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Impact of Structural and Environmental Parameters on Indoor Radon Gas Levels from Locations in Gombe, Adamawa and Yobe States Nigeria

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ABSTRACT
Indoor radon gas concentrations are influenced by structural and environmental factors, including ventilation rates, room volume, foundation floor thickness, indoor temperature, and relative humidity. This study investigates the impact of these parameters on radon accumulation in residential dwellings across Adamawa, Gombe, and Yobe States, Nigeria. Using Solid-State Nuclear Track Detectors (CR-39 SSNTDs), radon concentrations were measured over six months. Results indicate that poor ventilation, small room volumes, and high indoor temperatures significantly increase radon levels, while thicker foundation floors and higher relative humidity reduce radon accumulation/concentrations in an indoor spaces. Almost all the sampling locations considered in this study indicates high accumulated values of indoor radon gas above the recommended limit set by UNSCEAR, ICRP and WHO 100 Bq/m^3. The findings highlight the need for improved building designs and ventilation systems to mitigate indoor radon gas accumulation and possible radon-related health risks.

Keywords:
Indoor radon,
Structural parameters,
Environmental factors,
Ventilation,
Foundation floor thickness,
Temperature,
Relative humidity.

INTRODUCTION

Radon-222 (^{222}Rn), a radioactive gas produced from the uranium-238 (^{238}U) decay series, is a significant environmental health concern. It is the second leading cause of lung cancer worldwide, following smoking (Lusimbo, 2019; Kitson-Mills et al., 2019; Maheso, 2021). Radon exposure has been strongly linked to the rising incidence of lung cancer in recent years, particularly among underground miners and non-miners who experience prolonged exposure. Studies have classified radon as a human carcinogen (Lusimbo, 2019), further reinforcing its role in global lung cancer cases (Kitson-Mills et al., 2019; Maheso, 2021). Approximately 50% of natural radiation exposure received by humans comes from radon gas (McCarron et al., 2020). The most significant isotope contributing to lung cancer cases is radon-222 (^{222}Rn), formed from radium-226 (^{226}Ra) in the uranium decay chain.

High radon concentrations in soil allow the gas to seep into indoor spaces through diffusion and advection processes, driven by concentration gradients and pressure differences between indoor and outdoor environments (Font, 2008; Ravikumar et al., 2014; Salih et al., 2013). Since radon is approximately 7.5 times denser than air, it accumulates in the lower parts of buildings but can be transported to upper levels through human activities and air circulation (Salih et al., 2013). Indoor radon concentrations vary depending on climate, seasonal changes, and soil moisture content (McCarron et al., 2020). Therefore, long-term monitoring (≥3 months) is necessary for a comprehensive assessment of exposure risks.

Several studies have investigated indoor radon accumulation in Nigeria and globally. Afolabi et al. (2015) examined radon levels in offices at Obafemi Awolowo University, Ile-Ife, using Pro 3-series radon detectors, revealing significant deviations from the WHO-recommended limit of 100 Bq/m³. Ajayi et al. (2016) studied radon levels in 70 homes across southwestern Nigeria using CR-39 detectors, reporting elevated indoor concentrations that pose a public health concern. Aladeniyi (2020) analyzed radon exposure in southwestern Nigeria using solid-state nuclear track detectors (SSNTDs) and found that radon levels followed a lognormal distribution, significantly influenced by building characteristics. Bashir et al. (2023) further explored the impact of structural features on radon levels and associated excess lifetime cancer risk (ELCR), concluding that radon exposure exceeded the global average of 1.15 mSv/y, though remaining below the ICRP threshold of 3 mSv/y.

In northeastern Nigeria, insecurity and economic hardship have led to the construction of poorly designed residential dwellings, particularly among internally displaced persons (IDPs). Inadequate ventilation, thin foundation floors, and unfavorable climatic conditions (high humidity and temperature) contribute to increased indoor radon accumulation. Uranium deposits have been identified in locations such as Gujba, Buni Yadi, and Bara in Yobe State, as well as Telasse, Tula, and Ashaka in Gombe State (Abba et al., 2020; Ma'aji et al., 2024). Similarly, Michika, Ganye, and Mayo-Belwa in Adamawa State show strong uranium exploration potential (Shehu et al., 2022; Meludu et al., 2023).

