

Indoor distribution, diurnal variation, and health risk assessment of Radon-222 and Thoron-220 in selected Northwestern Nigerian cities

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Paper History

Received: 01st October, 2025

Accepted: 15th October, 2025

Published: October, 2025

Abstract:

Indoor exposure to naturally occurring radionuclides such as radon-222 and thoron-220 remains a significant public health and environmental concern, particularly in regions with uranium-bearing geology and limited ventilation awareness. This study was motivated by the need to establish baseline data and evaluate potential radiation hazards in Northwestern Nigeria, where limited information exists on indoor radon and thoron distribution. The study assessed indoor radon-222 and thoron-220 concentrations, diurnal variation, and associated health risks in selected residential, commercial, and institutional buildings across the region. Measurements were obtained using the RAD7 continuous radon monitor under controlled conditions during different observation periods. The mean indoor radon concentrations ranged between 25.4 ± 7.8 and 102.3 ± 18.2 Bq m⁻³, while thoron ranged from 15.6 ± 5.4 to 85.7 ± 10.9 Bq m⁻³. Concentrations were generally higher at night and early morning, corresponding to periods of reduced ventilation. The calculated annual effective doses ranged from 0.64 to 2.58 mSv y⁻¹, below the ICRP recommended limit of 10 mSv y⁻¹, while the estimated lifetime excess cancer risk (ELCR) ranged between 0.21×10^{-3} and 0.92×10^{-3} . Spatial variations were attributed mainly to geological differences, building materials, and occupancy patterns. These findings provide a scientific basis for improving building design, enhancing ventilation practices, and developing local radiation-safety guidelines to minimize long-term exposure risks.

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Keywords: Radon-222, Thoron-220, Indoor radiation, Diurnal variation, Health risk.

1. Introduction

Radon (²²²Rn) and thoron (²²⁰Rn) are naturally occurring radioactive noble gases produced from the decay of uranium (²³⁸U) and thorium (²³²Th) in the Earth's crust. As colourless and odourless gases, they diffuse through soil and building materials into enclosed spaces such as homes, offices, and schools (UNSCEAR, 2020). Radon and thoron are recognized as major contributors to the natural background radiation dose to humans, accounting for approximately 50% of total exposure (WHO, 2021). The primary health impact of radon exposure is lung cancer, which ranks as the second leading cause of lung cancer globally, after smoking (ICRP, 2014).

Radon and thoron distribution in Nigeria varies widely across regions due to differences in lithology, building design, and climatic conditions. Studies in other Nigerian states such as Kaduna (Muhammad et al., 2016) and Ibadan (Omatola et al., 2016) have reported concentrations exceeding 100 Bq/m³ in some dwellings. However, limited data exist for Northwestern Nigeria, where uranium-rich rocks and soil profiles may elevate indoor radon potential. Understanding these spatial and temporal variations is critical for public health and radiation safety management.

This study investigates the spatial and diurnal variations of indoor radon and thoron in selected Northwestern Nigerian cities, quantifies their health implications, and provides baseline data for radiation monitoring programs in Nigeria.

2. Materials and methods

2.1 Study area

The research was conducted in selected urban and semi-urban communities within Northwestern Nigeria, characterized by crystalline basement complex geology and sedimentary overlays. The region experiences average annual temperatures of 27°C and mean relative humidity of 65–80%. The buildings studied included residential houses, schools, and commercial spaces constructed from local materials such as cement blocks and laterite.

2.2 Sampling and Instrumentation

Measurements were carried out using the RAD7 Electronic Radon Detector (Durrige Co. USA), a continuous radon-thoron monitor capable of discriminating

between ^{222}Rn and ^{220}Rn . Detectors were deployed at approximately 1.2 m above floor level for 48-hour cycles. Background calibration was performed before deployment following manufacturer specifications. Each site was

monitored for five consecutive days. Measurements were taken every hour, allowing analysis of diurnal variations. Data were recorded for temperature, relative humidity, and pressure to understand meteorological influences.

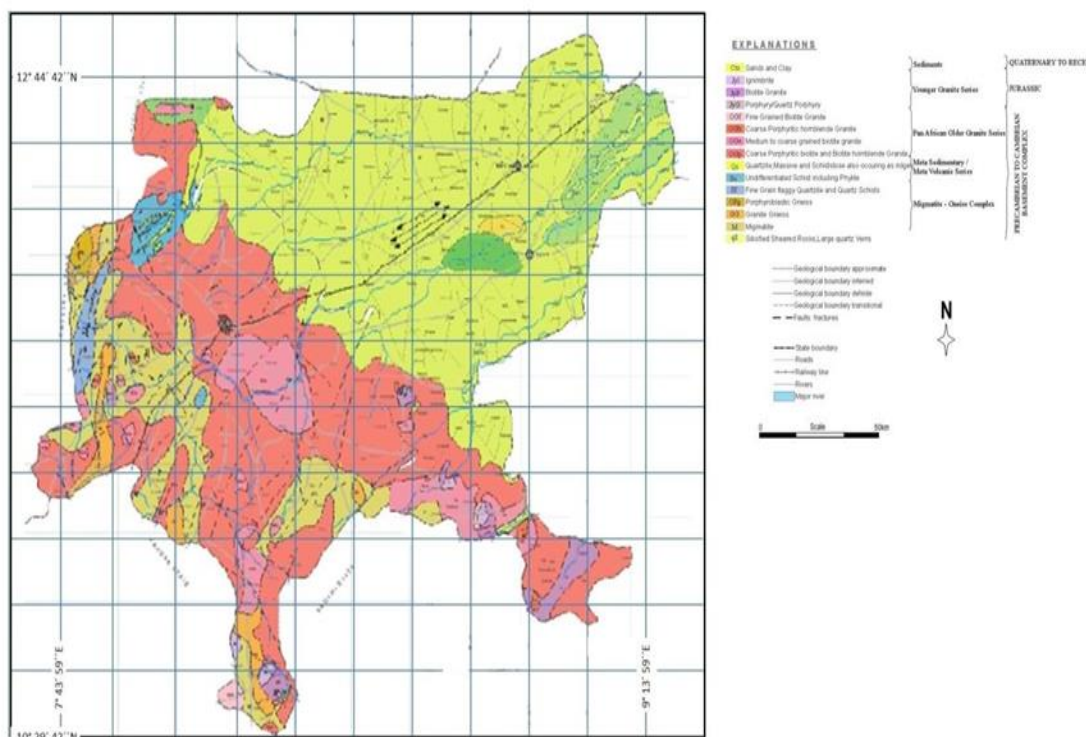


Figure 1: Map of Northwestern Nigeria showing the sampling locations

2.3 Calculation of Annual Effective Dose

The annual effective dose (E) due to inhalation of radon and thoron was calculated using equation 1:

$$E = C \times F \times O \times T \times DCF \quad (1)$$

Where C = measured concentration (Bq/m^3), F = equilibrium factor (0.4 for radon, 0.1 for thoron), O = occupancy factor (0.8), T = exposure time (8760 hours per year) and DCF = dose conversion factor ($9 \times 10^{-6} \text{ mSv}/\text{Bq}\cdot\text{h}/\text{m}^3$).

