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Determination of Thoron Activity Concentration in Soils of Vi, Shaffa and Garta Sama Communities, Michika Local Government Area, Adamawa State, Nigeria

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ABSTRACT
Thoron (^{220}Rn) is often disregarded in environmental radioactivity surveys because of its short half-life of 55.6 s, yet its short-lived decay products can contribute a non-trivial share of the inhalation dose received close to the ground surface, particularly in areas underlain by thorium-bearing lithologies. This study reports the activity concentrations of thoron and radon (^{222}Rn) determined in soils of the Vi, Shaffa and Garta Sama communities of Michika Local Government Area, Adamawa State, Nigeria, an area associated with artisanal mineral extraction and previously reported enrichment in uranium- and thorium-series radionuclides. Twenty-five soil-gas stations were established at 50 m, 100 m, 200 m, 500 m and 2 km from fixed reference points within the two communities, and radon and thoron activity concentrations were obtained in situ with a RAD7 electronic radon/thoron detector coupled to a soil-gas probe. Thoron activity concentration ranged from 117 to 3,580 Bq/m³, with a mean of 1,345.4 Bq/m³, while radon ranged from 75 to 210 Bq/m³, with a mean of 133.0 Bq/m³. Mean thoron and radon levels were markedly higher in Vi,Shaffa (1,767.5 and 155.6 Bq/m³, respectively) than in Garta Sama (712.2 and 99.2 Bq/m³, respectively). A moderate-to-strong positive correlation was found between radon and thoron ($r = 0.75$, $R^2 = 0.56$), and the thoron-to-radon ratio averaged 9.5, confirming that thoron dominates the soil-gas radioactive inventory of the study area. These results are consistent with reports of elevated natural radionuclide content in Michika soils and highlight the need for routine thoron monitoring, alongside radon, in radiological risk assessments of mineralised terrains.

INTRODUCTION

Naturally occurring radioactive materials distributed within the Earth's crust give rise to two short-lived noble-gas isotopes of environmental and radiological significance: radon (^{222}Rn), a member of the uranium-238 decay series, and thoron (^{220}Rn), a member of the thorium-232 decay series. Both gases and their solid decay products are recognized as major contributors to the natural background radiation dose received by humans, and inhalation of their progeny is implicated in the development of lung cancer (United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR], 2021; Belete & Anteneh, 2021).

Because of its markedly shorter half-life (55.6 s, against 3.82 days for radon), thoron has traditionally received far less research attention, and its presence has often been treated merely as an interference in radon instrumentation rather than as an independent radiological hazard (Bachirou et al., 2024). Recent surveys conducted in thorium-enriched terrains, however, indicate that indoor and near-surface thoron concentrations can be substantial and, in places, exceed those of radon, so that the dose contributed by the thoron progeny principally lead-212 can rival or surpass that from radon progeny (Bachirou et al., 2024; Waida et al., 2024; Soumayah et al., 2023).

In Nigeria, soil-gas radon has been investigated extensively using portable electronic monitors in south-western and north-central locations (Oladapo et al., 2022; Samuel et al., 2022), but comparable soil-gas thoron surveys remain scarce, especially in the north-eastern part of the country. Michika Local Government Area of Adamawa State has recently drawn attention because of its association with artisanal solid-mineral extraction and elevated natural radionuclide content. Gamma-spectrometric surveys of soils across the area reported mean activity concentrations of 81.3 Bq/kg for radium-226, 101.3 Bq/kg for thorium-232 and 324.8 Bq/kg for potassium-40, values that exceed the world average reference levels recommended by UNSCEAR (Zarma et al., 2023). A subsequent assessment of artisanal mining sites within the same local government area, including the Garta locality, reported still higher thorium-232 and uranium-238 concentrations and associated radiological hazard indices well above internationally recommended limits (Yusuf et al., 2025). These findings signal a matrix rich enough in thorium-series radionuclides that a dedicated evaluation of soil thoron rather than gamma-emitting parent radionuclides alone is warranted.