Recent hospital reports indicate 4,681 recorded cancer cases in university teaching hospitals across northeastern Nigeria, with 2,770 affecting females and 1,911 males (Ezenkwa et al., 2024). Among these, 1,465 cases were identified as lung cancer, with most cases originating from Adamawa, Gombe, and Yobe States. Figure 1 provides a detailed statistical representation of these cases for further clarity.

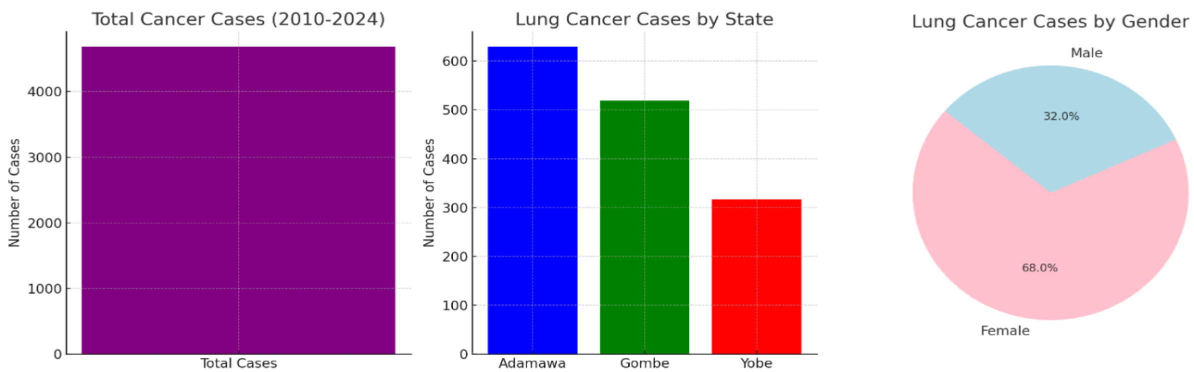


Figure 1: Report of cancer and lung cancer cases in Northeast Nigerian
Source: (Ezenkwa *et al*., 2024)

MATERIALS AND METHODS

Study Areas

The study locations covered in this study were Adamawa, Gombe, and Yobe States. Figure 2 shows the various sampling points.

