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Assessment of Ambient Gamma Dose Rates and Estimated External Radiological Risks at an Artisanal Gold-Mining Site in Shakwatu, Niger State, Nigeria

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ABSTRACT

Artisanal gold mining may alter ambient environmental radiation through the redistribution of naturally occurring radioactive materials. This study assessed ambient terrestrial gamma radiation and associated radiological dose parameters in the Shakwatu artisanal gold-mining area, Minna, Niger State, Nigeria. In-situ measurements were conducted at 30 locations covering soil, tailings and mineralised areas over a period of 20 days in July 2025 using a GMC-500 Plus Geiger–Mueller survey meter, which was checked at the Physics Laboratory before the survey. Measurements were taken approximately 1 m above ground level, with two readings averaged at each location. Annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) were estimated using an occupancy factor of 0.375, a lifetime of 70 years and a risk coefficient of 0.05 Sv^{-1}. Ambient dose equivalent rates (ADR) ranged from 0.124 to 0.181 µSv h^{-1}, with an overall mean of 0.151 ± 0.017 µSv h^{-1}. The corresponding AEDE ranged from 0.407 to 0.595 mSv y^{-1}, with an overall mean of 0.495 ± 0.056 mSv y^{-1}, while ELCR ranged from 1.426×10^{-3} to 2.081×10^{-3}, with an overall mean of $(1.732 \pm 0.195) \times 10^{-3}$. Mean AEDE values for soil, tailings and mineralised areas were 0.451 ± 0.031, 0.550 ± 0.029 and 0.455 ± 0.025 mSv y^{-1}, respectively. Tailings recorded the highest mean ADR, AEDE and ELCR. The ELCR values represent theoretical lifetime risk estimates under the assumed exposure conditions, not observed cancer incidence. The findings provide baseline data for environmental radiation assessment and highlight the need for further monitoring using calibrated instruments, radionuclide-specific measurements and occupational exposure assessment.

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INTRODUCTION

Background ionizing radiation is a natural component of the environment, and human exposure occurs continuously throughout life. It originates mainly from cosmic radiation and naturally occurring radioactive materials (NORM) in the earth's crust, particularly radionuclides in the ^{238}U and ^{232}Th decay series and ^{40}K (UNSCEAR, 2008). These radionuclides occur in varying concentrations in rocks, soils and other environmental materials, resulting in differences in terrestrial gamma radiation across geological and geographical settings (Jha *et al.*, 2024).

Although natural background radiation is generally present at relatively low levels, human activities such as mining, excavation and mineral processing can modify its distribution. These activities may bring naturally occurring radioactive materials from subsurface deposits to the ground surface and redistribute them through extracted ores, tailings and other mining residues (Glinsky *et al.*, 2021). Consequently, mining environments may exhibit radiation levels that differ from those of undisturbed areas, making them important locations for environmental radiation assessment and monitoring (Shi *et al.*, 2019).

Exposure to ionizing radiation can produce biological effects through the deposition of energy in living tissues. At sufficiently high doses, this may result in tissue reactions, while exposure over prolonged periods may increase the probability of stochastic effects, including cancer (Mettler, 2012). The potential health implications depend on factors such as radiation type, energy, ambient dose and exposure duration. Therefore, measurements of ambient gamma radiation are useful for assessing external radiation exposure and identifying areas that may require further radiological investigation (Senthilkumar *et al.*, 2010).

Several studies have investigated environmental gamma radiation in Nigeria, reporting variations across different locations and environmental settings. Onumejor *et al.* (2019), for example, reported terrestrial background dose rates of 35.4–62.34 nGy h^{-1} in selected schools in Ota, Ogun State. Similarly, Agbalagba and Anekwe (2021) reported variations in background radiation levels across Asaba and Agbor, while Ugbede *et al.* (2022) recorded dose rates ranging from 77.21 to 180.53 nGy h^{-1} at outdoor locations in Enugu. Although these studies provide useful information on environmental radiation levels in Nigeria, their findings reflect different geological settings and exposure environments. In particular, measurements from schools and general outdoor locations may not adequately represent conditions within active mining sites, where excavation and the accumulation of mineral residues can influence the spatial distribution of terrestrial radionuclides.

Mining environments therefore require location-specific investigations. Mining-related disturbance can expose and redistribute naturally occurring radioactive materials, potentially modifying ambient radiation levels around extraction and tailings areas (Adewumi *et al.*, 2026). Previous environmental investigations have highlighted the importance of establishing baseline radiation levels in areas affected by mineral exploitation, particularly to support

subsequent monitoring (Bollhöfer *et al.*, 2014). However, the available information on environmental gamma radiation in Nigeria does not adequately establish the radiological conditions of every active artisanal mining location.

Artisanal and small-scale gold mining is practised in several parts of Nigeria, including Niger State. Shakwatu, an active artisanal gold-mining area in Minna, is characterised by mining-related activities involving the disturbance and redistribution of soil and mineralised materials. Despite the relevance of such activities to environmental radiation assessment, site-specific information on ambient gamma radiation across the soil, tailings and mineralised materials at Shakwatu remains limited. This knowledge gap makes it difficult to establish the current radiation conditions across the different material categories and provide baseline information for future environmental monitoring.