The present study was therefore designed to determine the activity concentration of thoron, alongside radon, in soils of two communities within Michika Local Government Area Vi, Shaffa and Garta Sama, that have not previously been the subject of a dedicated soil-gas thoron survey. The specific objectives of the research are to: measure radon and thoron activity concentrations in soil gas at multiple distances from reference points within each community; compare the radiological profile of the two communities; examine the relationship between radon and thoron levels; and discuss the results against relevant regional and international literature.

Study Area

Michika Local Government Area lies in the northern part of Adamawa State, north-eastern Nigeria, between latitudes 10°32′N and 10°41′N and longitudes 13°19′E and 13°25′E, and covers a land area of approximately 967 km² with a projected population of about 179,460 (Zarma et al., 2023). The area is bounded to the south by Mubi Local Government Area, to the east by the Republic of Cameroon, to the north by Madagali Local Government Area, and to the west by Borno State. Topographically, the western part of the area is relatively flat while the eastern part is hilly, with elevations exceeding 2,500 feet in places; several rivers drain the mountainous terrain (Zarma et al., 2023). Geologically, the area lies within the Precambrian Basement Complex of north-eastern Nigeria, with outcrops of granitic and migmatitic rock hosting vein-type uranium and thorium mineralisation that has attracted artisanal mining activity in several districts, including Garta (Yusuf et al., 2025).

Vi, Shaffa and Garta Sama are two of the communities within Michika Local Government Area situated close to zones of historical and ongoing artisanal mineral extraction. Soil sampling stations in the present study were distributed around fixed reference points within each community at radial distances of 50 m, 100 m, 200 m, 500 m and 2 km, in order to capture the spatial gradient of soil-gas radioactivity with increasing distance from the presumed source areas.

MATERIALS AND METHODS

Sampling Design

A total of twenty-five (25) soil-gas sampling stations were established across the two communities: fifteen (15) within Vi, Shaffa and ten (10) within Garta Sama. Station codes combine a location identifier with the sampling distance from the community reference point (for example, VsS100m denotes a station 100 m from the Vi, Shaffa reference point, while GS500m denotes a station 500 m from the Garta Sama reference point). At each station, a shallow probe hole was driven into undisturbed soil to a nominal depth of about 0.8 m, consistent with common soil-gas sampling practice for radon and thoron surveys (Oladapo et al., 2022; Samuel et al., 2022), and the position of each station was fixed with a hand-held global positioning system receiver.

Instrumentation and Measurement

Soil-gas radon and thoron activity concentrations were measured in situ using a RAD7 electronic radon/thoron detector coupled to a soil-gas probe driven to a nominal depth of about 0.8 m, an approach consistent with regional soil-gas radon and thoron surveys conducted in Nigeria and neighboring Cameroon using the same instrument (Oladapo et al., 2022; Samuel et al., 2022; Waida et al., 2024; Nkoulou Ndjana II et al., 2024). The RAD7 is a solid-state, ion-implanted silicon alpha-spectrometry detector that discriminates radon and thoron by the distinct alpha-particle energies of their respective progeny, allowing simultaneous and specific measurement of both gases without the cross-interference that affects some other radon instruments (Durridge Company, 2024).

At each station, the instrument's internal pump drew soil gas continuously from the probe into the detector's counting cell, and because the RAD7's response to thoron is essentially instantaneous, the pump was run without interruption throughout each measurement cycle to obtain a representative reading, following the manufacturer's recommended soil-gas protocol (Durridge Company, 2024). Radon and thoron activity concentrations, together with their associated one-sigma counting uncertainties, were logged for each station. Between successive measurements the sampling line and counting cell were purged with ambient air to minimise carry-over from the preceding station.

Data Analysis

The recorded radon and thoron activity concentrations (Bq/m³) were compiled and analysed descriptively (minimum, maximum, arithmetic mean and standard deviation) for the full data set and separately for the Vi, Shaffa and Garta Sama subsets. The strength of association between radon and thoron activity concentrations was assessed using the Pearson product-moment correlation coefficient, and the thoron-to-radon activity ratio was computed for each station to characterise the relative dominance of the two gases in the soil-gas inventory.