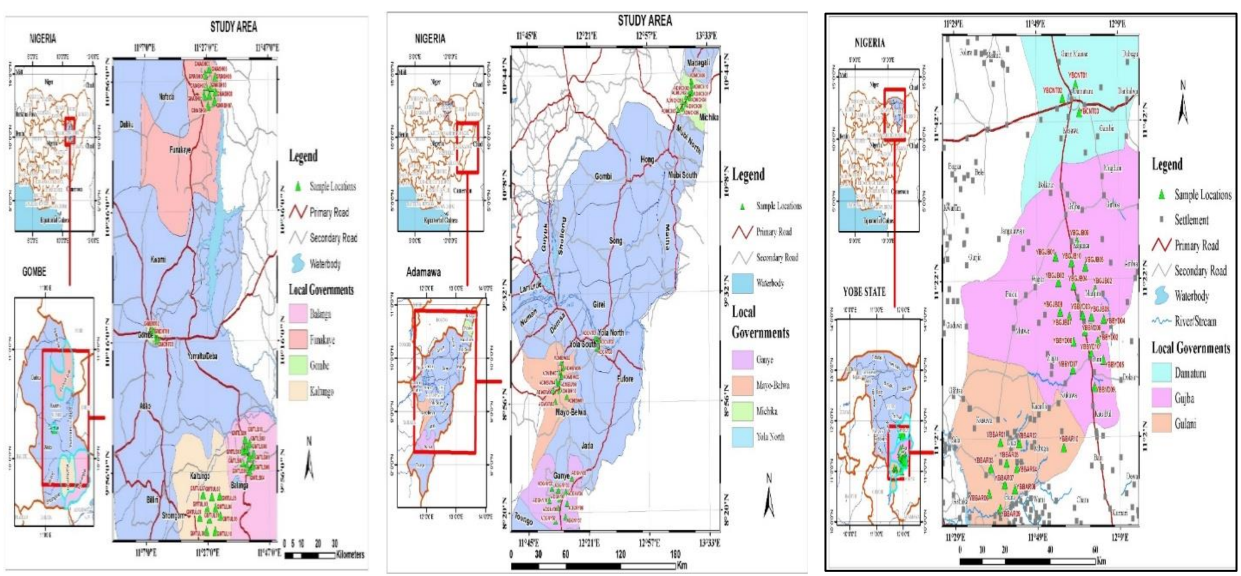


Figure 2: Maps of Gombe, Adamawa and Yobe States showing Study Sites and Sampling Points (Generated using QGIS 2.3.1 software)

Materials

Table 1: The materials used for this study and their functions

S/No.	Materials	Brief Functions
1	Solid State Nuclear Track Detectors (Columbian Resin CR-39 detectors).	They were used to record the track effects caused by the indoor radon gas due to contact with Alpha particles.
2	Detector holders	They were used to hold the detectors on the walls of the sampling rooms at any point/position of interest.
3	Radon proof containers	They were used to keep the detectors after exposure periods before taking to laboratory for analysis.
4	Global positioning system (Garmin etrrex10)	It is used to obtain geo-referencing points at which measurements were taken.
5	Measuring tape	It is used to measure the height at which the detectors were placed, and to measure sizes of the sampling rooms.
6	Masking tape	It is used to tide and level the detectors appropriately on the detector holders.
7	"Zeiss" LMS 780 laser scanning confocal microscope.	It was used to view and obtain 3-D image data and count the alpha tracks registered by the detectors and interpret into equivalent radon gas concentrations.
8	Sodium hydroxide (NaOH) 2.5 mol	The solution was used to arrest further interaction between surrounding radon gas and the detectors surfaces and help to etch by magnifying the tracks caused by the radon gas when heated.
9	Beaker	It was used as container for chemical etching process of the detectors using 2.5mol of Sodium hydroxide (NaOH) solution.
10	Oven furnace	It was used for heating the 2.5mol of Sodium hydroxide (NaOH) solution containing the detectors to about 70^{o}C for 1hr. 30mins
11	Distilled water	It was used to rinse the detector after etching process in Sodium hydroxide (NaOH) solution.
12	Dual Channel data digital humidity loggers (HIOKI LR 5001)	They are digital active dual (temperature and relative humidity) loggers, were used to measure, record and store indoor temperature and relative humidity data for a long period of time.
13	Rotating Vane Anemometer (Model LCA301)	It was used to measure the in-situ indoor Air exchange rate in a unit of (h^{-1}).

Indoor Radon Gas Monitoring and Counting

Indoor radon gas measurements were conducted from February 4 to August 4, 2024, using CR-39 Solid State Nuclear Track Detectors (SSNTDs). The detectors, sourced from Bilkent University, Turkey, were rectangular (2 cm × 4 cm) and deployed in residential dwellings. The SSNTDs were hung on specially designed holders at 1.5 m height (breathing zone) in bedrooms, facing downward for optimal radon gas entry, and were placed away from ventilation points to avoid disruptions and ensure accurate measurements. Sampling locations were selected based on factors like proximity to mining, poor ventilation, soil type, and building materials. Ninety detectors were distributed across nine communities in Adamawa, Gombe, and Yobe States, with nine additional detectors used as controls in low-radon areas. The study focused on areas with poor structural conditions, such as thin foundation floors and small room sizes, which contribute to radon accumulation. After six months, the detectors were retrieved and sealed in radon-proof envelopes to prevent further exposure. The detectors were transported to laboratory for chemical preparation using 2.5 mol. Of NaOH solution and imaging using "Zeiss" LSM 780 laser scanning confocal microscope to count alpha tracks at Biomedical Science Research and training center BioRTC Yobe State University, Damaturu. The alpha tracks registered by the detectors were counted and interpreted using track density model to obtain the equivalent steady state radon gas concentrations. This indoor radon monitoring protocol was in line with standard procedures sets by Nigerian Nuclear regulatory Authority NNRA (Taufiq, 2022).