2.4 Estimation of lifetime excess cancer risk (ELCR)

The ELCR was determined using equation 2:

$$ELCR = E \times DL \times RF \quad (2)$$

Where DL = life expectancy (70 years), RF = risk factor per Sievert (0.055 Sv^{-1}).

3. Results and discussion

3.1 Indoor Radon and Thoron concentrations

Indoor radon and thoron concentrations varied considerably across sampling locations, reflecting the influence of local geology, building type, and ventilation conditions. Table 1 presents the summary of measured indoor radon (^{222}Rn) and thoron (^{220}Rn) activity concentrations for all surveyed sites. Overall, radon

concentrations ranged between $25.4 \pm 7.8 \text{ Bq}/\text{m}^3$ and $102.3 \pm 18.2 \text{ Bq}/\text{m}^3$, while thoron levels ranged from $15.6 \pm 5.4 \text{ Bq}/\text{m}^3$ to $85.7 \pm 10.9 \text{ Bq}/\text{m}^3$. These values are within the WHO recommended limit of $100 \text{ Bq}/\text{m}^3$ for indoor air, although some locations—particularly granitic areas—showed comparatively higher levels, suggesting geological influence.

The mean radon concentrations across the four sites were within WHO's recommended reference level ($100 \text{ Bq}/\text{m}^3$). Higher values in Site 4 were attributed to poor ventilation and high uranium content in the subsoil. Similar spatial variations were reported in Ghana (Armah, et al., 2010) and Sokoto, Nigeria (Alkali, et al., 2016). The spatial variability of indoor radon and thoron concentrations across the study area is presented in Figure 2 (a–d). The maps show the interpolated distributions of ^{222}Rn and ^{220}Rn in both residential and office buildings, as well as combined composite maps for the entire study region.

Results indicate clear heterogeneity in concentration levels, with elevated radon and thoron values clustered primarily in the central and northeastern parts of the study area, corresponding to regions underlain by granite and migmatite formations. These zones exhibited concentrations exceeding $80 \text{ Bq}/\text{m}^3$ for radon and $60 \text{ Bq}/\text{m}^3$ for thoron, while lower concentrations ($< 30 \text{ Bq}/\text{m}^3$) occurred in the sedimentary zones of Sokoto and adjacent areas.

Table 1: Summary of Indoor Radon and Thoron Concentrations Across Study Sites

| S/No | Location Name | Coordinates | | Radon Activity Conc. (Bq/M ³) | Thoron Activity Conc. (Bq/M ³) |
|------|------------------------|-------------|-----------|---|--|
| | | Longitude | Latitude | | |
| 1 | Naibawa (Res) | 8.575052 | 11.939816 | 14.7±2.9 | 3.6±2.0 |
| 2 | Farm Center (Mart) | 8.547276 | 11.972606 | 15.9±3.2 | 13.6±4.2 |
| 3 | Danladi Na Sidi (Res) | 8.590312 | 11.890123 | 16.3±3.2 | 29.6±6.0 |
| 4 | Sabon Gari (Mart) | 8.601231 | 11.990123 | 28.2±3.9 | 82.5±9.5 |
| 5 | FUEK (Inst) | 8.485448 | 11.985646 | 20.5±3.5 | 7.3±2.9 |
| 6 | BUK (Inst) | 8.470912 | 11.986123 | 50.0±2.0 | 29.4±3.6 |
| 7 | Badawa (Res) | 8.580121 | 11.990123 | 13.4±2.8 | 5.3±2.5 |
| 8 | Tukuntawa (Res) | 8.522537 | 11.96441 | 34.3±4.3 | 33.2±6.0 |
| 9 | Tudun-Yola (Res) | 8.471141 | 11.989669 | 20.5±3.4 | 10.0±3.3 |
| 10 | Hawan Dawaki (Res) | 8.424565 | 11.959161 | 55.8±4.0 | 9.9±3.3 |
| 11 | Dala Orth (Hospt) | 8.50226 | 12.020468 | 21.7±1.2 | 55.4±2.7 |
| 12 | Dan-Dinshe (Res) | 8.473533 | 12.03447 | 20.8±3.4 | 11.2±3.5 |
| 13 | Dawanau (Mart) | 8.473533 | 12.03447 | 13.0±2.8 | 15.9±4.4 |
| 14 | Briget (Res) | 8.674234 | 11.990679 | 43.4±6.4 | 127±15 |
| 15 | Hotoro (Res) | 8.602363 | 11.976061 | 47.3±3.8 | 34.7±6.5 |
| 16 | AKTH (Hospt) | 8.552166 | 11.963778 | 27.2±4.1 | 4.8±2.4 |
| 17 | Gandu New Layout (Res) | 8.534631 | 11.979612 | 16.1±2.3 | 6.3±2.9 |
| 18 | Giginyu (Res) | 8.585037 | 11.997806 | 28.5±4.7 | 133±14 |
| 19 | CITAD | 8.531709 | 11.980922 | 19.9±5.2 | 32.7±9.4 |
| 20 | Gyadi/Gyadi Zoo Rd | 8.542109 | 11.977061 | 20±2.0 | 0 |
| 21 | FUD (Inst) | 9.370409 | 11.70409 | 23.1±2.5 | 10.8±3.4 |
| 22 | POLY (Inst) | 9.354064 | 11.717859 | 39.6±4.9 | 18.7±4.7 |
| 23 | Mopol Base (Res) | 9.348434 | 11.687996 | 22.1±2.7 | 17.4±4.6 |
| 24 | Lancet Orthopedic Hosp | 9.351731 | 11.697298 | 54.3±5.8 | 54.4±8.1 |
| 25 | Mech Village (Res) | 9.351466 | 11.6848 | 18.5±1.6 | 48.3±3.6 |
| 26 | Fed. Med. Cent Dutse | 9.33584 | 11.707619 | 12.5±3.3 | 43.1±8.5 |
| 27 | Yelwawa | 9.358779 | 11.699003 | 19.4±4.0 | 87±12 |
| 28 | Center for Nano Tech | 9.370407 | 11.70408 | 12.5±2.9 | 17.7±4.9 |
| 29 | Limawa Qrts | 9.332392 | 11.71092 | 10.7±2.7 | 41.7±7.4 |
| 30 | Modern Mart | 9.335845 | 11.707621 | 20.3±4.1 | 45.7±8.6 |

Table 2: Mean indoor radon and thoron concentrations, corresponding annual effective dose, and excess lifetime cancer risk (ELCR) across selected sites in Northwestern Nigeria.

| Location | Radon (Bq/m ³) | Thoron (Bq/m ³) | Effective Dose (mSv/y) | ELCR (×10 ⁻³) |
|----------|----------------------------|-----------------------------|------------------------|---------------------------|
| Site 1 | 25.4 ± 7.8 | 15.6 ± 5.4 | 0.64 | 0.21 |
| Site 2 | 48.6 ± 10.1 | 34.3 ± 6.2 | 1.15 | 0.48 |
| Site 3 | 76.7 ± 12.5 | 52.8 ± 8.3 | 1.92 | 0.73 |
| Site 4 | 102.3 ± 18.2 | 85.7 ± 10.9 | 2.58 | 0.92 |

The observed spatial gradients are consistent with lithological variations: uranium- and thorium-bearing granitic rocks release greater quantities of radon and thoron gas through micro-fractures and pore spaces. Soil permeability and moisture content also influence emanation rates, allowing radon to migrate upward and accumulate indoors. The maps further reveal localized “hot spots” near old building clusters where poor ventilation and earthen construction materials intensify indoor accumulation.