RESULTS AND DISCUSSION

Radon and Thoron Activity Concentration by Station

Table 1 presents the radon and thoron activity concentrations obtained at the twenty-five sampling stations across Vi, Shaffa and Garta Sama, together with the station-level thoron-to-radon ratio.

Table 1: Radon and Thoron Activity Concentrations (Bq/m³) in Soils of Vi, Shaffa and Garta Sama, Michika LGA

S/N	Sample ID	Community	Distance	Radon (Bq/m³)	Thoron (Bq/m³)	Tn/Rn ratio
1	VsS100m	Vi, Shaffa	100 m	156.0 ± 22.0	2550.0 ± 120.0	16.35
2	VwS2km	Vi, Shaffa	2000 m	137.0 ± 2.1	407.0 ± 5.1	2.97
3	GS2km	Garta Sama	2000 m	82.0 ± 1.6	327.0 ± 4.4	3.99
4	VES100m	Vi, Shaffa	100 m	141.0 ± 2.2	1414.0 ± 9.2	10.03
5	VES2km	Vi, Shaffa	2000 m	117.0 ± 1.9	1063.0 ± 8.1	9.09
6	VwS100m	Vi, Shaffa	100 m	136.0 ± 2.1	1800.0 ± 11.0	13.24
7	VES50m	Vi, Shaffa	50 m	154.0 ± 2.1	1431.0 ± 9.2	9.29
8	VsS500m	Vi, Shaffa	500 m	130.0 ± 2.1	657.0 ± 6.3	5.05
9	VwS500m	Vi, Shaffa	500 m	130.0 ± 2.0	800.0 ± 7.0	6.15
10	GS100m	Garta Sama	100 m	108.0 ± 1.8	326.0 ± 4.4	3.02
11	GS50m	Garta Sama	50 m	82.0 ± 1.5	117.0 ± 3.1	1.43
12	SS100m-1	Garta Sama	100 m	79.0 ± 1.6	836.0 ± 7.3	10.58
13	SS2km	Garta Sama	2000 m	75.0 ± 1.5	691.0 ± 6.7	9.21
14	SS100m-2	Garta Sama	100 m	108.0 ± 1.8	1900.0 ± 11.0	17.59
15	GS200m	Garta Sama	200 m	96.0 ± 1.7	610.0 ± 6.0	6.35
16	SS50m	Garta Sama	50 m	112.0 ± 1.9	929.0 ± 7.6	8.29
17	SS200m	Garta Sama	200 m	130.0 ± 2.0	1017.0 ± 7.9	7.82
18	VsS2km	Vi, Shaffa	2000 m	150.0 ± 2.0	3130.0 ± 13.0	20.87
19	GS500m	Garta Sama	500 m	120.0 ± 2.0	369.0 ± 4.8	3.08
20	VsS50m	Vi, Shaffa	50 m	210.0 ± 2.5	3580.0 ± 15.0	17.05
21	VsS200m	Vi, Shaffa	200 m	203.0 ± 2.5	2790.0 ± 13.0	13.74
22	VwS200m	Vi, Shaffa	200 m	203.0 ± 2.4	1950.0 ± 11.0	9.61
23	VES500m	Vi, Shaffa	500 m	171.0 ± 2.2	1100.0 ± 8.0	6.43
24	VES200m	Vi, Shaffa	200 m	145.0 ± 2.2	1740.0 ± 11.0	12.00
25	VwS50m	Vi, Shaffa	50 m	151.0 ± 1.9	2100.0 ± 10.0	13.91

Descriptive Statistics

Across all twenty-five stations, thoron activity concentration ranged from 117.0 to 3580.0 Bq/m³, with a mean of 1345.4 Bq/m³ and a standard deviation of 920.3 Bq/m³, while radon ranged from 75.0 to 210.0 Bq/m³, with a mean of 133.0 Bq/m³ and a standard deviation of 36.9 Bq/m³. Both parameters showed a wide spread, with thoron exhibiting a coefficient of variation of about 68%, considerably higher than that of radon (about 28%), reflecting the greater spatial heterogeneity typically associated with the short diffusion length and rapid decay of thoron in soil pore spaces.

