Assessment of Radon-222, Radium-226 Concentrations and Potential Risk to Artisanal Miners Around Ririwai Tin Mine Kano State, North Western Nigeria.

Abdullahi Muhammad Attahiru[+] , Muhammad Sani Abdulkarim and Suraj Aliyu
Department of Applied Physics, College of Science and Technology Kaduna Polytechnic, Kaduna, Nigeria.

Abstract. Mining and mineral processing in Nigeria generate substantial economic benefits through employment and wealth creation, yet they also present significant environmental and public health challenges due to exposure to naturally occurring radioactive materials (NORMs). This study evaluated the radiological hazards associated with artisanal tin mining in Ririwai, Kano State, by analyzing Radon-222 (^{222}Rn) and Radium-226 (^{226}Ra) concentrations in soil samples using RAD7 and NaI(Tl) gamma spectrometry. Results showed elevated ^{222}Rn levels with a mean concentration of 412.2±11.46 Bq·m^{-3} (range: 234-782 Bq·m^{-3}), significantly higher than global background levels. The radon exhalation rate averaged 17.175±5.87 Bq·m^{-2}·h^{-1}, while ^{226}Ra activity concentrations ranged from 4.36-107.30 Bq·kg^{-1} (mean: 51.017±5.87 Bq·kg^{-1}). The calculated annual effective dose of 3.21 mSv·yr^{-1} exceeded both the global average (2.4 mSv·yr^{-1}) and the ICRP recommended limit of 1 mSv·yr^{-1} for public exposure. Radiological risk assessment revealed concerning values, including a fatality risk of 1.7×10^{-4} and lifetime fatality risk of 10.2×10^{-3}, which are substantially higher than the USEPA's negligible risk range (1×10^{-6}-1×10^{-4}). Similarly, severe hereditary effects (6.4×10^{-5}) and lifetime hereditary risks (3.84×10^{-3}) were significantly elevated. These findings demonstrate that artisanal miners and nearby communities face substantial radiation exposure that could lead to increased cancer incidence and other health effects. The study underscores the urgent need for regulatory interventions, including radiation monitoring programs, improved mining practices, and public awareness campaigns to mitigate these environmental health risks while maintaining the economic benefits of small-scale mining operations in Nigeria.

Keywords: Radon, Radium, Concentrations Exhalation rate, Activity concentration Effective dose, Risk

1. Introduction

Radon, a naturally occurring radioactive gas, exists as three isotopes: Actinon (^{219}Rn) from the ^{235}U series, Thoron (^{220}Rn) from the ^{232}Th series, and Radon (^{222}Rn) from the ^{238}U series (UNSCEAR, 2019). While ^{219}Rn poses negligible risk due to its ultra-short half-life (3.96 s) (Sahoo et al., 2020), and ^{220}Rn (half-life: 55.6 s) primarily affects thorium-rich environments (Meisenberg et al., 2017), ^{222}Rn (half-life: 3.82 days) remains the most significant contributor to human radiation exposure (WHO, 2021). This dense (9.73 g/L at 0°C), alpha-emitting noble gas shows temperature-dependent water solubility, decreasing from 510 cm³/L at 0°C to 130 cm³/L at 50°C (Porstendörfer, 2019). Its generation in geological materials correlates directly with ^{226}Ra content, with inhalation of decay products (^{210}Pb, ^{210}Po) constituting >50% of natural radiation dose globally (ICRP, 2020).

Spatiotemporal variability in ^{222}Rn concentrations is well-documented, ranging from 2–30 Bq/m³ in ambient air to 50,000 Bq/m³ in groundwater systems (Girault et al., 2021). Recent studies in mining areas report soil gas concentrations exceeding 100 kBq/m³ (Ademola et al., 2022), far above the ICRP (2020) intervention level of 1,000 Bq/m³ (equivalent to 6 mSv/yr at 2000 h exposure). Building infiltration occurs through sub-slab pressure differentials and porous construction materials, with modern energy-efficient structures showing 30% higher indoor concentrations (Kumar et al., 2023).

The stochastic nature of radiation-induced effects (carcinogenesis, germline mutations) is now recognized as having no safe threshold (Abdullahi et al., 2016; IAEA, 2018). Artisanal mining operations in West Africa have been shown to increase local radiation doses by 4–15× background levels (Bramki et al., 2022). This study employs RAD7 and NaI(Tl) spectrometry to quantify $^{222}Rn/^{226}Ra$ in Ririwai Tin Mine soils, addressing critical data gaps in Nigeria's radiological risk assessment (Tchokossa et al., 2019).

