammed@mau.edu, ng

recommends an annual public dose limit of 1.0 mSv/year for external exposure from non-medical sources (ICRP, 2021) [7]. However, several recent assessments have shown that many Nigerian mining communities exceed this threshold. For example, a study in Jos, Plateau State, revealed mean absorbed dose rates exceeding 3000 nGy/h, which was largely attributed to granitic bedrock and prolonged mining operations [15-18]. Similarly, annual effective doses recorded in southeastern and central Nigerian mining areas have been found to surpass the global average of 2.4 mSv/year, indicating heightened exposure risks [19-22].

This current study seeks to assess the levels of background ionizing radiation in selected mining locations within the Anka Local Government Area of Zamfara State, namely Anka, Bagega, and Abare. By employing field measurements and radiological hazard indices such as absorbed dose rate (ADR), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR), this work seeks to evaluate potential health risks and compare observed values against both international benchmarks and findings from similar mining environments.

2 Materials and Methods

2.1 Study Area

The study centers on communities located in Anka, a local government area in Zamfara State, North-western Nigeria, where the study areas are located (see Fig. 1). Anka is one of the fourteen Local Government Areas of the State. It lies within latitudes 11° 40′ 0″ and 12° 20′ 0″ North and longitudes 5° 50′ 0″ and 6° 20′ 0″ East, and it is about 80 km from Gusau, the State capital. Anka town is the headquarters of the Anka Local Government Area (LGA). The study area is: Anka, Bagega, and Abare in Anka L.G.A of Zamfara State. The areas are chosen because of the nature of the mining sites and the local nature of the mining activities, to ascertain the level of mining hazards (health hazards) or the harmful effects of background ionizing radiation on the miners and people living in the area.

2.2 Population of Samples

Background ionizing radiation measurements were conducted at selected artisanal mining sites located in Anka, Bagega, and Abare communities in the Anka Local Government Area of Zamfara State, Nigeria. The study population comprises all active and abandoned artisanal gold mining sites within these three communities, as well as adjacent residential areas situated within a 100-meter radius from each mining location. A total of 45 sampling sites were systematically selected across the study areas, 15 sites each from Anka, Bagega, and Abare to ensure spatial representation. At each location, measurements of ambient gamma radiation were recorded both at the mining spot and 100 meters away using a handheld Inspector Alert Nuclear Radiation Meter. From these sampling locations, radiological health indices were calculated, including absorbed dose rate (ADR), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR). These indicators were used to assess the potential radiological hazards associated with prolonged exposure to natural background radiation in the mining environment.

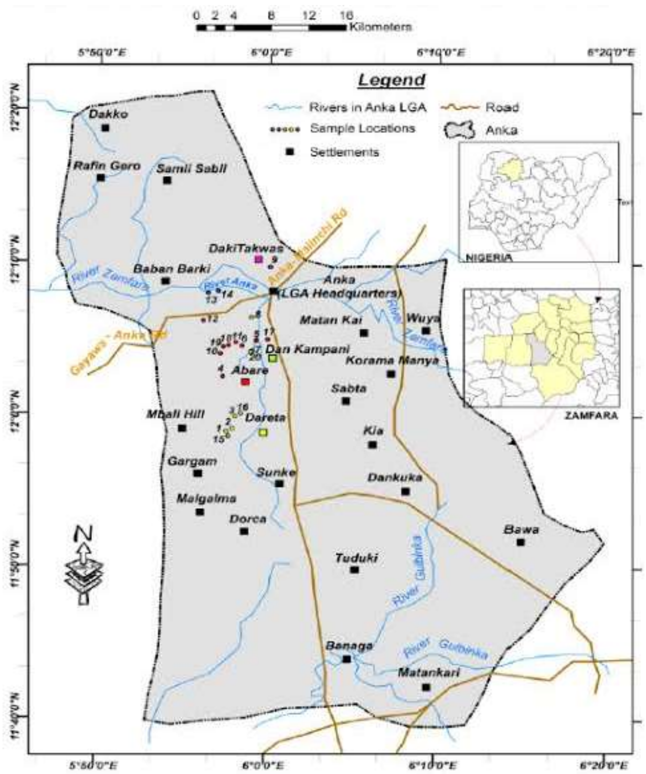

Fig.1: Map of the Anka Local Government Area of Zamfara State.