The aim of this study was to assess ambient terrestrial gamma radiation at selected soil, tailings and mineralised material locations in the Shakwatu artisanal gold-mining area of Minna, Niger State, Nigeria, and estimate the associated annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR).

MATERIALS AND METHODS

Study Area and Its Geology

This study employed a field-based environmental radiation survey design to assess ambient gamma radiation levels within an active artisanal gold-mining environment. The study was conducted at Shakwatu, a rural community in Bosso Local Government Area of Niger State, North-Central Nigeria. The study area is located approximately at latitude 9.6641° N and longitude 6.6232° E (Fig. 1), along the Minna–Gwada axis and is accessible through the eastern bypass of Minna.

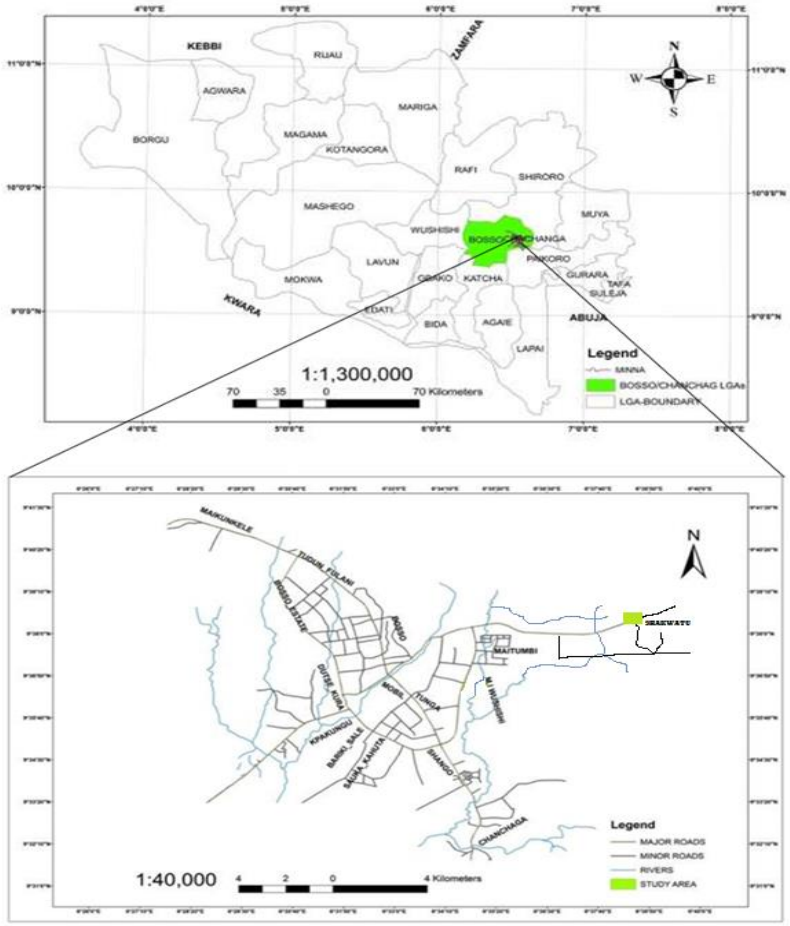


Figure 1: Location of the study area in Minna, Niger State, Nigeria

Shakwatu is characterised by dispersed settlements, agricultural land and active artisanal mining sites. The local climate is typical of the Guinea Savannah zone, with a rainy season generally extending from April to October and a dry season from November to March. The area is underlain by rocks of the Nigerian Basement Complex, including schists, quartzites, granites, granodiorites and associated pegmatitic intrusions. Gold mineralisation in the area is associated mainly with quartz veins within the basement complex terrain (Olomo *et al.*, 2022).

A reconnaissance survey was conducted before the radiation measurements to identify active mining areas and establish suitable measurement locations. Based on the distribution of mining and mineral-processing activities, 30 measurement locations were selected to represent different components of the mining environment. These comprised seven soil locations (S1–S7), thirteen tailings locations (T1–T13) and ten mineralised-material locations (M1–M10). The selected locations covered mining zones, processing areas, accumulated mine waste and relatively undisturbed areas.

***In-situ* Gamma Radiation Measurement**

Ambient gamma radiation measurements were conducted over a period of 20 days in July 2025 using a portable GQ GMC-500 plus Geiger–Müller survey meter (Figure 3). The instrument was checked at the Physics Laboratory before the field survey. Measurements were performed at the 30 selected locations (Fig. 2). At each location, the detector was positioned approximately 1.0 m above the ground surface, with the detector window oriented vertically downward.



Figure 2: Sampling points in Shakwatu mining area

The instrument was allowed to stabilise for approximately one minute before measurements were recorded (Knoll, 2010). Two consecutive readings were obtained at each location, and their arithmetic mean was used as the representative dose-rate value (Umar *et al.*, 2026). The repeatability of the paired measurements was evaluated using the relative percentage difference (RPD), calculated as:

$$\text{RPD}\ (\%) = \frac{|D_1 - D_2|}{\frac{D_1 + D_2}{2}} \times 100 \qquad (1)$$

Where D_1 and D_2 represent the first and second readings, respectively. The RPD ranged from 0.63% to 2.55%, with a mean of 1.53% across the 30 locations.