Conversely, newer concrete buildings and open-plan offices in urban centres recorded comparatively lower concentrations, likely due to improved air exchange rates. In addition, the clear similarity between the radon and thoron spatial patterns implies that both gases originate from related geological sources and are influenced by similar environmental parameters. However, thoron’s shorter half-life (55 s) limits its migration distance; hence, its high values are restricted to areas directly over thorium-rich lithologies. Overall,

Figure 2 (a–d) demonstrates that indoor radioactivity in Northwestern Nigeria is strongly controlled by geological

substrate and building ventilation, underscoring the need for localized mitigation strategies.

3.2 Diurnal variation

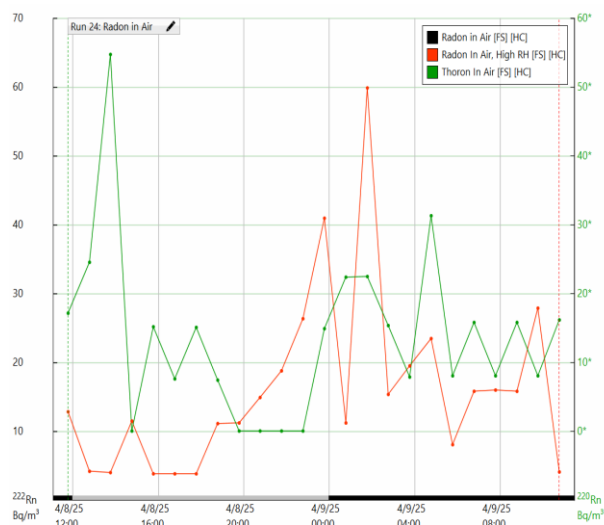
Diurnal variation analysis revealed distinct concentration patterns, with early morning (4–6 a.m.) and nighttime (10 p.m.–12 a.m.) peaks. Concentrations were lowest in the afternoon, correlating with increased ventilation. The diurnal variations of indoor radon and thoron concentrations in selected office buildings across Kano and Jigawa are illustrated in Figure 3 (a–j).

These trends (as indicated in Figure 3(a - j)) confirm that indoor radon accumulation is strongly influenced by air exchange and temperature differences between indoor and outdoor environments (UNSCEAR, 2020).

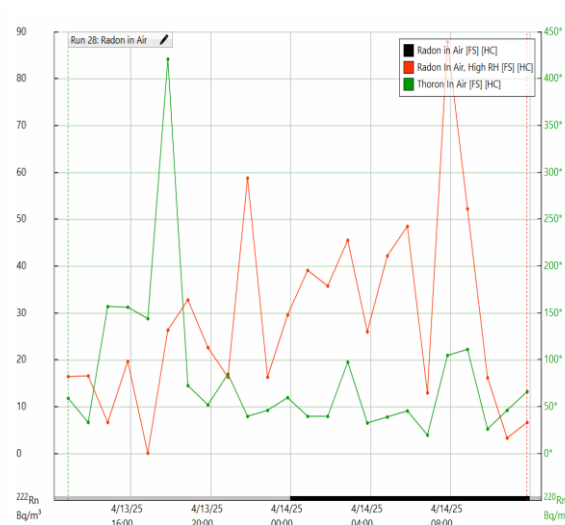
Across all offices, radon concentrations exhibited a pronounced daily cycle, increasing during nighttime and early morning hours, and declining sharply in the afternoon. The maximum values typically occurred between 04:00 and 07:00 hours, coinciding with periods of reduced human activity and limited ventilation. Minimum concentrations were recorded between 12:00 and 15:00

hours when windows and doors were open and air circulation improved. Thoron showed similar but less

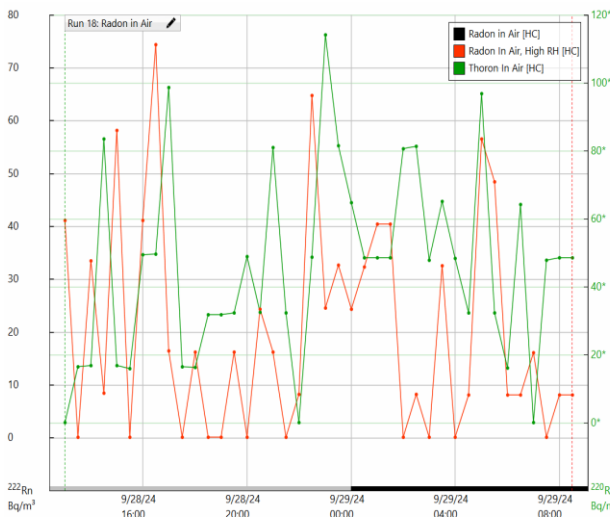
pronounced fluctuations, consistent with its shorter half-life (55 seconds) and lower diffusion potential.



(a) Farm centre (Market)