The indoor radon gas concentration at steady state value Cs is given to be:

$$C_s = \frac{\rho(\text{Track/m}^2)}{k(\text{Track/m}^2\text{per Bq/m}^3 \text{ x day})T_{180day}} \quad (1)$$

Where; C_s ,is the steady state radon gas concentration in Bq/m^3, ρ is the track density of the detectors (Track/m^2) and k is the sensitivity factor of the SSNT detector. Given to be 3.7 Track/m^2 per Bq/m^3 x day (Gewali *et al.*, 2019) and (Nader, 2015).

Measurement of Structural and Environmental Parameters

The indoor temperature and relative humidity (RH) were measured using a Digital thermo-hygrometer (HIOKI LR 5001). The meters were rented from the Nigerian Meteorological Agency and deployed at sampling sites. They were placed at a height of 1.5m near SSNTDs CR-39 to record environmental conditions. Data was stored in the device's memory and later retrieved via a data cable into a PC in Excel format. The average indoor temperature and RH values for each sampling room were recorded in tables (2, 3, and 4).

The indoor air exchange rates (ACH) were measured using a rotating vane anemometer (Model LCA301). The device detected indoor air movement, converting it into ACH values, which were recorded for each sampling room in tables (2, 3, and 4). Room volume was measured using a handheld tape, as smaller rooms tend to accumulate more radon gas. The volume was calculated using the formula:

$$Volume_{room} = Lenght_{room} \times Width_{room} \times height_{room} \quad (2)$$

Ventilation rates of each of the sampling rooms were computed using equation (3) (Afolabi *et al.*, 2015).

$$Vent_{Indoor} = Volume_{room} \times ACH \quad (3)$$

Data Analysis

Radon concentrations were correlated with structural and environmental parameters using SPSS statistical analysis software.

RESULTS AND DISCUSSION

Radon Concentrations

Table 2: Gombe State long time (Six months) indoor radon gas concentration results with structural and Atmospheric parameters

Locations	Building materials	Room volume (m^3)	Air Exchange Rate (h^{-1})	Ventilation Rate (m^3/h)	Averag Temp. (°C)	AverageRH (%)	Long time radon Concentration (Bq/m^3)
GMASH01	MUD	25.32	1.20	30.384	36.65	14.64	193.31
GMASH02	MUD	25.21	1.16	29.2436	37.25	14.57	204.57
GMASH03	CEMENT	26.04	1.27	33.0708	34.81	22.78	185.81
GMASH04	CEMENT	25.41	1.25	31.7625	34.95	22.62	189.56
GMASH05	CEMENT	25.32	1.21	30.6372	37.35	14.66	193.32
GMASH06	CEMENT	25.41	1.24	31.5084	37.10	14.51	191.44
GMASH07	MUD	25.22	1.18	29.7596	37.70	14.44	202.70
GMASH08	CEMENT	25.42	1.24	31.5208	36.85	14.54	189.56
GMASH09	MUD	25.08	1.10	27.588	37.74	14.43	208.33
GMASH10	CEMENT	25.28	1.17	29.5776	37.54	14.48	198.94
GMTLS01	CEMENT	36.45	3.34	121.743	31.60	26.86	105.11
GMTLS02	MUD	25.27	1.19	30.0713	36.50	14.78	202.70
GMTLS03	CEMENT	36.31	2.14	77.7034	34.0	22.60	138.88
GMTLS04	CEMENT	36.35	3.31	120.3185	30.50	28.27	108.85
GMTLS05	CEMENT	36.45	2.16	78.732	34.20	23.00	135.14
GMTLS06	CEMENT	36.45	3.25	118.4625	29.80	23.54	103.23
GMTLS07	MUD	25.22	1.19	30.0118	37.30	14.67	204.57
GMTLS08	CEMENT	36.45	3.27	119.1915	29.20	24.90	110.74
GMTLS09	CEMENT	36.45	2.18	79.461	33.50	23.40	135.14
GMTLS10	CEMENT	25.28	1.21	30.5888	37.20	14.76	197.07
GMTUL01	CEMENT	25.2	1.18	29.736	37.70	14.44	197.23
GMTUL02	CEMENT	25.28	1.17	29.5776	37.62	14.48	198.94
GMTUL03	MUD	25.2	1.19	29.988	37.55	14.50	197.42
GMTUL04	MUD	25.22	1.22	30.7684	37.10	14.51	195.19
GMTUL05	CEMENT	36.45	2.17	79.0965	34.00	22.60	133.25
GMTUL06	MUD	25.28	1.15	29.072	37.90	14.80	200.83
GMTUL07	CEMENT	25.32	1.21	30.6372	37.35	14.66	197.09
GMTUL08	CEMENT	25.35	1.17	29.6595	37.62	14.48	195.19
GMTUL09	CEMENT	25.35	1.16	29.406	37.65	14.44	197.12
GMTUL10	CEMENT	25.28	1.15	29.072	37.85	14.40	198.94
GMCNT01	CEMENT	56.45	4.25	239.9125	27.6	36.56	58.18
GMCNT02	CEMENT	56.45	4.10	231.445	28.1	35.90	63.81
GMCNT03	CEMENT	56.45	4.14	233.703	27.8	36.50	60.06