In total, 90 radiation readings (45 mining spots and 45 adjacent residential locations) were analyzed. The data formed the basis for evaluating environmental safety conditions and estimating long-term health risks to both occupational and non-occupational populations living within proximity to these mining zones

2.3 Method of Data Collection

Measurement of background ionizing radiation was done using an Inspector Alert nuclear radiation meter manufactured by S.E. International, Inc., USA, with serial number 35440. The meter has a halogen quenched Geiger-Muller Tube + 45 mm effective diameter and mica window density of 1.5 2.0 mg/cm3. The Geiger tube generates a pulse of electrical current each time radiation is incident on the tube and causes ionization. Each pulse is electronically detected and registered as a count in the choice mode of the operator. The meter was held one meter above the ground surface to reflect the abdominal level of readings, in counts per minute, were taken at each point of the fifteen mining sites, mean accurate reading was calculated from the fifteen readings conducted in each. The analytical procedure was conducted for a week, in Anka, Bagega, and Abare mining sites, by analyzing fifteen different readings from the mining sites for a week. In count per minute (CPM) mean average reading in count per minute (CPM) is taken in each of the fifteen mining sites. Also, readings in counts per minute are taken from the mining spot and 100m away from the mining spot.

2.4 Method of Statistical Analysis

The measured results (raw data) obtained from the study area (Anka, Bagega, and Abare) in Anka L.G.A of Zamfara State, Nigeria were analysed using the Microsoft Excel computer program. The radiological hazard parameters (Absorbed dose rate, Annual Effective Dose Equivalent, and Excess lifetime cancer risk) were also computed. The locations of each of the sample points were determined using a geographical positioning system (GPS). The exposure rate obtained was quantitatively used to assess the radiation health impact on the public in the study area and radiation effective doses to different organs of the body by performing several radiological health hazard indices calculations using well-established mathematical relations.

$$Count\ rate\ per\ minute\ (CPM) = 10^{-3}\ Roentgen\ x\ F \quad (1)$$

where F is the quality factor, which is equal to 1 for external environments (ICRP, 2007) [23].

2.5 Calculation of Radiological Hazards Indices

2.5.1 Absorbed dose rate (ADR) in air

The absorbed dose is used to assess the potential for any biochemical changes in specific tissues. It quantifies the radiation energy that might be absorbed by a potentially exposed individual. The measured outdoor background exposure levels were converted to radiation absorbed dose rate in air using Equation 3 according to [24-27].

$$ADR = 1\ \mu Rh^{-1} = 8.7\ \eta Gyh^{-1} = \frac{8.7x10^{-3}}{(1/8760y)}\ nGyy^{-1} \quad (2)$$

This implies that:

$$1mRh^{-1} = 8.7\ \eta Gyh^{-1}\ x\ 10^{3} = 8700\ nGyh^{-1} \quad (3)$$

2.5.2 Annual effective dose equivalent (AEDE)

The AEDE is used in radiation assessment and protection to quantify the whole body absorbed dose per year. It is used to assess the potential for long-term effects that might occur in the future. The annual effective dose equivalent (AEDE) per year received by workers and the population is obtained from equation 3 [28].

$$AEDE(mSv.y^{-1})_{outdoor} = D(nGy.h^{-1})x\ 8760h\ x\ CF\ x\ OFx10^{-3} \quad (4)$$

where D is the absorbed dose rate in nGyh-1, 8760h is the total hours in a year, CF is the dose conversion factor from absorbed dose in air to the effective dose in Sv/Gy (CF = 0.7 Sv/Gy), OF is the occupancy factor, the expected period the members of the population would spend within the study area. OF = 0.2 for outdoor, as it is expected that human beings would spend 20 % of their time outdoors, as recommended by [23].