Table 2: Summary Statistics of Radon and Thoron Activity Concentrations, Overall and by Community

Parameter / Group	N	Min.	Max.	Mean	SD
Radon, all stations (Bq/m³)	25	75.0	210.0	133.0	36.9
Thoron, all stations (Bq/m³)	25	117.0	3580.0	1345.4	920.3
Radon, Vi, Shaffa (Bq/m³)	15	117.0	210.0	155.6	27.8
Thoron, Vi, Shaffa (Bq/m³)	15	407.0	3580.0	1767.5	899.8
Radon, Garta Sama (Bq/m³)	10	75.0	130.0	99.2	18.2
Thoron, Garta Sama (Bq/m³)	10	117.0	1900.0	712.2	484.4

When disaggregated by community, Vi, Shaffa recorded a substantially higher mean thoron activity concentration (1767.5 Bq/m³) than Garta Sama (712.2 Bq/m³), and a similar pattern was observed for radon (155.6 Bq/m³ versus 99.2 Bq/m³). This spatial contrast is consistent with reports of pronounced local variability in natural radionuclide content across Michika Local Government Area, where soils close to zones of mineral extraction and thorium-bearing outcrops have been shown to carry substantially higher radium-226 and thorium-232 activity than more distal locations (Yusuf et al., 2025; Zarma et al., 2023).

Spatial Trend with Distance from the Reference Point

At both communities, the highest thoron and radon activity concentrations were generally recorded at the stations closest to the reference points (50 m and 100 m), while the lowest values tended to occur at the most distant stations (2 km). For instance, in Vi, Shaffa the 50 m station (VsS50m) returned the highest thoron activity concentration in the entire data set (3,580 ± 15 Bq/m³), whereas the 2 km station on the same transect (VwS2km) returned one of the lowest values recorded for that community (407 ± 5.1 Bq/m³). A broadly comparable decreasing trend with distance was observed in Garta Sama. This pattern is consistent with a localised source of thorium-series radionuclides plausibly linked to the mineralised outcrops and artisanal workings reported in the area (Yusuf et al., 2025) whose influence on soil-gas activity concentration diminishes with increasing distance.

Relationship between Radon and Thoron

A Pearson correlation analysis between the paired radon and thoron activity concentrations across all twenty-five stations yielded a coefficient of $r = 0.75$ ($R^2 = 0.56$), indicating a moderate-to-strong positive association (Figure 1). Comparable lithology-driven co-variation between soil-gas radon and associated thorium-series indicators has been reported in basement-complex and mineralised terrains of Nigeria and Cameroon, where geological setting was identified as a principal control on soil-gas radioactivity (Oladapo et al., 2022; Nkoulou Ndjana II et al., 2024). The comparatively strong radon–thoron relationship observed in the present study suggests that, in Vi,Shaffa and Garta Sama, the two radioactive gases may be released from broadly co-located source minerals, consistent with the reported co-enrichment of uranium-238 and thorium-232 in Michika soils and mine-site materials (Yusuf et al., 2025; Zarma et al., 2023).

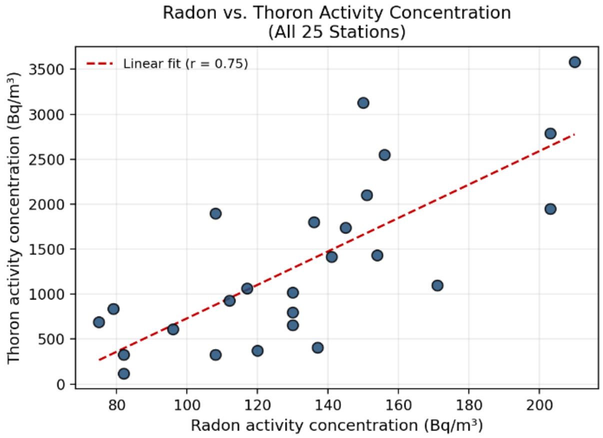

Figure 1: Scatter Plot of Radon Versus Thoron Activity Concentrations Across All Twenty-Five Sampling Stations in Vi-Shaffa and Garta Sama, Showing a Moderate-to-Strong Positive Correlation ($r = 0.75$, $R^2 = 0.56$)