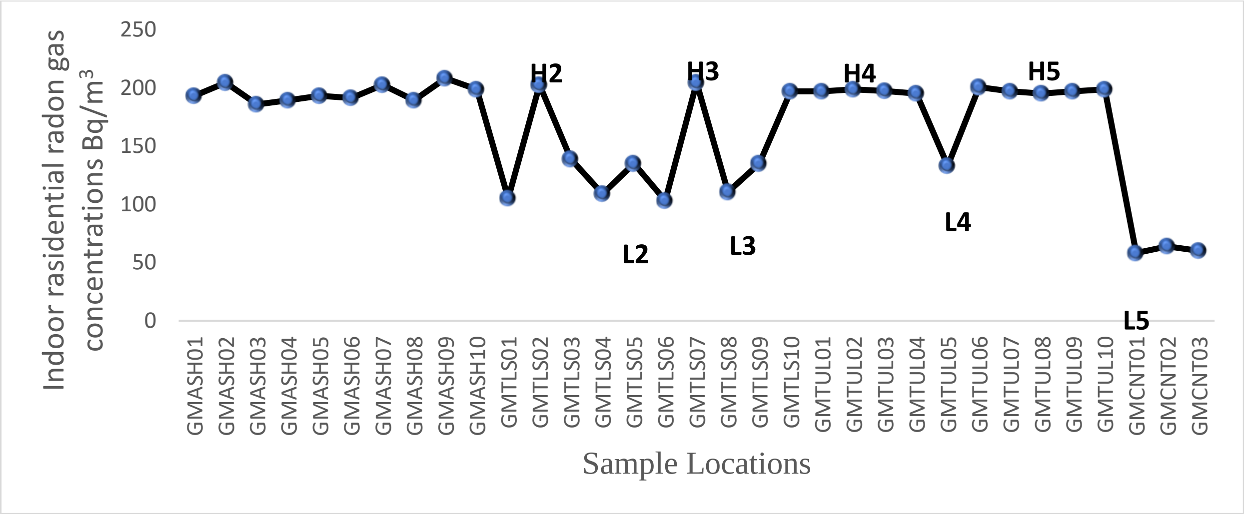


Figure 3: Gombe State Indoor Residential radon gas concentrations in Bq/m^3

Table 3: Adamawa State long time (Six months) indoor radon gas concentration results with structural and Atmospheric parameters