2. Objectives

The study aims to:

i. Determine the amount of ^{222}Rn and ^{226}Ra concentrations in the study area.
ii. Calculate the fatality and hereditary cancer risks for artisanal miners due to chronic exposure to ^{222}Rn and ^{226}Ra using ICRP risk assessment methodology.

3. Materials and Methods

Soil samples were collected within the mining area from ten (10) active mining pits. The sample location was marked using a geographical positioning system (GPS) and are tabulated in Table 1. While fig.1 shows the topographic map of the study area.

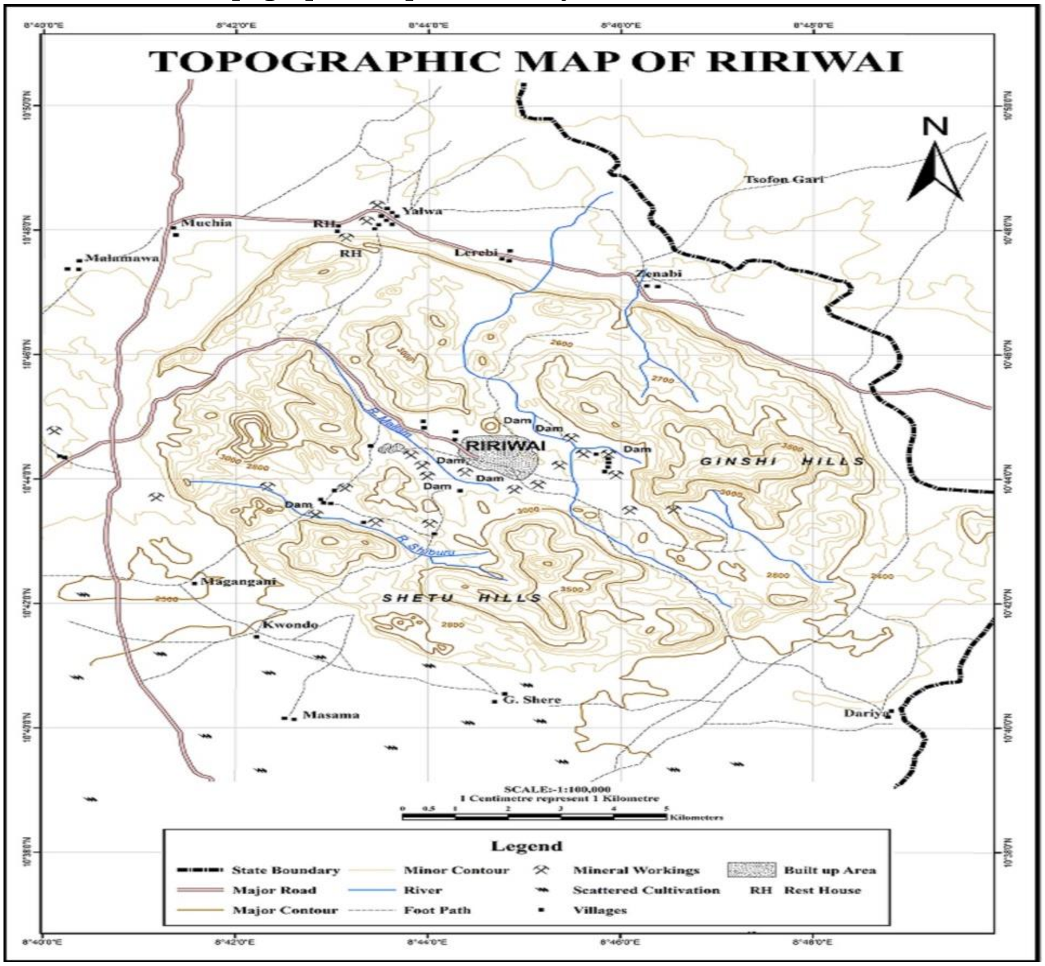
Table 1.