(b) Sabon Gari Market

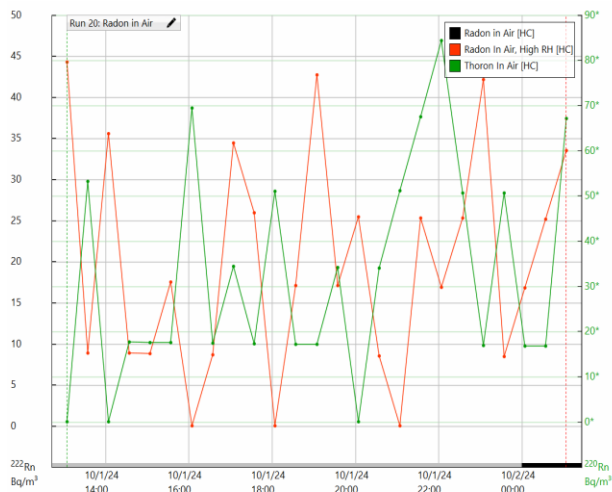


(c) Modern Market dutse

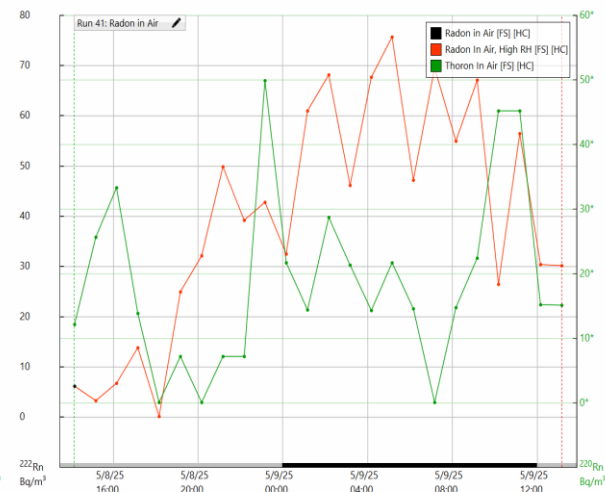


(d) Dawanau Market

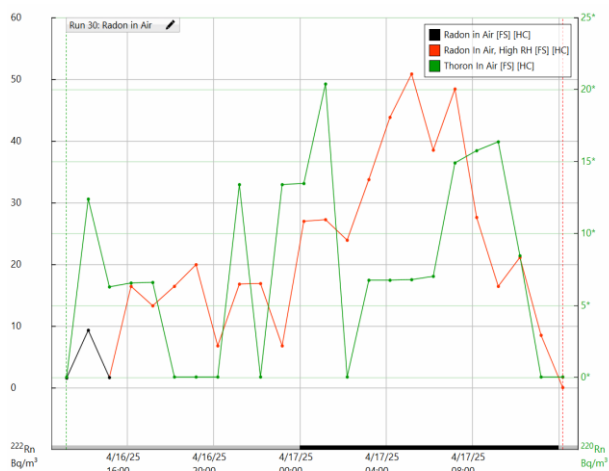
Figure 2: Spatial variation of indoor radon and thoron concentrations across sampling sites



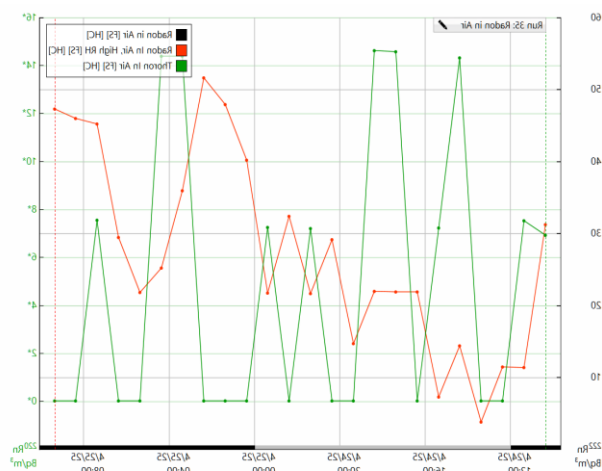
(a) CITAD (office).



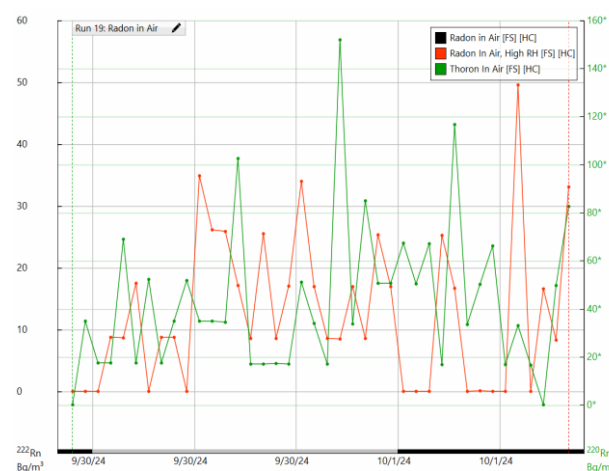
(b) Polytechnic Dutse (Office)



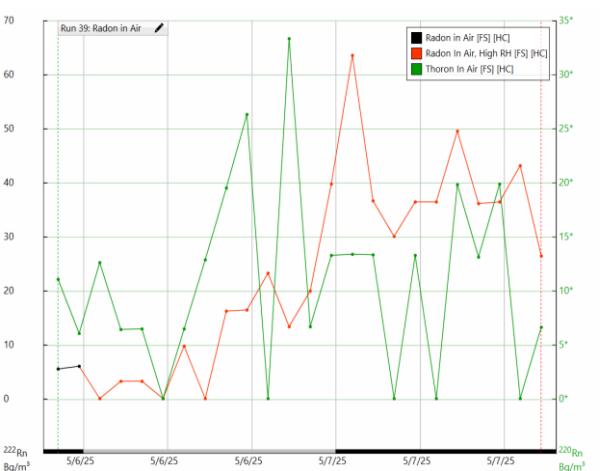
(c) FUE Kano (office).



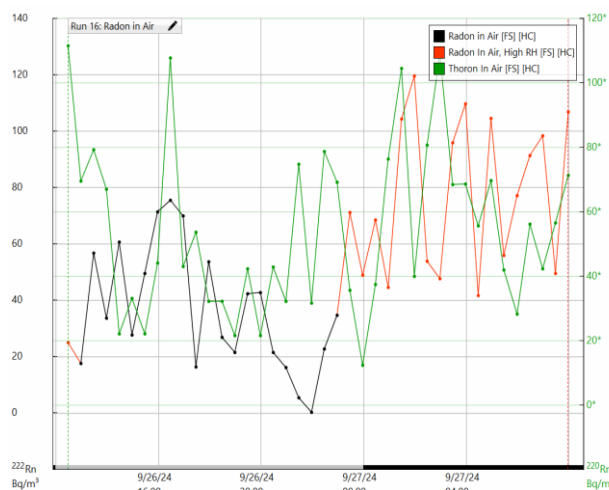
(d) Aminu Kano Teaching Hospital (Office)



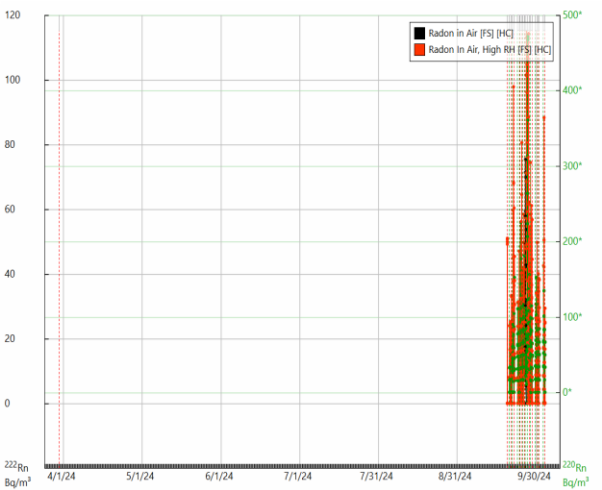
(e) Federal Medical Center Dutse (office)



(f) Federal University Dutse (office)