2.5.3 Excess lifetime cancer risk (ELCR)

The ELCR was evaluated using the AEDE values as shown in Equation 6 according to [24-27].

$$ELCR = AEDE\ (mSvy^{-1})\ x\ DL\ x\ RF \quad (5)$$

where DL is the 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, ICRP 103 uses a fatal cancer risk factor value of 0.05 for public exposure [23, 29].

3 Results and Discussion

The sampling location code, Latitude, and Longitude of the Background radiation level in active mining spots and a spot at a distance of 100 m away in Anka, Bagega, and Abare, in Anka local government, Zamfara State, are presented in Tables 1 to 3

Radiological parameters such as calculated annual absorbed dose rate (ADR), the annual effective dose rate (AEDR), and estimated excess cancer lifetime risk (ECLR) are calculated using Equations 1 to 6 and are presented in Tables 2, 3, and 4.

The assessment of background ionizing radiation at selected mining sites in Anka, Bagega, and Abare within the Anka Local Government Area of Zamfara State was conducted using a handheld radiation monitoring device (Inspector Alert Nuclear Radiation Meter). Radiological health hazard indices, including absorbed dose rate (ADR), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR), were employed to evaluate potential health risks to residents in the study area.

In Anka, ADR values at the mining sites ranged from 957 to 7,743 nGy/h, while those recorded 100 m away ranged from 348 to 1,827 nGy/h, with corresponding mean values of 3,984.6 nGy/h and 4,698 nGy/h. In Bagega, ADR values ranged from 1,218 to 5,916 nGy/h at the mining sites and 609 to 5,220 nGy/h at 100 m distance, with mean values of 2,575.2 nGy/h and 1,782.92 nGy/h**,** respectively. In Abare, ADR values ranged from 1,218 to 8,613 nGy/h at mining sites and 365.4 to 3,567 nGy/h at 100 m away, with mean values of 4,628.4 nGy/h and 1,670.98 nGy/h, respectively. Notably, the highest mean ADR was recorded in Abare.

These mean dose rates far exceed the global population-weighted average of 59.0 nGy/h [24, 30]; Monica et al., 2016) and the UNSCEAR-recommended outdoor exposure limit of 84.0 nGy/h [31-32]. Such elevated radiation levels indicate environmental contamination and potential long-term radiological health risks, despite the absence of immediate observable effects. Compared to previous studies, these values are significantly higher than the 126.15 ± 5.10 nGy/h reported by [33] in Enugu State, although still lower than the 132.16 ± 24.36 nGy/h reported in Ughelli, Delta State.

The AEDE values also followed a similar trend. In Anka, AEDE at the mining sites ranged from 1.813 to 9.496 mSv/yr, and from 0.426 to 3.200 mSv/yr at 100 m distance, with mean values of 4.886 mSv/yr and 0.576 mSv/yr, respectively. In Bagega, values ranged from 1.493 to7.255mSv/yr and 0.746 to 6.402 mSv/yr, with mean values of 3.158 mSv/yr and 2.186 mSv/yr, respectively. For Abare, AEDE values ranged from 1.493 to 10.562 mSv/yr and 0.448 to 4.374 mSv/yr, with means of 5.67 mSv/yr and 2.049 mSv/yr, respectively.

These results exceed the 1.0 mSv/yr public dose limit recommended by the International Commission on Radiological Protection [23] and the global average background radiation of 2.4 mSv/yr [34], further confirming the heightened exposure risks in the study areas.

The ELCR values recorded are of significant concern. In Anka, ELCR ranged from 6.348 $\times10^{-3}$ to 33.236 $\times10^{-3}$ at the mining sites and 1.493 $\times10^{-3}$ to 2.016 $\times10^{-3}$ at 100 m away, with respective mean values of 17.103 $\times10^{-3}$ and 2.016 $\times10^{-3}$**.** In Bagega, ELCR ranged from 5.228 $\times10^{-3}$ to 25.393 $\times10^{-3}$ and 2.614 $\times10^{-3}$ to 22.406 $\times10^{-3}$**,** with mean values of 11.053 $\times10^{-3}$ and 7.653 $\times10^{-3}$**.** In Abare, ELCR ranged from 5.228 $\times10^{-3}$ to 36.970 $\times10^{-3}$ and 1.568 $\times10^{-3}$ to 15.310 $\times10^{-3}$**,** with mean values of 19.866 $\times10^{-3}$ and 7.172 $\times10^{-3}$**,** respectively.