Locations Pits where Samples were collected

S/no	***North***	***East***	***Elevatior***
1	***10^0 44′ 35.3″***	**008^0 45′ *16.4″***	**856m**
2	10^0 44′ 36.7″	008^0 45′ 15.8″	856m
3	10^0 44′ 33.8″	008^0 45′ 17.8″	856m
4	10^0 44′ 32.3″	008^0 45′ 21.0″	858m
5	10^0 44′ 30.3″	008^0 45′ 27.0″	862m
6	10^0 43′ 48.2″	008^0 44′ 57.1″	896m
7	10^0 43′ 49.1″	008^0 44′ 53.4″	894m
8	10^0 43′ 48.5″	008^0 44′ 53.0″	895m
9	10^0 43′ 50.2″	008^0 44′ 58.7″	892m
10	10^0 43′ 49.5″	008^0 44′ 59.2″	894m

Fig. 1

Topographic map of the study area



One kilogram (1 kg) of each sample was collected for analysis. The samples were oven dried at temperature of 105^0C (IAEA, 2018). The samples were then grinded into fine powder and sieved through 32μm. The prepared samples were analysed for Radon-222 concentrations with RAD7 detector fig.2 while the Ra-226 activity concentration were analysed with NaI (Tl) detector at the Centre for Energy Research and Training A.B.U. Zaria.

The annual effective dose, (D_E) due to indoor radon inhalation, which corresponds to the value of the average activity concentration of radon in indoor, was calculated using equation (1) (UNSCEAR, 2000):

$$D_E = A_{Rn} \times E_f \times T \times 9 \text{ nSv/(Bq h m}^{-3}) \quad (1)$$

where A_{Rn} is the average activity concentration of indoor radon in Bq/m^3, E_f is the indoor equilibrium factor between radon and its progeny (estimated by 0.4); T is the exposure time to this concentration in hours (assumed to be equal to 2190 h/y 6hours per day), and 9 nSv/

(Bq h m^{-3}) is the estimated dose conversion factor. Following this equation, inhalation of 1Bq/m^3 of indoor radon causes an annual effective dose of about 7.84 μSv. The Emanation coefficient was calculated using equation (2) (Arabi et al., 2015)

$$E = VC/MR \tag{2}$$

Where E is the emanation coefficient, V is the volume of the sampling device (0.00012m^3), C Radon concentration (Bq/m^3), M, total mass of the sample in kg and R, Radium activity concentration in Bq/kg. The cancer and hereditary risks due to low doses without threshold dose known as stochastic effect were estimated using the ICRP cancer risk assessment methodology (ICRP, 2007; 2019).

$$\text{Fatality cancer risk} = \text{Annual effective dose} \times \text{Cancer nominal risk factor} \tag{3}$$

$$\text{Hereditary effect} = \text{Annual effective dose} \times \text{Hereditary nominal risk factor} \tag{4}$$

4. Results

The activity concentration for ^{222}Rn and the ^{222}Rn Exhalation rate determined using RAD7 are tabulated in Table 2. The result of ^{226}Ra activity concentrations (Bqkg^{-1}) and the calculated values of the emanation coefficient (EF) are shown in Table 3.

Table 2.
Radon-222 concentrations and Exhalation rate

S/No.	Sample ID	^{222}Rn Concentrations (Bqm^{-3})	^{222}Rn Exhalation rate (Bqm^{-3}h^{-1})
1	RS 24	584 ± 18.9	24.33 ± 9.91
2	RS 06	234 ± 9.46	9.75 ± 5.68
3	RS 28	782 ± 23.4	32.58 ± 10.42
4	RS 16	336 ± 8.7	14 ± 2.81
5	RS 20	372 ± 7.23	15.5 ± 4.84
6	RS 04	384 ± 7.82	16 ± 3.47
7	RS 02	543 ± 13.2	22.63 ± 9.96
8	RS 11	311 ± 8.63	12.96 ± 3.91
9	RS 21	311 ± 8.08	12.96 ± 5.92
10	RS 10	265 ± 9.2	11.04 ± 1.78
	MEAN	**412.2 ± 11.462**	**17.175 ± 5.87**

Table 3.
Rn-222 and Ra-226 Concentrations and Emanation Coefficient (EM)

S/No.	*Sample ID*	*^{222}Rn Concentration (Bqm^{-3})*	*^{226}Ra Concentration (Bqkg^{-1})*	*Emanation Coefficient*
1	RS 24	584 ± 18.9	103.45 ± 9.91	0.0135
2	RS 06	234 ± 9.46	19.12 ± 5.68	0.0294
3	RS 28	782 ± 23.4	66.13 ± 10.42	0.0285
4	RS 16	336 ± 8.7	14.36 ± 2.81	0.0562
5	RS 20	372 ± 7.23	26.65 ± 4.84	0.0335
6	RS 04	384 ± 7.82	29.08 ± 3.47	0.0317
7	RS 02	543 ± 13.2	107.3 ± 9.96	0.0121
8	RS 11	311 ± 8.63	28.29 ± 3.91	0.0264
9	RS 21	311 ± 8.08	67.36 ± 5.92	0.0111
10	RS 10	265 ± 9.2	48.43 ± 1.78	0.0131
	MEAN	412.2 ± 11.462	51.017 ± 5.87	0.02555