The geographical coordinates of the measurement locations were determined using a Garmin GPSMAP 78s (Figure 3) handheld Global Positioning System receiver. Measurements were conducted under relatively stable field conditions to minimise possible effects associated with rainfall and excessive surface moisture (Morosh *et al.*, 2021). The dose-rate values were recorded directly from the instrument display in μSv h^{-1}. No separate background measurement was made or subtracted; consequently, the reported values represent the measured ambient dose-rate readings.



Figure 3: GQ GMC-500 Plus



Figure 4: Garmin (GPSmap 78s)

Estimation of Radiological Parameters

The measured ambient gamma dose rates were used to estimate the annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) associated with outdoor exposure at the measurement locations.

Annual Effective Dose Equivalent

The annual effective dose equivalent (AEDE) was estimated as the products of the measured ambient dose equivalent, H (μSv hr^{-1}), the total number of hours in a year (8760 hours), and occupancy factor (F) for outdoor exposure according to (Taskin *et al.*, 2009; UNSCEAR, 2008).

$$AEDE\ (mSv\ y^{-1}) = \frac{H \times 8760 \times F}{1000} \qquad (2)$$

Where F is the outdoor occupancy factor. In this study, F=0.375, representing an average of approximately 9 hours/day exposure for miners based on field observations.

Excess Lifetime Cancer Risk

The excess lifetime cancer risk (ELCR) estimates the probability of developing cancer as a result of prolonged

exposure to ionizing radiation. It was estimated using Equation (2): (Munyaradzi *et al.*, 2018; Taskin *et al.*, 2009)

$$ELCR = AEDE \times DL \times RF \quad (3)$$

where, AEDE is the annual effective Dose Equivalent, DL is the average duration of human life (assumed to be 70 years) and RF is the nominal cancer risk coefficient, expressed in (Sv^{-1}) or fatal cancer risk per sievert. A risk coefficient of 0.05 Sv^{-1} was adopted for the estimation. The calculated ELCR represents a theoretical lifetime risk based on the assumed exposure conditions and does not indicate observed cancer incidence.

The estimated values were subsequently compared with the reference value of 0.29×10^{-3}, as reported by relevant literature, to provide a basis for comparison (Munyaradzi *et al.*, 2018; Taskin *et al.*, 2009).

RESULTS AND DISCUSSION

Radiological Exposure and Risk Assessment in Soil Areas (SA)

As presented in Table 1, the ambient dose equivalent rate (ADR) across the soil locations ranged from 0.127 ± 0.001 to 0.151 ± 0.001 μSv h^{-1}, with a mean of 0.137 ± 0.009 μSv h^{-1}. The corresponding annual effective dose equivalent (AEDE) ranged from 0.417 ± 0.005 to 0.496 ± 0.005 mSv y^{-1}, with a mean of 0.451 ± 0.031 mSv y^{-1}. The mean AEDE was approximately 6.0% below the worldwide average of 0.48 mSv y^{-1} reported by UNSCEAR (2008), although the maximum value slightly exceeded this reference. Nevertheless, both the mean and maximum estimated doses were below the ICRP (2007) recommended public dose limit of 1 mSv y^{-1}.

Table 1: *In-Situ* Gamma Radiation Measurements and Estimated Radiological Parameters in Soil Locations

Sample Code	Latitude	Longitude	ADR (μSv hr^{-1})	AEDE (mSv/y)	ELCR (x10^{-3})
S1	9.632374N	6.611160E	0.133 ± 0.002	0.435 ± 0.007	1.523 ± 0.024
S2	9.637061N	6.616265E	0.127 ± 0.001	0.417 ± 0.005	1.460 ± 0.016
S3	9.632780N	6.620196E	0.135 ± 0.002	0.442 ± 0.007	1.546 ± 0.024
S4	9.642154N	6.627397E	0.131 ± 0.001	0.430 ± 0.005	1.506 ± 0.016
S5	9.644670N	6.635306E	0.135 ± 0.001	0.444 ± 0.005	1.552 ± 0.016
S6	9.651893N	6.621509E	0.150 ± 0.001	0.493 ± 0.005	1.725 ± 0.016
S7	9.652726N	6.620301E	0.151 ± 0.001	0.496 ± 0.005	1.736 ± 0.016
Min			0.127 ± 0.001	0.417 ± 0.005	1.460 ± 0.016
Max			0.151 ± 0.001	0.496 ± 0.005	1.736 ± 0.016
Mean			0.137 ± 0.009	0.451 ± 0.031	1.578 ± 0.108

The estimated excess lifetime cancer risk (ELCR) ranged from (1.460 ± 0.016) × 10^{-3} to (1.736 ± 0.016) × 10^{-3}, with a mean of (1.578 ± 0.108) × 10^{-3}. The mean ELCR was approximately 5.4 times the comparison value of 0.29 × 10^{-3} reported by (UNSCEAR, 2008). This indicates an elevated theoretical lifetime risk relative to the adopted comparison value. However, ELCR is a model-derived estimate based on assumed exposure conditions and a nominal risk coefficient; it does not represent observed cancer incidence or establish the actual occurrence of cancer among the exposed population.