These values are significantly higher than the global average of 0.29 $\times10^{-3}$ for lifetime cancer risk. This suggests a substantially increased likelihood of cancer development among residents exposed over a lifetime. The values recorded here surpass those reported in environments such as the Uburu Salt Lake [34-35] and industrial areas of Warri [24], but are somewhat lower than those from the Okposi Okwu Salt Lake.

Table1: Background radiation level in active mining spots and a spot at a distance of 100 m away in Anka, Zamfara State.

S/n	**Sampling Location Code**	**Latitude**	**Longitude**	**E (mR.h-1)**	
				Minning Spot	100m away
1	A1	80 28’21.112’’ N	8033’11.728’’E	0.29	0.054
2	A2	8028’21.113’’N	8033’11.729’’E	0.17	0.097
3	A3	80 28’ 21.115’’N	8033’11.725’’E	0.31	0.13
4	A4	8028’21.117’’N	8033’11.726’’E	0.24	0.094

5	A5	8028’21.119’’N	8033’11.721’’E	0.38	0.068
6	A6	8029’121’’N	8031’301’’E	0.56	0.15
7	A7	8029’123’’N	8031’302’’E	0.45	0.065
8	A8	8029’125’’N	8031’305’’E	0.89	0.09
9	A9	8029’129’’N	8031’309’’E	0.76	0.17
10	A10	8029’127’’N	8031’307’’E	0.45	0.21
11	A11	8031’470’’N	8031’332’’E	0.56	0.051
12	A12	8031’471’’N	8031’333’’E	0.8	0.12
13	A13	8031’473’’N	8031’335’’E	0.34	0.19
14	A14	8031’475’’N	8031’337’’E	0.11	0.3
15	A15	8031’478’’N	8031’339’’E	0.56	0.04
	Mean			0.458	0.054

Table 2: Background radiation level in an active mining spot and a spot at a distance of 100 m away in Bagega, Zamfara State.

S/n	**Sampling Location Code**	**Latitude**	**Longitude**	**E (mR.h-1)**	
				Mining Spot	100m Away
1	B1	70 28’21.112’’ N	7033’11.728’’E	0.24	0.21
2	B2	7028’21.113’’N	7033’11.729’’E	0.37	0.07
3	B3	70 28’ 21.115’’N	7033’11.725’’E	0.30	0.12
4	B4	7028’21.117’’N	7033’11.726’’E	0.24	0.023
5	B5	7028’21.119’’N	7033’11.721’’E	0.68	0.12
6	B6	7029’121’’N	7031’201’’E	0.15	0.20

7	B7	7029’123’’N	7031’202’’E	0.65	0.11
8	B8	7029’125’’N	7031’205’’E	0.09	0.29
9	B9	7029’129’’N	7031’209’’E	0.17	0.10
10	B10	7029’127’’N	7031’207’’E	0.21	0.30
11	B11	7031’470’’N	7031’232’’E	0.51	0.081
12	B12	7031’471’’N	7031’233’’E	0.17	0.42
13	B13	7031’473’’N	7031’235’’E	0.19	0.60
14	B14	7031’475’’N	7031’237’’E	0.33	0.30
15	B15	7031’478’’N	7031’239’’E	0.14	0.13
	Mean			0.296	0.204

Table 3: Background radiation level in an active mining spot and a spot at a distance of 100 m away in Abare, Zamfara State.