Annual Effect Dose

The annual effect dose was calculating using equation 1,

$$DE = {}^{222}Rn \text{ Mean Concentration in } Bqm^{-3} \times 7.84\mu Sv = 412.2 \times 7.84\mu Sv = 3.2 \times 10^{-3} Sv.$$

Cancer Risk Estimate

From equations 3 and 4, and nominal risk factors, the following were calculated:

$$\text{Fatality cancer risk} = 3.2 \times 10^{-3} Sv \times 5.5 \times 10^{-2} = 1.7 \times 10^{-4}$$

$$\text{Hereditary effects} = 3.2 \times 10^{-3} Sv \times 0.2 = 6.4 \times 10^{-5}$$

Also, lifetime fatality and hereditary risks were estimated.

5. Discussion of Findings

The results revealed significant variations in indoor radon (^{222}Rn) concentrations across the study area, ranging from 234 to 782 Bq/m^3, with a mean value of 412.2 ± 11.46 Bq/m^3 (Table 2). This average concentration is approximately 10 times higher than the global average of 40 Bq/m^3 (UNSCEAR, 2000) and nearly three times the USEPA recommended action level of 148 Bq/m^3 (USEPA, 1987). While it exceeds the World Health Organization (WHO) reference level of 300 Bq/m^3 (WHO, 2021), it remains below the ICRP intervention threshold of 1,000 Bq/m^3**,** suggesting that while elevated, the radon levels do not yet necessitate immediate remediation measures.

The radon exhalation rate, a critical factor in assessing radon release from soil, ranged from 9.75 to 32.58 Bq·m^{-2}·h^{-1}, with a mean of 17.175 ± 5.87 Bq·m^{-2}·h^{-1}. These values indicate a moderate to high exhalation rate, which contributes to the elevated indoor radon concentrations observed. Gamma spectrometry analysis of ^{226}Ra activity concentrations showed a range of 14.36 to 107.30 Bq/kg, with a mean of 51.017 ± 5.87 Bq/kg, significantly higher than the global average of 32 Bq/kg. A strong positive correlation (Fig. 3) was observed between ^{222}Rn and ^{226}Ra concentrations, reinforcing the role of ^{226}Ra as a primary source of radon in the study area.

The radon emanation coefficient (EF), which quantifies the fraction of radon gas released from soil grains, varied between 0.011 and 0.056, with a mean of 0.025 ± 0.0139. These values fall within the typical range reported for soils (0.05–0.7) by Nazaroff et al. (1988). Notably, the EF exhibited no dependence on ^{226}Ra activity concentrations (Fig. 4), suggesting that other factors, such as soil porosity and moisture content, may play a more dominant role in radon release.

The estimated annual effective dose from radon exposure was 3.21 mSv/yr, exceeding the global average of 1.9 mSv/yr (UNSCEAR, 2021). This elevated dose translates to increased health risks, as evidenced by the calculated cancer risk values: fatality risk (1.7×10^{-4})**,** lifetime fatality risk (10.2×10^{-3})**,** severe hereditary effects (6.4×10^{-5}), and lifetime hereditary effects (3.84×10^{-3}). All these values surpass the USEPA's negligible risk range (1×10^{-6} to 1×10^{-4}), indicating a significant radiological hazard for the local population, particularly artisanal miners and residents in proximity to the mining sites.

These findings underscore the need for regulatory measures, including radon monitoring programs and public health interventions, to mitigate exposure and reduce associated cancer risks while maintaining the economic benefits of mining activities in the region.

Fig. 3.