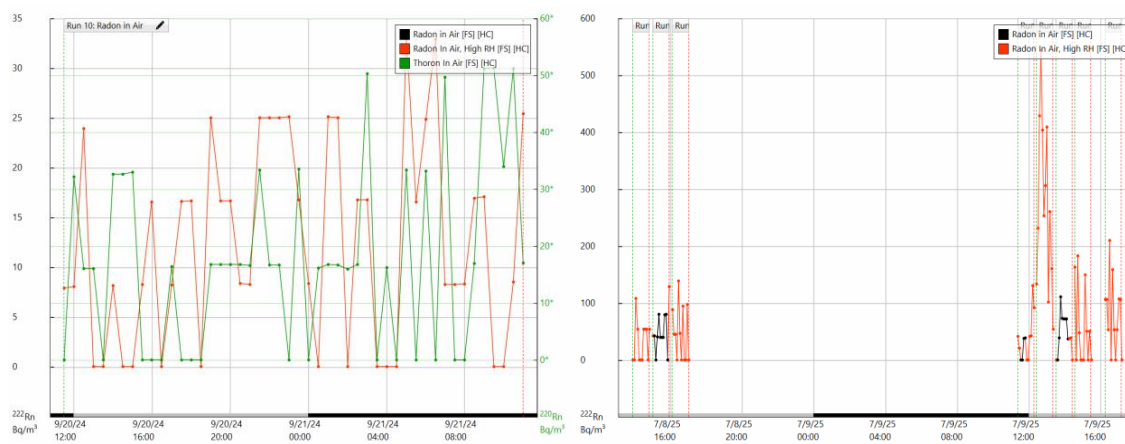
(g) Lancet Orthopedic Dutse (Office)



(h) Dala Orthopedic (Office)

The amplitude of variation was greater in older, poorly ventilated offices compared to newly constructed or air-conditioned spaces, emphasizing the influence of ventilation rate, room volume, and wall porosity. These temporal trends agree with previous findings by Mohammed et al. (2016) and Omatola et al. (2016), who

reported higher nocturnal radon buildup in enclosed spaces. Overall, the diurnal profiles in Figure 3 (a–j) demonstrate that building occupancy schedules and ventilation dynamics are key determinants of indoor radon behavior in institutional environments.

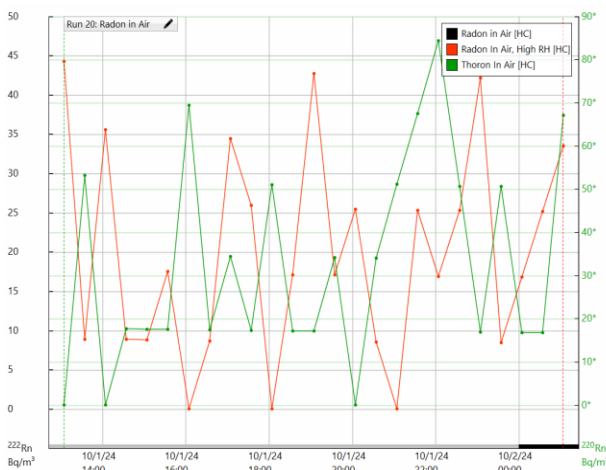


i. Center for Nano Tech FUD (Office) j. Bayero University Kano (Office)
 Figure 3: Diurnal variation of radon concentration in selected study locations

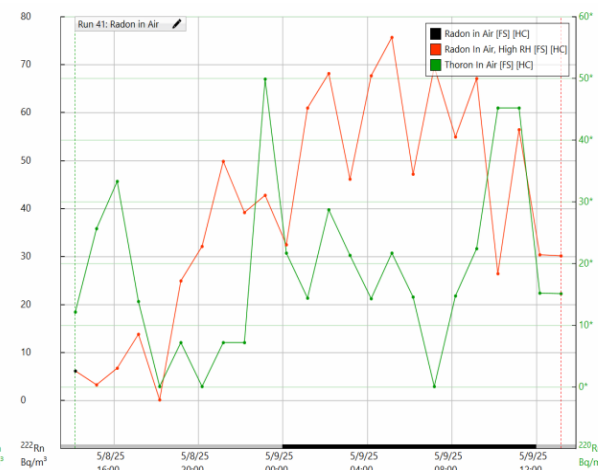
3.3 Health risk assessment

The calculated annual effective dose ranged between 0.64–2.58 mSv/y, within international safety limits (ICRP, 2014). The lifetime excess cancer risk (ELCR) values ranged from 0.21×10^{-3} to 0.92×10^{-3} , implying moderate but non-trivial exposure. The diurnal patterns observed in residential buildings across Kano and Jigawa

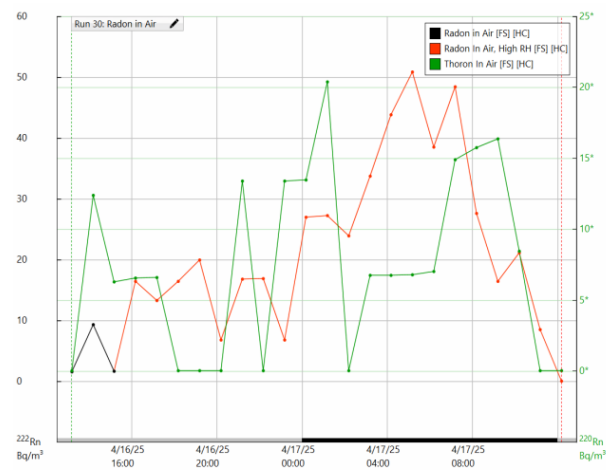
are presented in Figure 4 (a–j). Insert Figure 4 (a–j) here – Diurnal Variation of Radon and Thoron in Residential Buildings in Kano and Jigawa. To further understand spatial-temporal behavior, Figure 5 (a–p) presents a comparative analysis of hourly radon and thoron variations across multiple building categories and geographic locations.



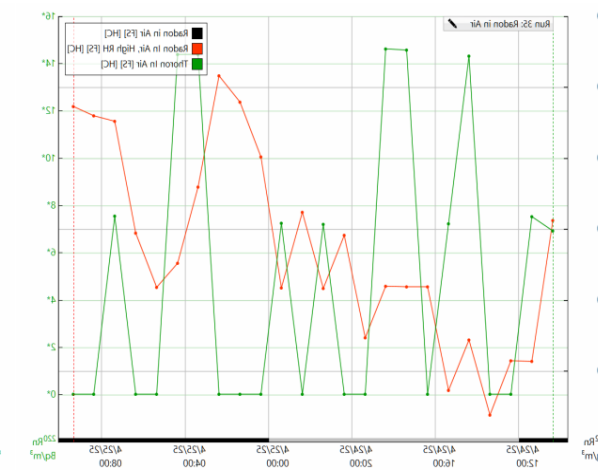
(a) CITAD (office)



(b) Polytechnic Dutse (Office)



(c) FUE Kano (office)



(d) Aminu Kano Teaching Hospital (Office)