S/n	**Sampling Location Code**	**Latitude**	**Longitude**	**E (mR.h^{-1})**	
				Mining Spot	100 m Away
1	G1	60 28’21.112’’ N	6033’11.728’’E	0.99	0.14
2	G2	6028’21.113’’N	6033’11.729’’E	0.57	0.047
3	G3	60 28’ 21.115’’N	6033’11.725’’E	0.35	0.2
4	G4	6028’21.117’’N	6033’11.726’’E	0.14	0.042
5	G5	6028’21.119’’N	6033’11.721’’E	0.48	0.18
6	G6	6029’121’’N	6031’101’’E	0.5	0.2
7	G7	6029’123’’N	6031’102’’E	0.95	0.051
8	G8	6029’125’’N	6031’105’’E	0.69	0.29

9	G9	6029'129''N	6031'109''E	0.7	0.21
10	G10	6029'127''N	6031'107''E	0.21	0.41
11	G11	6031'470''N	6031'132''E	0.36	0.051
12	G12	6031'471''N	6031'133''E	0.57	0.32
13	G13	6031'473''N	6031'135''E	0.39	0.4
14	G14	6031'475''N	6031'137''E	0.31	0.2
15	G15	6031'478''N	6031'139''E	0.77	0.14
	Mean			0.532	0.192066667

Table 4: Calculated values of Absorb Dose Rate, Annual Effective Dose Equivalent, and Excess Life Time Cancer Risk in both the mining spots and the corresponding spots at a distance of 100m away from the mining spot in Anka, Zamfara State.

S/n	**Sampling Location Code**	**Minning Spot**			**100m Away**		
		ADR (nGy.h-1)	AEDE (mSv.y-1)	ELCR	ADR (nGy.h-1)	AEDE (mSv.y-1)	ELCR
1	A1	2523	3.094	10.829	469.8	0.576	2.016
2	A2	1479	1.813	6.348	843.9	1.034	3.622
3	A3	2697	3.307	11.576	1131	1.387	4.854
4	A4	2088	2.560	8.962	817.8	1.002	3.510
5	A5	3306	4.054	14.190	591.6	0.725	2.539
6	A6	4872	5.975	20.912	1305	1.600	5.601
7	A7	3915	4.801	16.804	565.5	0.693	2.427
8	A8	7743	9.496	33.236	783	0.960	3.360
9	A9	6612	8.108	28.381	1479	1.813	6.348
10	A10	3915	4.801	16.804	1827	2.240	7.842
11	A11	4872	5.975	20.912	443.7	0.544	1.904

12	A12	6960	8.535	29.875	1044	1.280	4.481
13	A13	2958	3.627	12.696	1653	2.027	7.095
14	A14	957	1.173	4.107	2610	3.200	11.203
15	A15	4872	5.975	20.912	348	0.426	1.493
	Mean	3984.6	4.886	17.103	469.8	0.576	2.016

Table 6: Calculated values of Absorb Dose Rate, Annual Effective Dose Equivalent, and Excess Life Time Cancer Risk in both the mining spots and the corresponding spots at a distance of 100m away from the mining spot in Abare, Zamfara State.

S/n	**Sampling Location Code**	**Mining Spot**			**100m Away**		
		ADR ($nGy.h^{-1}$)	AEDE ($mSv.y^{-1}$)	ELCR	ADR ($nGy.h^{-1}$)	AEDE ($mSv.y^{-1}$)	ELCR
1	G1	8613	10.562	36.970	1218	1.493	5.228
2	G2	4959	6.081	21.286	408.9	0.501	1.755
3	G3	3045	3.734	13.070	1740	2.133	7.468
4	G4	1218	1.493	5.228	365.4	0.448	1.568
5	G5	4176	5.121	17.925	1566	1.920	6.721
6	G6	4350	5.334	18.672	1740	2.133	7.468
7	G7	8265	10.136	35.476	443.7	0.544	1.904
8	G8	6003	7.362	25.767	2523	3.094	10.829
9	G9	6090	7.468	26.140	1827	2.240	7.842
10	G10	1827	2.240	7.842	3567	4.374	15.310
11	G11	3132	3.841	13.443	443.7	0.544	1.904
12	G12	4959	6.081	21.286	2784	3.414	11.951
13	G13	3393	4.161	14.564	3480	4.267	14.937