Locations	Building materials	Room volume (m^3)	Air Exchange Rate (h^{-1})	Ventilation Rate (m^3/h)	Averag Temp. (°C)	AverageRH (%)	Long time radon Concentration (Bq/m^3)
ADMCK01	MUD	25.28	1.20	30.336	37.4	15.0	204.57
ADMCK02	MUD	25.1	1.18	29.618	37.7	14.5	189.56
ADMCK03	CEMENT	36.45	2.38	86.751	34.5	22.5	148.27
ADMCK04	CEMENT	25.28	1.20	30.336	37.5	15.0	202.70
ADMCK05	MUD	25.28	1.22	30.8416	37.6	14.8	206.45
ADMCK06	CEMENT	36.45	2.39	87.1155	34.2	23.0	150.15
ADMCK07	CEMENT	36.45	2.40	87.48	34.1	23.3	108.85
ADMCK08	MUD	25.28	1.20	30.336	37.45	15.1	204.57
ADMCK09	CEMENT	25.28	1.22	30.8416	37.6	14.8	202.70
ADMCK10	MUD	25.2	1.19	29.988	37.65	14.7	209.32
ADGNY01	CEMENT	36.46	2.39	87.1394	34.2	23.0	150.15
ADGNY02	CEMENT	25.28	1.20	30.336	37.45	15.1	200.83
ADGNY03	CEMENT	25.36	1.23	31.1928	37.55	14.9	197.07
ADGNY04	CEMENT	36.45	2.40	87.48	34.1	23.3	110.74
ADGNY05	MUD	25.28	1.21	30.5888	37.5	15.0	198.95
ADGNY06	MUD	25.28	1.22	30.8416	37.6	14.8	200.83
ADGNY07	CEMENT	36.45	2.38	86.751	34.2	23.0	150.15
ADGNY08	CEMENT	25.28	1.22	30.8416	37.6	14.8	197.07
ADGNY09	CEMENT	25.28	1.21	30.5888	37.5	15.0	202.70
ADGNY10	CEMENT	25.2	1.18	29.736	37.7	14.5	204.57
ADMBW01	MUD	25.28	1.19	30.0832	37.65	14.7	195.19
ADMBW02	CEMENT	36.45	2.39	87.1155	34	22.6	152.03
ADMBW03	CEMENT	25.28	1.19	30.0832	37.66	14.7	200.83
ADMBW04	CEMENT	36.45	2.37	86.3865	34.5	22.5	110.74
ADMBW05	CEMENT	36.45	2.39	87.1155	34.2	23.0	114.48
ADMBW06	MUD	25.28	1.21	30.5888	37.5	15.0	198.95
ADMBW07	CEMENT	25.28	1.23	31.0944	37.56	14.9	200.83
ADMBW08	MUD	25.2	1.19	29.988	37.65	14.7	204.57
ADMBW09	CEMENT	36.45	2.42	88.209	34.2	23.0	146.39
ADMBW10	CEMENT	36.45	2.44	88.938	34.1	23.3	108.85
ADCNT01	CEMENT	56.48	4.51	254.7248	31.4	30.20	73.19
ADCNT02	CEMENT	56.7	4.53	256.851	30.2	33.10	69.44
ADCNT03	CEMENT	56.78	4.55	258.349	29.8	31.50	71.32