Radiological Exposure and Risk Assessment in Tailings Areas (TA)

As presented in Table 2, the ambient dose equivalent rate (ADR) across the tailings locations ranged from 0.156 ± 0.001 to 0.181 ± 0.001 μSv h^{-1}, with a mean of 0.167 ± 0.009 μSv h^{-1}. The corresponding annual effective dose equivalent (AEDE) ranged from 0.512 ± 0.005 to 0.595 ± 0.005 mSv y^{-1}, with a mean of 0.550 ± 0.029 mSv y^{-1}. The mean AEDE exceeded the UNSCEAR (2008) worldwide average of 0.48 mSv y^{-1} by approximately 14.5%, although it remained below the ICRP (2007) recommended public dose limit of 1 mSv y^{-1}. The higher mean AEDE compared with the soil locations suggests greater ambient gamma exposure around the tailings deposits.

Table 2: *In-Situ* Gamma Radiation Measurements and Estimated Radiological Parameters in Tailings Locations

Sample Code	Latitude	Longitude	ADR (μSv hr^{-1})	AEDE (mSv/y)	ELCR (x10^{-3})
T1	9.633669N	6.612534E	0.157 ± 0.003	0.516 ± 0.009	1.805 ± 0.033
T2	9.652177N	6.621247E	0.178 ± 0.003	0.585 ± 0.009	2.047 ± 0.033
T3	9.652667N	6.620407E	0.171 ± 0.001	0.562 ± 0.005	1.966 ± 0.016
T4	9.640859N	6.623443E	0.160 ± 0.001	0.524 ± 0.002	1.834 ± 0.008
T5	9.641902N	6.626607E	0.156 ± 0.001	0.512 ± 0.005	1.794 ± 0.016
T6	9.642902N	6.629770E	0.163 ± 0.002	0.534 ± 0.007	1.868 ± 0.024
T7	9.644419N	6.634515E	0.174 ± 0.001	0.572 ± 0.005	2.001 ± 0.016
T8	9.644922N	6.636097E	0.181 ± 0.001	0.595 ± 0.005	2.081 ± 0.016
T9	9.637173N	6.616405E	0.171 ± 0.002	0.560 ± 0.007	1.960 ± 0.024
T10	9.652653N	6.620396E	0.164 ± 0.003	0.539 ± 0.009	1.886 ± 0.033
T11	9.641399N	6.625025E	0.167 ± 0.001	0.549 ± 0.005	1.920 ± 0.016
T12	9.642405N	6.628188E	0.179 ± 0.002	0.586 ± 0.007	2.052 ± 0.024
T13	9.643915N	6.632933E	0.156 ± 0.001	0.512 ± 0.005	1.794 ± 0.016
Min			0.156 ± 0.001	0.512 ± 0.005	1.794 ± 0.016
Max			0.181 ± 0.001	0.595 ± 0.005	2.081 ± 0.016
Mean			0.167 ± 0.009	0.550 ± 0.029	1.924 ± 0.102

The estimated excess lifetime cancer risk (ELCR) ranged from (1.794 ± 0.016) × 10^{-3} to (2.081 ± 0.016) × 10^{-3}, with a mean of (1.924 ± 0.102) × 10^{-3}. This mean was approximately 6.6 times the comparison value of 0.29 × 10^{-3} reported by UNSCEAR (2008), representing the highest estimated lifetime risk among the three material categories. The relatively elevated values may be associated with the concentration and redistribution of naturally occurring radionuclides during mining and ore-processing activities, although variations in the underlying geological composition may also contribute to the observed radiation levels. Nevertheless, these estimates represent theoretical radiological risks rather than observed health outcomes.

Radiological Exposure and Risk Assessment in Mineral Areas (MA)

As presented in Table 3, the ambient dose equivalent rate (ADR) across the mineralised locations ranged from 0.124 ± 0.001 to 0.150 ± 0.001 μSv h^{-1}, with a mean of 0.138 ± 0.008 μSv h^{-1}. The corresponding annual effective dose equivalent (AEDE) ranged from 0.407 ± 0.005 to 0.491 ± 0.002 mSv y^{-1}, with a mean of 0.455 ± 0.025 mSv y^{-1}. This mean was approximately 5.2% below the UNSCEAR (2008) worldwide average of 0.48 mSv y^{-1} and remained below the ICRP (2007) recommended public dose limit of 1 mSv y^{-1}.

Table 3: *In-Situ* Gamma Radiation Measurements and Estimated Radiological Parameters in Mineralised Locations

Sample Code	Latitude	Longitude	ADR (μSv hr^{-1})	AEDE (mSv/y)	ELCR (x10^{-3})
M1	9.632667N	6.611750E	0.147 ± 0.002	0.481 ± 0.007	1.684 ± 0.024
M2	9.652010N	6.620942E	0.139 ± 0.001	0.457 ± 0.005	1.598 ± 0.016
M3	9.641650N	6.625816E	0.143 ± 0.001	0.470 ± 0.005	1.644 ± 0.016
M4	9.643160N	6.630561E	0.138 ± 0.001	0.453 ± 0.005	1.587 ± 0.016
M5	9.643412N	6.631352E	0.150 ± 0.001	0.491 ± 0.002	1.719 ± 0.008
M6	9.643664N	6.632143E	0.142 ± 0.001	0.465 ± 0.002	1.627 ± 0.008
M7	9.644167N	6.633724E	0.139 ± 0.001	0.455 ± 0.002	1.592 ± 0.008
M8	9.660158N	6.619588E	0.124 ± 0.001	0.407 ± 0.005	1.426 ± 0.016
M9	9.641147N	6.624234E	0.137 ± 0.002	0.448 ± 0.007	1.569 ± 0.024
M10	9.642657N	6.628979E	0.128 ± 0.001	0.420 ± 0.005	1.472 ± 0.016
Min			0.124 ± 0.001	0.407 ± 0.005	1.426 ± 0.016
Max			0.150 ± 0.001	0.491 ± 0.002	1.719 ± 0.008
Mean			0.138 ± 0.008	0.455 ± 0.025	1.592 ± 0.089