The thoron-to-radon activity ratio at individual stations ranged from 1.43 to 20.87, with a mean of 9.49, confirming that thoron activity concentration in the soil gas of the study area consistently exceeded that of radon, in most cases by close to an order of magnitude. Comparable dominance of thoron over radon has been reported for the thorium-enriched, radon-thoron-prone terrain of the neighbouring Adamawa Region of Cameroon, where indoor thoron concentrations and equilibrium factors were found to exceed globally assumed values (Bachirou et al., 2024; Soumayah et al., 2023). Given that Michika lies within the same broader north-eastern Nigeria–Cameroon geological province, a similarly elevated thoron contribution to the local radiological environment is plausible and merits continued monitoring.

Comparison with Other Studies

The mean radon activity concentration obtained in this study (133.0 Bq/m³) is markedly lower than soil-gas radon levels reported for granitic and gneissic terrains of south-western Nigeria, where means in the low tens of kBq/m³ have been documented using comparable soil-probe methods (Oladapo et al., 2022; Samuel et al., 2022). This difference may reflect contrasts in probe depth, soil permeability, moisture content and the specific radium-226 content of the sampled horizons between the two regions, in addition to genuine differences in underlying lithology. By contrast, the pronounced dominance of thoron over radon observed here aligns with the broader picture emerging from thorium-rich basement terrains of the Adamawa geological province spanning north-eastern Nigeria and northern Cameroon (Bachirou et al., 2024; Soumayah et al., 2023), reinforcing the case for including thoron, and not radon alone, in radiological surveys of this region.

Radiological Implication

Although the short half-life of thoron limits its capacity to migrate far from its point of generation and to accumulate indoors compared with radon, its short-lived progeny particularly lead-212, with a half-life of about 10.6 hours can build up to appreciable levels in the breathing zone close to ground level and within poorly ventilated structures built directly on, or with materials derived from, thorium-rich soils (Belete & Anteneh, 2021; UNSCEAR, 2021). The consistently elevated thoron-to-radon ratios recorded in this study, together with previously reported enrichment in thorium-232 and associated radiological hazard indices for Michika soils (Yusuf et al., 2025; Zarma et al., 2023), suggest that thoron exposure in Vi, Shaffa and Garta Sama should not be dismissed on the basis of radon-focused assessments alone.

CONCLUSION

Soil-gas radon and thoron activity concentrations were determined at twenty-five stations within the Vi, Shaffa and Garta Sama communities of Michika Local Government Area, Adamawa State, Nigeria. Thoron activity concentration (mean 1,345.4 Bq/m³; range 117–3,580 Bq/m³) consistently and substantially exceeded radon activity concentration (mean 133.0 Bq/m³; range 75–210 Bq/m³) across the study area, with a mean thoron-to-radon ratio of about 9.5. Vi, Shaffa recorded higher mean values of both gases than Garta Sama, and activity concentrations generally decreased with increasing distance from community reference points, consistent with a localised thorium- and uranium-bearing source. A moderate-to-strong positive correlation (r = 0.75) was found between radon and thoron, differing from the weak or absent correlation reported in some other soil radioactivity studies and pointing to a degree of shared source mineralogy in the study area. These findings corroborate earlier reports of elevated natural radionuclide content in Michika soils and mining sites and underscore the need for thoron to be incorporated, alongside radon, into routine radiological monitoring and risk assessment programmes for communities situated near mineralised and artisanal mining terrains in Adamawa State.