Plot of Rn-222 and Ra-226 Vs Samples

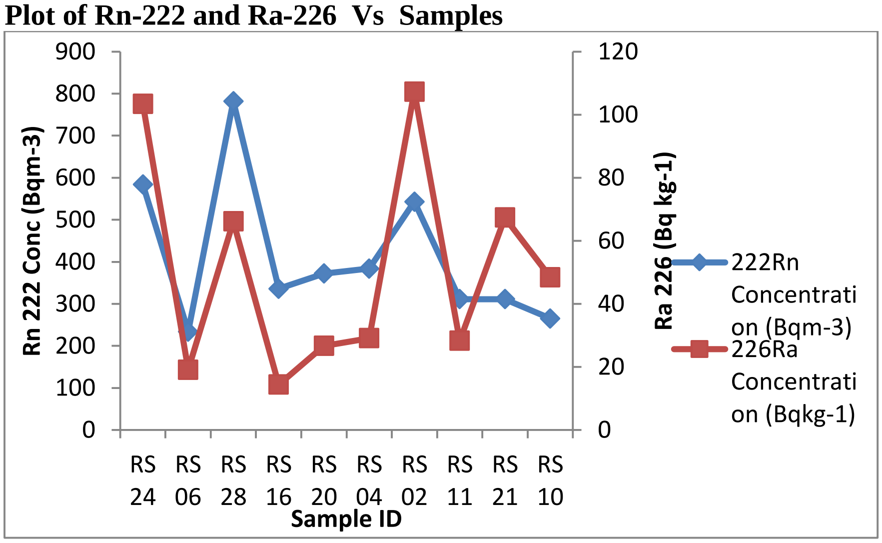
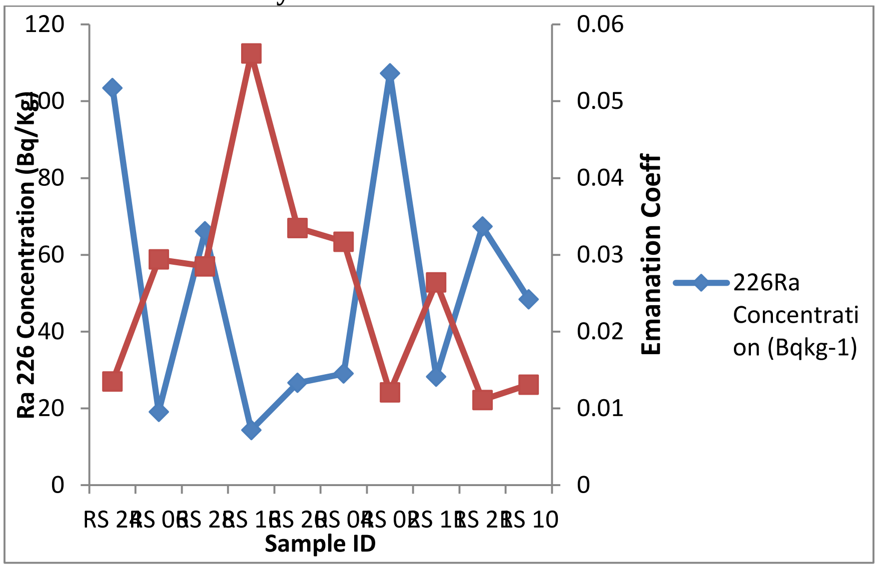


Fig. 4.
Plot of Ra-226 Activity Concentration Vs Emanation Coefficient



6. Conclusion

The significantly elevated concentrations of ^{222}Rn (234-782 Bq/m³) and ^{226}Ra (14.36-107.30 Bq/kg) observed in this study, along with the high annual effective dose (3.21 mSv/yr), reflect the substantial presence of naturally occurring radioactive materials in the local soil. While the radon emanation coefficients (0.011-0.056) fell within expected global ranges and demonstrated independence from ^{226}Ra activity concentrations, the calculated cancer risks - including fatality risk (1.7×10^{-4}) and lifetime fatality risk (10.2×10^{-3}) - consistently exceeded USEPA's negligible risk range (1×10^{-6} to 1×10^{-4}). These findings indicate a serious radiological hazard for artisanal miners who typically spend six or more hours daily in underground pits, exposing them to potentially dangerous radiation levels that could lead to increased cancer risks and other health effects. The results underscore the urgent need for radiation monitoring programs, mitigation strategies, worker education, and regulatory oversight to balance the economic benefits of mining with necessary health protections in this high-background radiation region.

7. Acknowledgements

The authors gratefully acknowledge the financial support provided by **Kaduna Polytechnic** and the **Tertiary Education Trust Fund (TETFund)** for sponsoring this research and enabling participation in relevant academic conferences. Their contributions were instrumental in facilitating the successful completion of this study, including fieldwork, laboratory analyses, and the dissemination of findings. We also extend our appreciation to the technical staff and colleagues who provided valuable insights during the course of this work.

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