The estimated excess lifetime cancer risk (ELCR) ranged from (1.426 ± 0.016) × 10^{-3} to (1.719 ± 0.008) × 10^{-3}, with a mean of (1.592 ± 0.089) × 10^{-3}. This mean was approximately 5.5 times the comparison value of 0.29 × 10^{-3} reported by (UNSCEAR, 2008). Although the estimated lifetime risk exceeded the adopted comparison value, it was lower than that obtained for the tailings areas. This pattern suggests differences in ambient gamma exposure among the investigated material categories, with the tailings areas exhibiting the highest mean estimated exposure and associated theoretical lifetime risk.

Table 4: Summary Statistics of Ambient Gamma Dose Rates and Associated Radiological Risk Parameters across the Investigated Material Groups

Material category	No. of Locations (n)	ADR (μSv hr^{-1})	AEDE (mSv y^{-1})	ELCR (x10^{-3})
Soil	7	0.137 ± 0.009	0.451 ± 0.031	1.578 ± 0.108
Tailings	13	0.167 ± 0.009	0.550 ± 0.029	1.924 ± 0.102
Minerals	10	0.138 ± 0.008	0.455 ± 0.025	1.592 ± 0.089

Note: Values are presented as mean ± sample standard deviation (SD) across monitoring locations within each material category.

Comparison of Radiological Parameters across the Three Material Categories

Across the three material categories, the mean annual effective dose equivalent (AEDE) followed the order: tailings (0.550 ± 0.029 mSv y^{-1}) > mineralised areas (0.455 ± 0.025 mSv y^{-1}) > soil areas (0.451 ± 0.031 mSv y^{-1}). A similar pattern was observed for the estimated excess lifetime cancer risk (ELCR), with mean values of (1.924 ± 0.102) × 10^{-3}, (1.592 ± 0.089) × 10^{-3} and (1.578 ± 0.108) × 10^{-3} for tailings, mineralised and soil areas, respectively. These results indicate that the tailings locations recorded the highest mean estimated dose and associated theoretical lifetime risk, whereas the mineralised and soil locations exhibited relatively comparable values.

The mean AEDE values for the soil and mineralised areas were below the UNSCEAR (2008) worldwide average of 0.48 mSv y^{-1}, while the tailings mean exceeded this reference by approximately 14.5%. Nevertheless, all three category means remained below the ICRP (2007) recommended public dose limit of 1 mSv y^{-1}. In contrast, the mean ELCR values across all three categories exceeded the adopted comparison value of 0.29 × 10^{-3}. This value serves as a comparative reference rather than a regulatory safety limit. The estimated ELCR values represent theoretical lifetime risks based on the assumed exposure conditions, a lifetime duration of 70 years and the adopted nominal risk coefficient of 0.05 Sv^{-1}. They do not represent observed cancer cases or establish the occurrence of cancer among miners or residents in the study area, as no medical or epidemiological investigation was conducted.

The comparison showed that tailings had consistently higher mean radiological parameters than soil and mineralised areas. However, the interpretation of these differences is descriptive, considering the unequal numbers of measurement locations across the categories (soil, n = 7; tailings, n = 13; mineralised areas, n = 10) and their spatial distribution within the mining area. Consequently, the

observed differences should not be interpreted as statistically significant differences among the material categories.