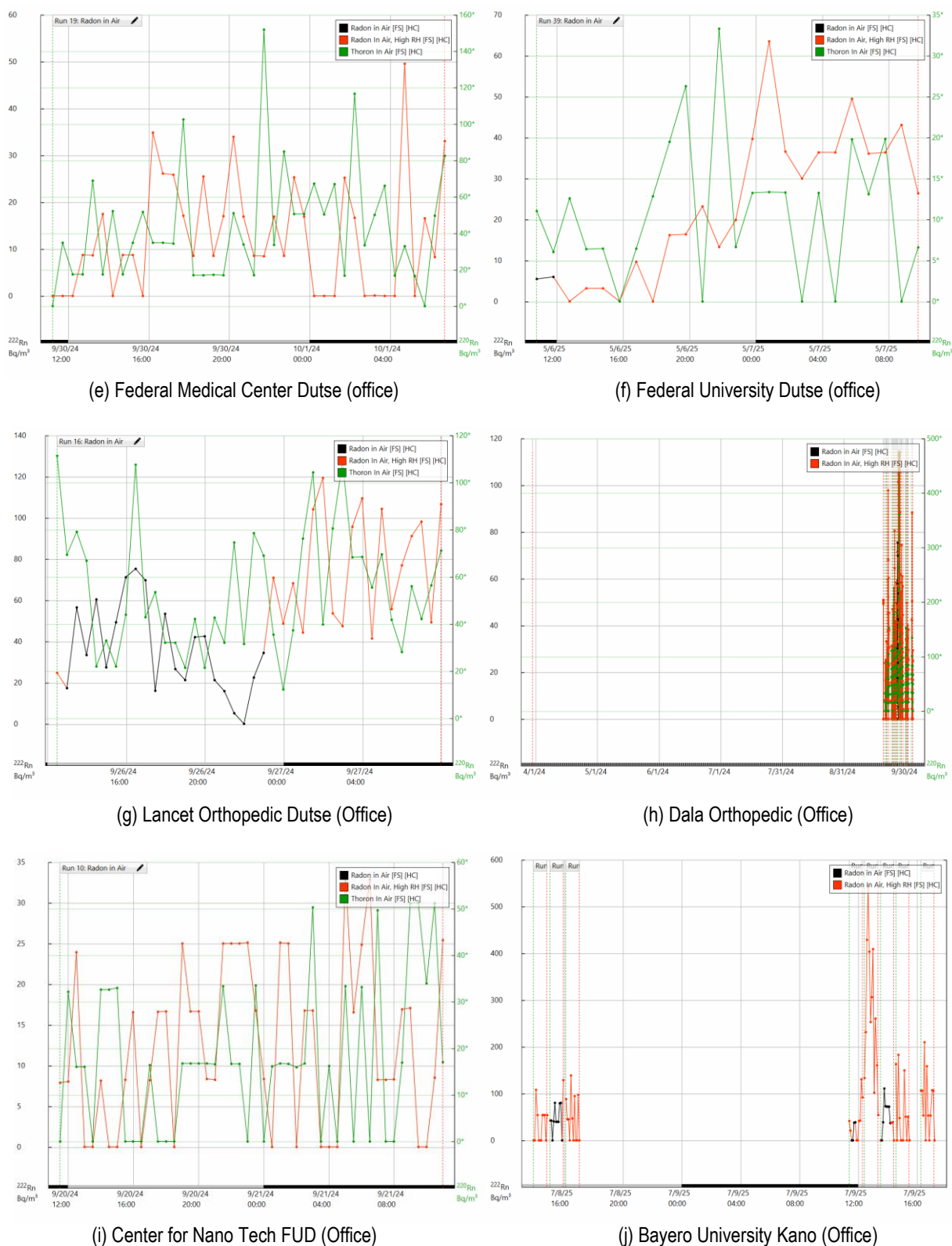
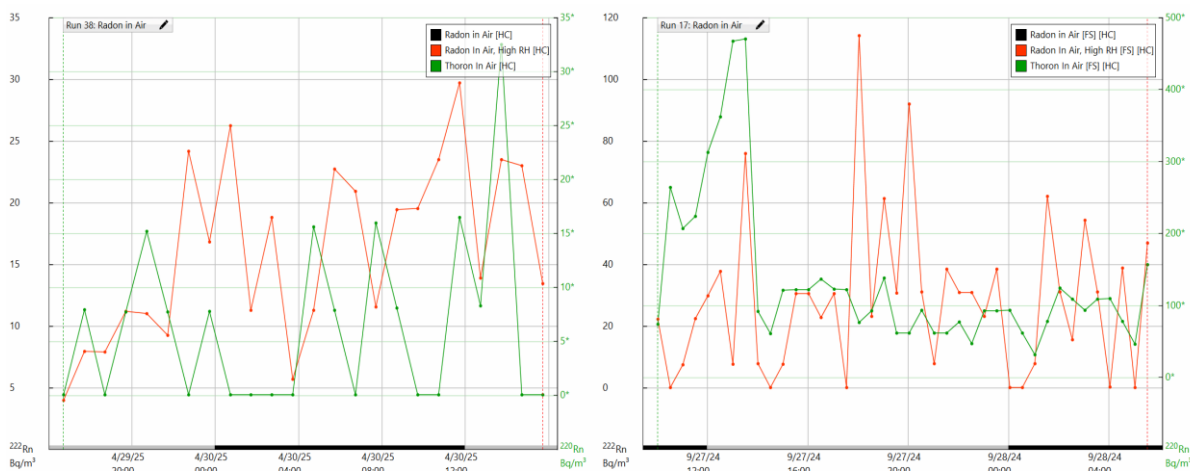


Figure 4: Comparison of annual effective dose across study sites

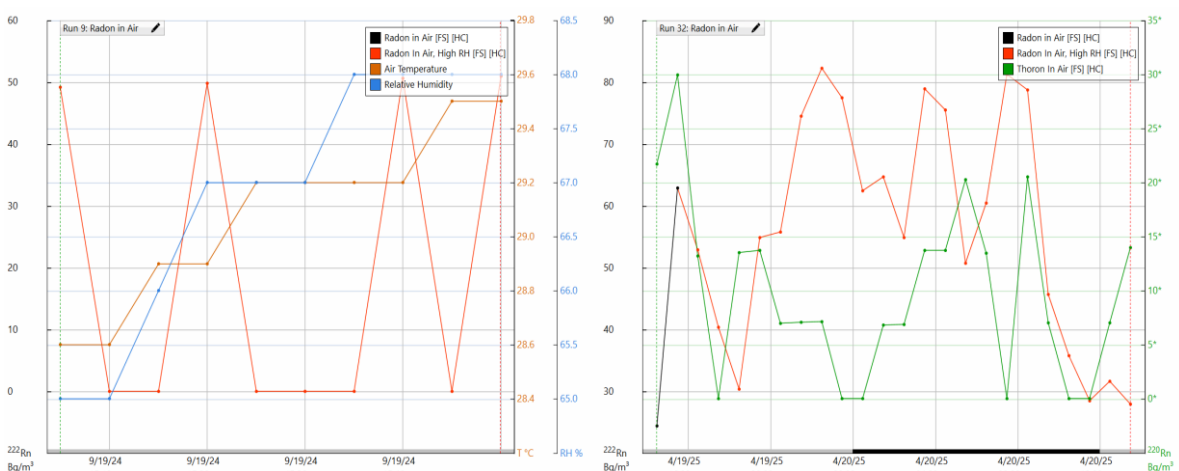
These results are comparable to findings from similar tropical environments in East Africa and South Asia, confirming that radon risk in naturally ventilated structures remains relatively low, but increased awareness and periodic monitoring are crucial. As in office environments, radon and thoron concentrations fluctuated considerably over 24-hour cycles. Peak concentrations were observed

during the early morning and late-night hours, while the lowest levels occurred during the day when windows were open. Residential structures constructed with clay or mud blocks exhibited higher mean concentrations, likely due to enhanced radon exhalation from wall materials and limited air exchange.