14	G14	2697	3.307	11.576	1740	2.133	7.468
15	G15	6699	8.215	28.754	1218	1.493	5.228
	Mean	4628.4	5.676	19.866	1670.98	2.049	7.172

4 Conclusions

This study has demonstrated elevated levels of background ionizing radiation in 45 mining sites across the Anka Local Government Area of Zamfara State, Nigeria. The results show significantly high values of absorbed dose rate, annual effective dose equivalent, and excess lifetime cancer risk both at the mining spots and within 100 meters from the sites. These radiation levels exceed the permissible dose limits set by the Nigerian Nuclear Regulatory Authority (2.0 mSv/yr) and the ICRP (1.0 mSv/yr) for the general public. The elevated radiological parameters suggest environmental contamination and an increased potential for adverse health effects over prolonged exposure, especially for residents and miners in the area. Although no immediate health impact is evident, the cumulative exposure over time poses serious health threats, including a heightened risk of cancer development. Consequently, urgent regulatory attention, public health monitoring, and remediation measures are recommended. There is a critical need to enforce radiation safety protocols, establish exclusion zones around high-dose areas, and sensitize local communities about radiation risks associated with artisanal mining activities.

References

[1] Ali, M. A., Yusuf, B. A., & Musa, I. A. (2023). Risk analysis of background radiation exposure from gold mining sites in northwestern Nigeria. *Journal of Environmental Radioactivity, 263*, 106135. https://doi.org/10.1016/j.jenvrad.2022.106135

[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] Adekeye, J. D., Ibrahim, A. G., & Oladeji, O. I. (2022). Assessment of heavy metals and associated health risks in artisanal gold mining areas of Zamfara, Nigeria. Environmental Science and Pollution Research, 29(7), 10568–10580. https://doi.org/10.1007/s11356-021-15687-0

[5] 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.

[6] 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

[7] International Commission on Radiological Protection (ICRP). (2021). Radiological protection against radon exposure (ICRP Publication 126). Elsevier.

[8] 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.

[9] 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.

[10] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2020). Sources, effects, and risks of ionizing radiation: UNSCEAR 2020 report. United Nations.

[11] 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.

[12] El-Taher, A., Abdelhalim, M.K. (2013) Elemental analysis of phosphate fertilizer consumed in Saudi Arabia. Life Science Journal 10 (4), 701-708.

[13] Ononugbo, C. P., & Mgbemere, H. E. (2022). Outdoor background ionizing radiation levels in Delta State, Nigeria. Radiation Protection and Environment, 45(1), 33–40. https://doi.org/10.1097/RPE.0000000000000431

[14] Agbalagba, E. O., Avwiri, G. O., & Ononugbo, C. P. (2022). Estimation of radiological health risk due to natural background radiation in mining areas of Nigeria. Radiation Protection Dosimetry, 198(1), 1–9. https://doi.org/10.1093/rpd/ncac002

[15] Okonkwo, O. C., Agada, A. I., & Jibiri, N. N. (2023). Natural radionuclide concentrations and radiation dose assessment in granitic mining areas of Jos, Nigeria. Heliyon, 9(3), e14168. https://doi.org/10.1016/j.heliyon.2023.e14168

[16] 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.

[17] El-Taher, A., Badawy, W.M., 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.

[18] Elsaman, R., Omer, MAA., Seleem, EMM El-Taher, A., (2018) Natural radioactivity levels and radiological hazards in soil samples around Abu Karqas Sugar Factory. Journal of environmental science and technology, 11, 1, 28-38.

[19] Eze, C. U., Nwankwo, A. A., & Akinsola, E. O. (2022). Assessment of natural radioactivity and health hazard indices in mining communities in Nigeria. Scientific African, 17, e01247. https://doi.org/10.1016/j.sciaf.2022.e01247

[20] 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.

[21] Abdel Gawad, AE., Ghoneim, MM., El-Taher, A., Ramadan, 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.

[22] Abojassim, AA., Mohammed, HAU., Najam, LA., El-Taher, 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.