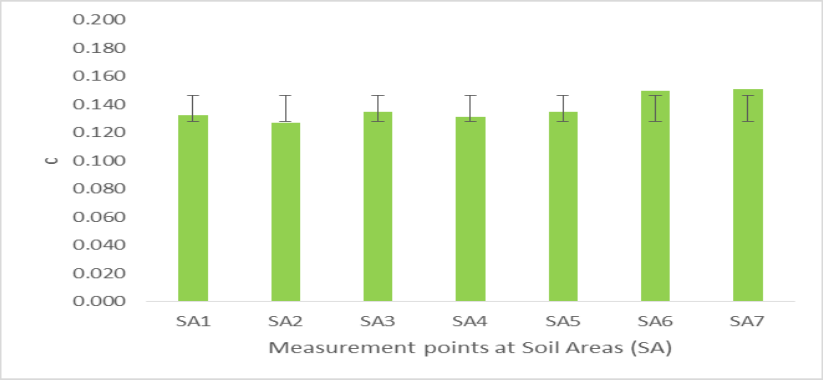


Figure 5: Ambient dose rate across Soil Areas (SA) measurement points

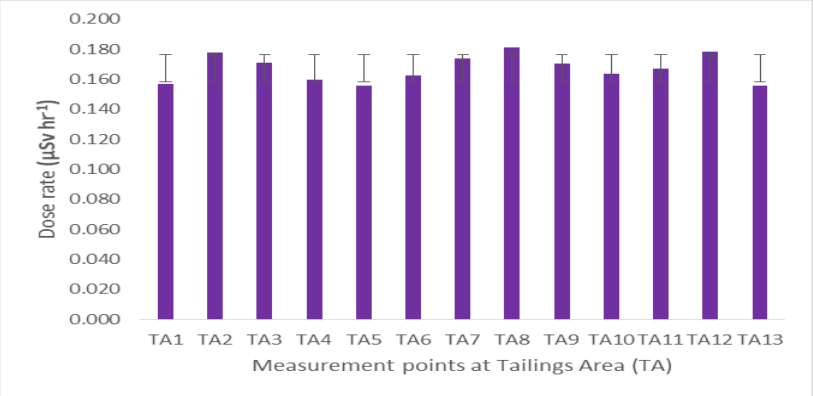


Figure 6: Ambient dose rate across Tailings Areas (TA) measurement points

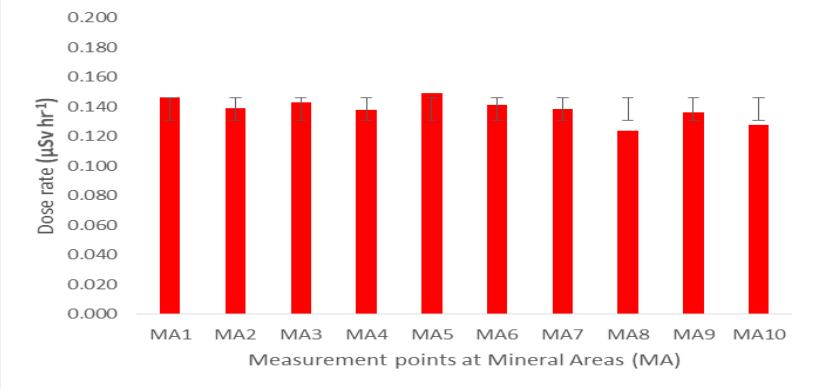


Figure 7: Ambient dose rate across mineral measurement points

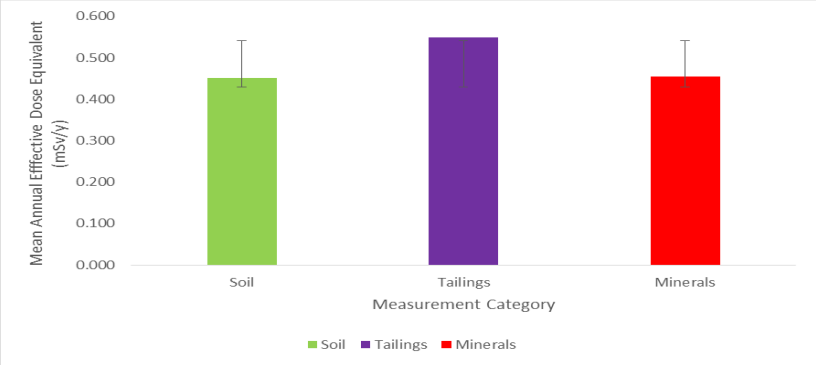


Figure 8: Mean annual effective dose equivalent across measurement categories

Table 5: Comparison of Reported Ambient Gamma Dose Rates in Selected Locations

Location	Environmental setting	Reported ADR (μSv hr^{-1})	Reference
Minna, Nigeria	Residential	0.154	(Olarinoye *et al.*, 2010)
Minna, Nigeria	Residential	0.137	(Shittu *et al.*, 2021)
Gababiyu, Nigeria	Gold mining	0.22	(Gomina *et al.*, 2019)
Luku, Nigeria	Gold mine	1.7	(Sabo *et al.*, 2018)
Minna, Nigeria	Residential	0.126	(Adeiza Stephen *et al.*, 2024)
Lapai, Nigeria	Gold mining	0.154	(Usman *et al.*, 2022)
Asaba, Nigeria	Residential	0.158	(Agbalagba and Anekwe, 2021)
Offa, Nigeria	Industrial	0.132	(Nwankwo and Akoshile, 2005)
Jos, Nigeria	Tin mining	0.83	(Atipo *et al.*, 2020)
Enugu. Nigeria	Residential	0.125	(Ugbede *et al.*, 2022)
Kano, Nigeria	Tin mining	0.202	(Muhammad *et al.*, 2022)
Lafia, Nigeria	Residential	0.185	(Mustapha *et al.*, 2021)
Katsina, Nigeria	Residential	0.116	(Abdulkadir *et al.*, 2023)
Gahkuch Ghizer, Pakistan	Residential	0.221	(Ali *et al.*, 2019)
Telangana, India	Residential	0.265	(Suman *et al.*, 2022)
Bangalore, India	Residential	0.117	(Shiva *et al.*, 2008)
World		0.07	(UNSCEAR, 2008)
Shakwatu, Nigeria	Gold mining	0.151	This work

The overall mean ambient dose equivalent rate (ADR) obtained in this study was 0.151 ± 0.017 μSv h^{-1}, with individual values ranging from 0.124 ± 0.001 to 0.181 ± 0.001 μSv h^{-1}. This mean is comparable to values reported in several Nigerian locations, including Minna (0.137 μSv h^{-1}), Asaba (0.158 μSv h^{-1}) and Enugu (0.125 μSv h^{-1}). However, it is lower than values reported in some mining environments, such as Gababiyu (0.22 μSv h^{-1}), Jos (0.83 μSv h^{-1}) and Luku (1.70 μSv h^{-1}). Standard deviations were not available for these previously reported comparison values. The observed variations may be attributed to differences in local geological characteristics, mineral composition and mining activities, as well as variations in measurement instruments, survey configurations and procedures. Therefore, these comparisons provide a contextual assessment of ambient radiation levels rather than strictly equivalent measurements.