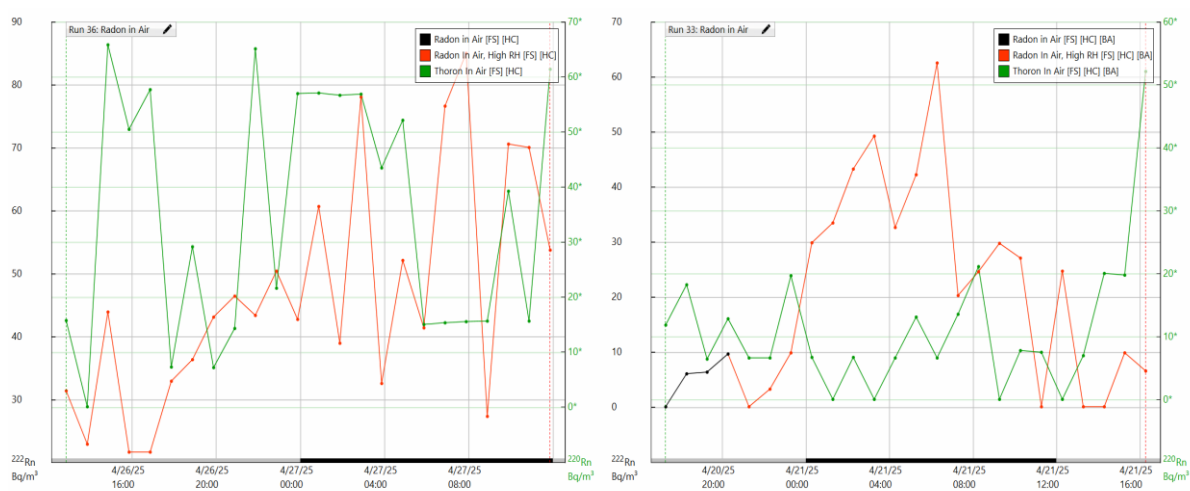
(a) Gandu New Layout (Resident)

(b) Giginyu (Resident)



(c) Gyadi Gyadi (Resident)

(d) Hawan Dawaki (resident)

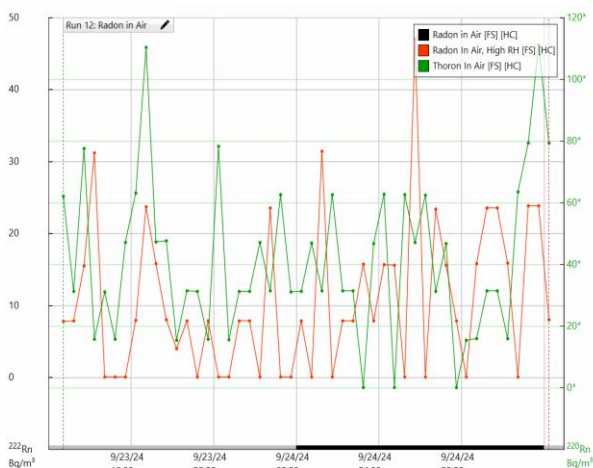


(e) Hotoro Warwarnu (Resident)

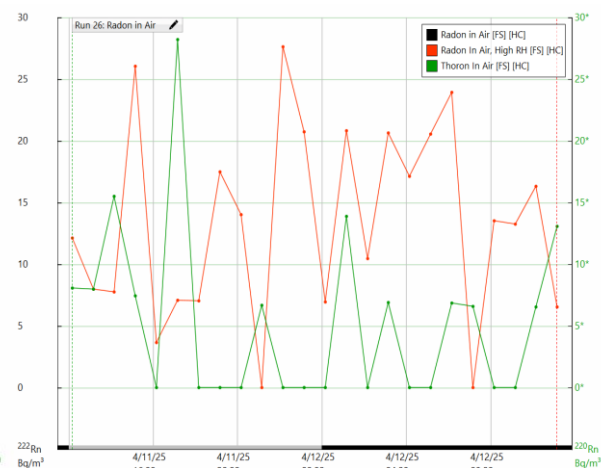
(f) Dan Dinshe (Resident)

Buildings located in low-lying areas or with concrete basements also recorded elevated nighttime levels, attributed to the stack effect and reduced outward diffusion of soil gas. In contrast, modern bungalows with open ventilation patterns showed smaller amplitude fluctuations. These results confirm that household ventilation practices,

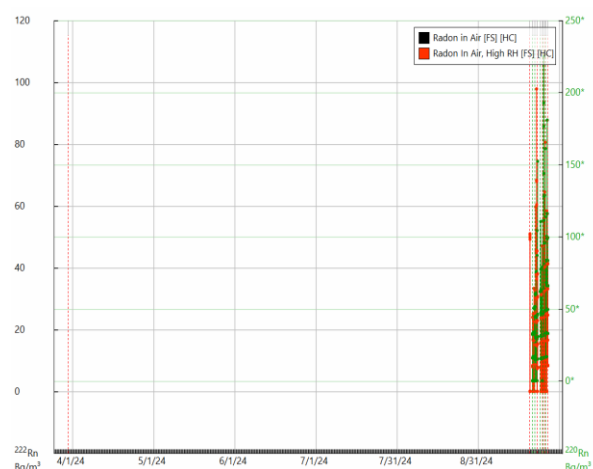
occupancy patterns, and building materials collectively modulate indoor radon and thoron accumulation in domestic settings. The trends displayed in Figure 4 (a–j) provide valuable input for formulating public awareness strategies on indoor air management in rural and urban communities.



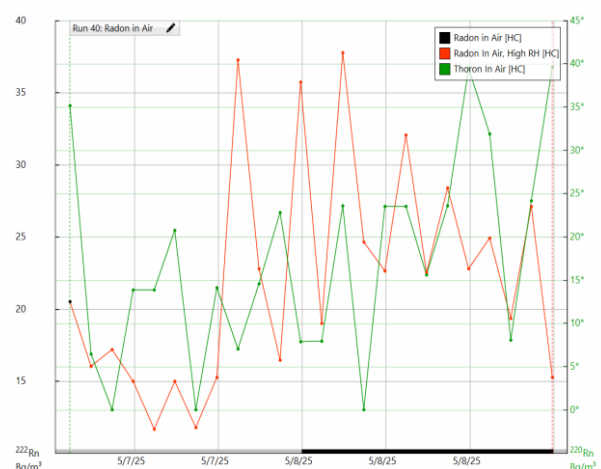
(g) Limawa Qrts (Resident)



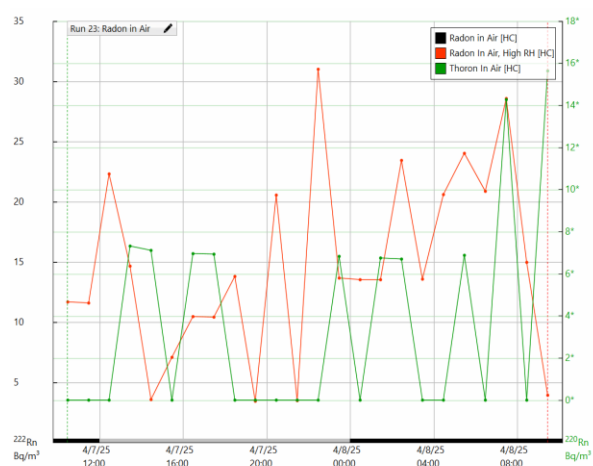
(h) Badawa Layout (Resident)