[23] ICRP (2007). The 2007 Protection: Annals of the International Commission on Radiological ICRP Publication 103. Ann. ICRP 37 (2-4), Elsevier Ltd

[24] Agbalagba, E.O., Avwiri, G.O. & Ononugbo, C.P. (2016). GIS mapping of the impact of industrial activities on the terrestrial background ionizing radiation levels of Ughelli metropolis and its Environs, Nigeria. Journal of Environmental Earth Science 75(1), 1425. DOI 10.1007/s12665-016-6216-y.

[25] Rafique, M., Saeed, U. R., Muhammad, B., Wajid, A., Iftikhar, A., Khursheed, A. L. & Khalil, A. M. (2014). Evaluation of excess lifetime cancer risk from gamma dose rates in Jhelum valley. Journal of Radiation Research and Applied Sciences, 7(1), 29 - 35.

[26] Idris, Mohammed Mustapha, Rahmat, Sadiq Tukur, Musa, Mohammed, Muhammed, Abdullahi Kana, Isah, Suleiman Hamza, Aisha, Bello, and Umar, Sa'ad Aliyu (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. https://www.arsvot.org/index.php/aseana/article/view/29

[27] Mohammed, M., Musa, A., Odoh, E. O., Yerima, J. B. (2024). Assessment of occupational dose level from conventional X-ray on personnel in Federal Medical Centre, Jalingo, Taraba State, Nigeria. Dutse Journal of Pure and Applied Sciences, 10(2c), 220–229. https://dx.doi.org/10.4314/dujopas.v10i2c.21

[28] Gupta, M. & Chauhan, R. P. (2011). Estimating radiation dose from building materials. Iran Journal of Radiation Research, 9(3), 187 – 194

[29] Idris M.M., Isah S.H., and Wada H.M. (2021). Indoor and Outdoor Background Radiation Levels and Radiological Hazard Assessment of Some Modern Houses in Keffi Metropolis, Nasarawa State, Nigeria. Dutse Journal of Pure and Applied Sciences (DUJOPAS), 7(2a), 146- 154. https://fud.edu.ng/journals.php

[30] Monica, S. Visnu P.A.K., Soniya, S.R. & Jojo, P. J. (2016). Estimation of indoor and outdoor effective doses and lifetime cancer risk from gamma dose rates along the coastal regions of Kollam district, Kerala. Journal of Radiation Protection and Environment, 39(1), 38-43.

[31] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). (2008). Sources, effects, and risks of ionizing radiation: UNSCEAR 2008 report. United Nations.

[32] Ononugbo, C. P. & Mgbemere, C. J. (2016). Dose rate and annual effective dose assessment of terrestrial gamma radiation in Notre fertilizer plant, Onne, Rivers State. Nigeria. International Journal of Emerging Research in Management and Technology, 5(9), 30-35.

[33] Essien, I. E. & Essiet, A. A. (2016).Investigation of radiological Hazards Indices within Uyo Metropolis Central Dumpsites, Akwa Ibom State. Nigeria. International Journal of Scientific Research Publications, 6(5), 687-691.

[34] Avwiri, G.O., Nwaka, B. U. & Ononugbo, C. P. (2016). Radiological health risk due to gamma dose rates around Okposi Okwu and Uburu salt lakes, Ebonyi

State. International Journal of Emerging Research in Management and Technology 5(9), 36 - 46.

[35] M.M. Idris, A. Ubaidullah, M.B. Sulayman, B. Abdullahi, and M.A. Sidi (2021). Assessment of Gamma Background Exposure Levels in some Selected Residential Houses in FCT Abuja, Nigeria. Journal of Radiation and Nuclear Applications, 6(3), 251- 254. http://dx.doi.org/10.18576/jrna/060311.

[36] Idris M.M., Isah S.H., and Wada H.M. (2021). Indoor and Outdoor Background Radiation Levels and Radiological Hazard Assessment of Some Modern Houses in Keffi Metropolis, Nasarawa State, Nigeria. Dutse Journal of Pure and Applied Sciences (DUJOPAS), 7(2a), 146- 154. https://fud.edu.ng/journals.php