CONCLUSION

This study assessed the *in-situ* terrestrial gamma radiation levels at 30 monitoring points comprising soil, tailings and mineralised areas within the Shakwatu artisanal gold-mining area, Minna, Niger State, Nigeria. The measured ambient dose equivalent rates (ADR) ranged from 0.124 ± 0.001 to 0.181 ± 0.001 μSv h^{-1}, with an overall mean of 0.151 ± 0.017 μSv h^{-1}. Tailings recorded the highest mean ADR (0.167 ± 0.009 μSv h^{-1}), annual effective dose equivalent (AEDE) (0.550 ± 0.029 mSv y^{-1}) and excess lifetime cancer risk (ELCR) ((1.924 ± 0.102) × 10^{-3}), followed by mineralised areas (0.138 ± 0.008 μSv h^{-1}, 0.455 ± 0.025 mSv y^{-1} and (1.592 ± 0.089) × 10^{-3}) and soil areas (0.137 ± 0.009 μSv h^{-1}, 0.451 ± 0.031 mSv y^{-1} and (1.578 ± 0.108) × 10^{-3}), respectively. Although the estimated ELCR values exceeded the adopted comparison value, they represent theoretical lifetime risks rather than observed cancer incidence. The estimates are subject to limitations associated with the portable Geiger–Mueller survey instrument, the limited number of repeat readings and the assumed occupancy factor of 0.375. Calibrated repeat surveys, radionuclide-specific measurements and occupational exposure assessments are therefore recommended to provide a more reliable evaluation of radiation exposure and potential health risks at the site.

REFERENCES

Abdulkadir, M., Garba, N. N., Nasiru, R., Saleh, M. A., Bello, S., & Khandaker, M. U. (2023). Statistical analysis of terrestrial gamma radiation dose rates in relation to different geological formations and soil types of Katsina State, Nigeria. International Journal of Environmental Analytical Chemistry, 103(14), 3251-3263.

Adeiza Stephen, A., Olarinoye, O. I., Kolo, M., & Kasim, I. (2024). Assessment of environmental background gamma radiation variation in Minna Area of Nigeria. Environmental Forensics, 25(5), 275-286.

Adewumi, T., Adegoke, B. A., Faweya, B. E., Akingboye, A. S., Kwaghhua, F. I., Adeeko, T. O., & Okwokwo, O. I. (2026). Active artisanal mining-induced radiogenic hazards: insights from radiogeochemistry of Wamba Areas, north-central Nigeria. Scientific Reports.

Agbalagba, O. E., & Anekwe, L. U. (2021). Radiometric mapping of terrestrial gamma radiation and evaluation of radiological health risk on the residents in Nigeria state commercial and capital cities. Environmental Forensics, 22(1-2), 75-90.

Ali, M., S. Bano, J. A. Qureshi, M. Wasim, G. Khan, F. Begum, & Alam., M. (2019). Indoor and outdoor gamma radiation level in mud and concrete houses and the annual effective dose and excess life time cancer risk in Gahkuch Ghizer valley of Hindukush Range. Journal of Himalayan Earth Science 52 (2).

Atipo, M., Olarinoye, O., Awojoyogbe, B., & Kolo, M. (2020). High terrestrial radiation level in an active tin-mine at Jos South, Nigeria.

Bollhöfer, A., Beraldo, A., Pfitzner, K., Esparon, A., & Doering, C. (2014). Determining a pre-mining radiological baseline from historic airborne gamma surveys: A case study. Science of the total environment, 468, 764-773.

Glinsky, M., Vetrov, V., Abramov, A., & Chertkov, L. (2021). Impact of nuclear enterprises on the subsoil. In Subsoil Monitoring at Nuclear Industry Enterprises: Foundations and Case Studies (pp. 13-43). Springer.

Gomina, M., Kolo, M. T., & Awojoyogbe, O. (2019). Radiological Implications of Artisanal Gold Mining Activities in Gababiyu, Minna Metropolis, Nigeria.

ICRP. (2007). ICRP Publication 103 The 2007 Recommendations of the International Commission on Radiological Protection.

Jha, S., Patra, A. C., Verma, G. P., Iyer, I. S., & Aswal, D. K. (2024). Natural radiation and environment. In Handbook on radiation Environment, volume 1: Sources, applications and policies (pp. 27-72). Springer.

Knoll, G. F. (2010). Radiation detection and measurement. John Wiley & Sons.

Mettler, F. A. (2012). Medical effects and risks of exposure to ionising radiation. Journal of Radiological Protection, 32(1), N9-N13.

Morosh, V., Röttger, A., Neumaier, S., Krasniqi, F., Živanović, M., Kržanović, N., Sperandio, L. (2021). Investigation into the performance of dose rate measurement instruments used in non-governmental networks. Radiation Measurements, 143, 106580.