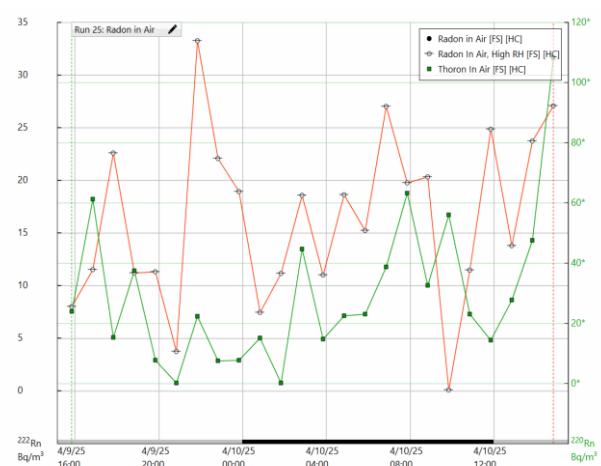
(i) Mechanic Village Dutse (Resident)



(j) Tukuntawa (Resident)



(k) Mopol Base (Resident)



(l) Naibawa Gabas (Resident)

Each sub-panel Figure 5 (a–p) represents a distinct measurement site, showing consistent nighttime increases followed by sharp declines after sunrise. The comparison reveals that areas within granitic terrains, particularly in Kano metropolis and southern Katsina, consistently registered higher baseline radon levels than those over sedimentary zones of Sokoto and Kebbi. Furthermore,

thoron concentrations followed similar diurnal patterns but with steeper decline rates after peak hours, reinforcing the short-lived nature of ^{220}Rn gas. Notably, the highest mean hourly concentration ($\approx 100 \text{ Bq m}^{-3}$) occurred in confined office basements, while the lowest ($< 20 \text{ Bq m}^{-3}$) was measured in ventilated upper-floor classrooms.

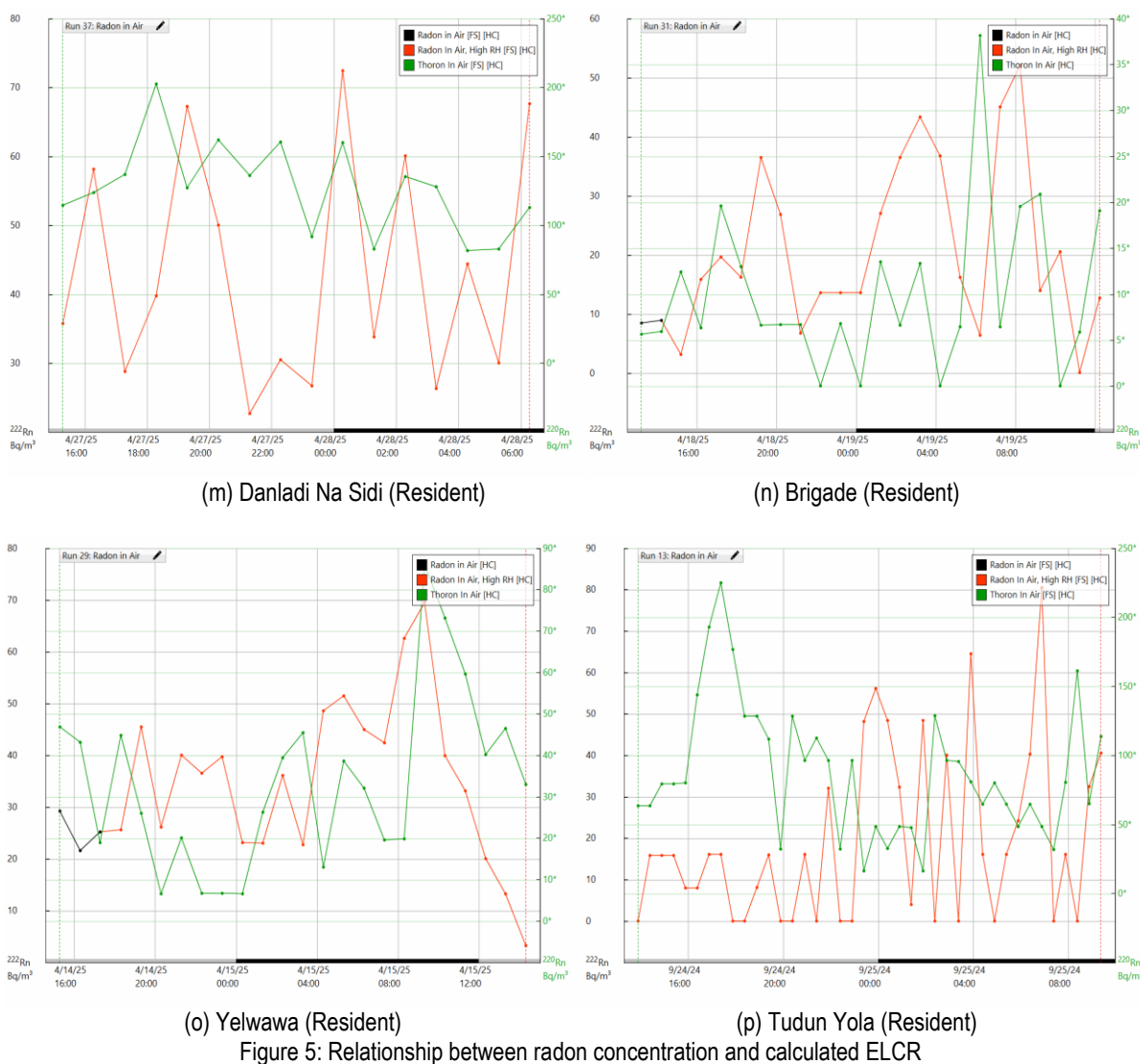


Figure 5: Relationship between radon concentration and calculated ELCR

These findings, illustrated in Figure 5 (a–p), underscore the combined effects of geology, building structure, and ventilation behaviour on the temporal dynamics of indoor radioactive gases. The integration of these multi-site results provides a robust dataset for validating simulation models of indoor radon dispersion under varying occupancy and climatic conditions.

4. Conclusion

This study presents baseline data on indoor radon and thoron concentrations in Northwestern Nigeria. The results indicate moderate exposure levels influenced by geology, building characteristics, and ventilation. Although the measured doses were below international limits, continued public health surveillance and improved ventilation in residential buildings are recommended to mitigate cumulative exposure risks.

Acknowledgment

The authors acknowledge the support of the Centre for Atmospheric Research, National Space Research and Development Agency (NASRDA), Anyigba, for providing

laboratory facilities, equipment, and technical assistance during field and analytical phases of this study.

Conflict of Interest

The authors declare no conflict of interest.

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