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RECOMMENDATIONS

Based on the findings of this study, it is recommended that:

i. A complementary gamma-spectrometric assessment of soil thorium-232 and radium-226 content be undertaken at the same stations to permit calculation of thoron and radon emanation and exhalation factors.
ii. Indoor thoron and radon measurements be carried out in dwellings within Vi, Shaffa and Garta Sama, particularly those closest to the identified high-activity zones, to evaluate actual public exposure.
iii. Relevant regulatory and public-health authorities extend routine radiological monitoring in Michika Local Government Area to explicitly include thoron, rather than radon alone.
iv. Further studies with a denser sampling grid and repeated seasonal measurements be conducted to characterise temporal variability and to refine the spatial extent of the elevated-activity zones identified in this study.

REFERENCES

Bachirou, S., Saïdou, Mishra, R., Kranrod, C., Hosoda, M., Jalaluddin, S., Sapra, B. K., Njock, M. G. K., & Tokonami, S. (2024). Thoron exposure in the radon-thoron prone area of the Adamawa Region, Cameroon. Applied Radiation and Isotopes, 213, Article 111498. https://doi.org/10.1016/j.apradiso.2024.111498

Belete, G. D., & Anteneh, Y. A. (2021). General overview of radon studies in health hazard perspectives. Journal of Oncology, 2021, Article 6659795. https://doi.org/10.1155/2021/6659795

Durridge Company. (2024). Soil gas measurement [Application note]. Durridge Company, Inc. https://durridge.com/support/technical-resources/application-notes/soil-gas-measurement/

Nkoulou Ndjana II, J. E., Saïdou, Hamadou Yerima, A., Oumar Bobbo, M., Nugraha, E. D., & Ipan, A. S. (2024). Lithological impact on radon levels: A study of indoor and soil gas radon in the centre region of Cameroon.

Journal of Geophysical Research: Atmospheres, 129, Article e2024JD040843. https://doi.org/10.1029/2024JD040843

Oladapo, O. O., Adagunodo, T. A., Aremu, A. A., Oni, O. M., & Adewoye, A. O. (2022). Evaluation of soil-gas radon concentrations from different geological units with varying strata in a crystalline basement complex of southwestern Nigeria. Environmental Monitoring and Assessment, 194(7), Article 486. https://doi.org/10.1007/s10661-022-10173-x

Samuel, T. D., Farai, I. P., & Awelewa, A. S. (2022). Soil gas radon concentration measurement in estimating the geogenic radon potential in Abeokuta, Southwest Nigeria. Journal of Radiation Research and Applied Sciences, 15(2), 55–58.

Soumayah, B., Saïdou, Ndjana Nkoulou II, J. E., Haman Fouda, S., & Kwato Njock, M. G. (2023). Mapping in a radon-prone area in Adamawa region, Cameroon, by measurement of radon activity concentration in soil. Radiation and Environmental Biophysics, 62, 391–402. https://doi.org/10.1007/s00411-023-01042-3

United Nations Scientific Committee on the Effects of Atomic Radiation. (2021). UNSCEAR 2019 report, Annex B: Lung cancer from exposure to radon. United Nations.

Waida, J., Oyeleke, O. A., & Ademola, J. A. (2024). Simultaneous indoor radon/thoron and in situ outdoor gamma dose measurements and estimation of annual effective dose in a tin mining area of Jos Plateau, Nigeria. Radiation Protection Dosimetry, 200(13), 1258–1265. https://doi.org/10.1093/rpd/ncae152

Yusuf, E. Y., Maitera, O. N., Moddibo, U. U., & Buba, O. M. (2025). Radiological assessment of artisanal mining sites in Michika Local Government Area, Adamawa State. African Journal of Medicine, Surgery and Public Health Research, 2(3), 436–454. https://doi.org/10.58578/ajmsphr.v2i3.6850

Zarma, S. S., Garba, N. N., Rabi'u, N., Dankawu, U. M., Bello, S., Adamu, G. D., & Ndikilar, C. E. (2023). Assessment of natural radionuclides in soil samples from Michika, Adamawa State, Nigeria. FUDMA Journal of Sciences, 7(4), 189–194. https://doi.org/10.33003/fjs-2023-0702-1917