Muhammad, A. N., A. F. Ismail, & Garba., N. N. (2022). Radiological mapping of tin mining areas in Doguwa, Kano State, Nigeria. Environmental Forensics, 1–12. https://doi.org/10.1080/15275922.2022.2125109

Munyaradzi, Z., Kgabi, N., & Tshivhase, M. (2018). Excess lifetime cancer risk due to natural radioactivity in soils: Case of Karibib town in Namibia. African Review of Physics, 13, 71-78.

Mustapha, I. M., Tukur, R. S., Mohammed, M., Kana, M. A., Hamza, I. S., Bello, A., & Aliyu, U. S. a. (2021). Outdoor background radiation level and radiological hazards assessment in Lafia Metropolis, Nasarawa State, Nigeria. ASEANA Science and Education Journal, 1(1), 27-35.

Nwankwo, L. I., & Akoshile, C. O. (2005). Background radiation study of Offa industrial area of Kwara State, Nigeria. J. Appl. Sci. Environ. Manage, 9 (3) 95 – 98.

Olarinoye, I., Sharifat, I., Baba-Kutigi, A., Kolo, M. T., & Aladeniyi, K. (2010). Measurement of Background gamma radiation levels at two Tertiary Institutions in Minna, Nigeria. Journal of Applied Sciences and Environmental Management, 14(1).

Olomo, K. O., Bayode, S., Alagbe, O. A., Olayanju, G. M., & Olaleye, O. K. (2022). Aeromagnetic mapping and radioelement influence on mineralogical composition of mesothermal gold deposit in part of ilesha schist belt, Southwestern Nigeria. NRIAG Journal of Astronomy and Geophysics, 11(1), 177-192.

Onumejor, C., Akinpelu, A., Arijaje, T., Usikalu, M., Oladapo, O., Emetere, M., Achuka, J. (2019). Monitoring of Background Radiation in Selected Schools in Ota, Ogun State Nigeria by Direct Measurement of Terrestrial Radiation Dose Rate. IOP Conference Series: Earth and Environmental Science,

Sabo, A., Sadiq, L. S., & Gamba, J. (2018). Radiological assessment of artisanal gold mining sites in Luku, Niger State, Nigeria. Journal of Environment Pollution and Human Health, 6(2), 45-50. https://doi.org/10.12691/jephh-6-2-1

Senthilkumar, B., Dhavamani, V., Ramkumar, S., & Philominathan, P. (2010). Measurement of gamma radiation levels in soil samples from Thanjavur using γ-ray spectrometry and estimation of population exposure. Journal of Medical Physics/Association of Medical Physicists of India, 35(1), 48.

Shi, Z., Wang, X., Shi, Y., Ni, S., Li, Y., Wang, D., & Wang, R. (2019). Impact of intensive mining on the distribution of heavy metals in water and sediment of Anning River, southwest China. Geochemistry: Exploration, Environment, Analysis, 19(1), 24-30.

Shittu, H. O., I. O. Olarinoye, M. T. Kolo, A. N. Amadi, S. F. Olukotun, O. F. Oladejo, & Samue., G. E. K. (2021). Mapping of Natural Gamma Radiation (NGR) Dose Rate Distribution around Gidan-Kwano Area, Minna, North-Central Nigeria. FUW Trends in Science & Technology Journal, 6 (3): , 93–936. www.ftstjournal.com

Shiva, P., Nagaiah N, Ashok GV, & N., K. (2008). Concentration of 226Ra, 232Th, and 40K in the soils of Bangalore region, India. . Health Phys., 94 (3), 264-271.

Suman, G., Vinay Kumar Reddy, K., Sreenath Reddy, M., Vidyasagar, D., Gopal Reddy, C., & Yadagiri Reddy, P. (2022). Dose assessment due to natural gamma radiation levels and radioactive nuclides in the environment of Dasarlapally, Nalgonda District, Telangana State, India. International Journal of Environmental Analytical Chemistry, 102(19), 7409-7418.

Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hidiroglu, S., & Karahan, G. (2009). Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. Journal of Environmental Radioactivity, 100(1), 49-53. https://doi.org/10.1016/j.jenvrad.2008.10.012

Ugbede, F. O., A. F. Akpolile, G. F. Ibeh, & Mokobia., C. E. (2022). "In-Situ Assessment of Background Gamma Radiation Dose Levels in Outdoor Environment of Enugu Urban Areas, Enugu State, Nigeria. Environmental Forensics, 23 (3–4), 334–345. https://doi.org/10.1080/15275922.2020.1850562

Umar, H., Onimisi, M. Y., Viva, Y. I., Ige, O. O., Shuaibu, H. K., Yahaya, A., Humphrey, B. B. (2026). In Situ Gamma Dose Rates and Radiological Risk Indices at Artisanal Mining Sites in Kauru, Kaduna State, Nigeria. Nigerian Journal of Physics, 35(S), 543-553.

UNSCEAR. (2008). Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. General Assembly 56. Session (10-18 July 2008). Official Records: 63. Session, suppl. no. 46 (A/63/46) (0255-1373).

Usman, Y. T., Bello, S., Yabagi, A., Suleiman, I., Ishaq, Y., & Salisu, U. (2022). Impact Assessment of Background Radiation on Habitant and the Mining Environment at Lapai, Area Niger State, Nigeria. Fudma Journal of Sciences, 6(2), 1-6.

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