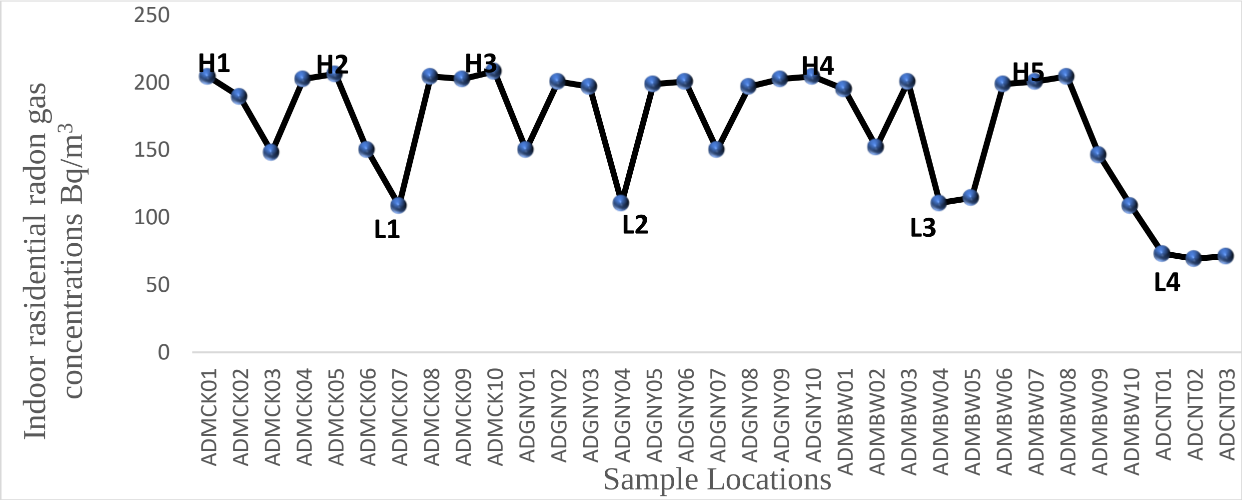


Figure 4: Adamawa State Indoor Residential radon gas concentrations in Bq/m^3

Table 4: Yobe State long time (Six months) indoor radon gas concentration results with structural and Atmospheric parameters

Locations	Building materials	Room volume (m^3)	Air Exchange Rate (h^{-1})	Ventilation Rate (m^3/h)	Averag Temp. (°C)	AverageRH (%)	Long time radon Concentration (Bq/m^3)
YBGJB01	MUD	25.28	1.20	30.336	34.8	22.95	185.81
YBGJB02	MUD	25.2	1.19	29.988	34.94	22.60	183.93
YBGJB03	CEMENT	36.45	2.38	86.751	30.0	30	131.38
YBGJB04	CEMENT	36.45	2.37	86.3865	30.08	29.88	135.14
YBGJB05	MUD	25.01	1.17	29.2617	35.2	15.5	189.56
YBGJB06	CEMENT	36.45	2.39	87.1155	29.7	31.0	133.25
YBGJB07	MUD	25.2	1.19	29.988	34.85	22.84	182.05
YBGJB08	MUD	25.14	1.18	29.6652	35.05	15.40	187.68
YBGJB09	MUD	25.4	1.22	30.988	34.85	22.75	180.18
YBGJB10	CEMENT	36.45	2.38	86.751	30.2	30.2	131.38
YBBYD01	MUD	25.22	1.17	29.5074	35.2	15.8	183.93
YBBYD02	CEMENT	36.45	2.37	86.3865	30.1	31	131.38
YBBYD03	CEMENT	36.51	2.38	86.8938	29.9	31.4	95.72
YBBYD04	MUD	25.14	1.18	29.6652	35.1	15.6	189.56
YBBYD05	CEMENT	36.45	2.40	87.48	29.7	31.4	99.47
YBBYD06	CEMENT	36.45	2.38	86.751	30.3	30	97.59
YBBYD07	CEMENT	36.45	2.37	86.3865	30.2	29.8	129.50
YBBYD08	MUD	25.3	1.20	30.36	34.8	23	180.18
YBBYD09	CEMENT	36.45	2.36	86.022	30.7	31	108.85
YBBYD10	MUD	25.1	1.17	29.367	35.2	15.6	191.44
YBBAR01	CEMENT	36.45	2.36	86.022	30.4	29	99.47
YBBAR02	MUD	25.18	1.16	29.2088	35.3	15.6	189.56
YBBAR03	MUD	25.07	1.14	28.5798	35.4	15.7	197.07
YBBAR04	CEMENT	36.45	2.36	86.022	30.2	30	133.25
YBBAR05	CEMENT	36.45	2.37	86.3865	30.1	29.8	99.47
YBBAR06	CEMENT	36.47	2.36	86.0692	30.2	30.2	97.59
YBBAR07	CEMENT	36.51	2.40	87.624	29.8	31.5	93.84
YBBAR08	MUD	25.1	1.16	29.116	35.3	16	193.32
YBBAR09	MUD	25.2	1.16	29.232	35.4	16.2	189.56
YBBAR10	CEMENT	36.55	2.41	88.0855	30.1	31.2	125.75
YBCNT01	CEMENT	56.76	4.54	257.6904	25.8	35	52.55
YBCNT02	CEMENT	56.71	4.53	256.8963	25.6	36	58.18
YBCNT03	CEMENT	56.48	4.51	254.7248	25.2	38	60.06

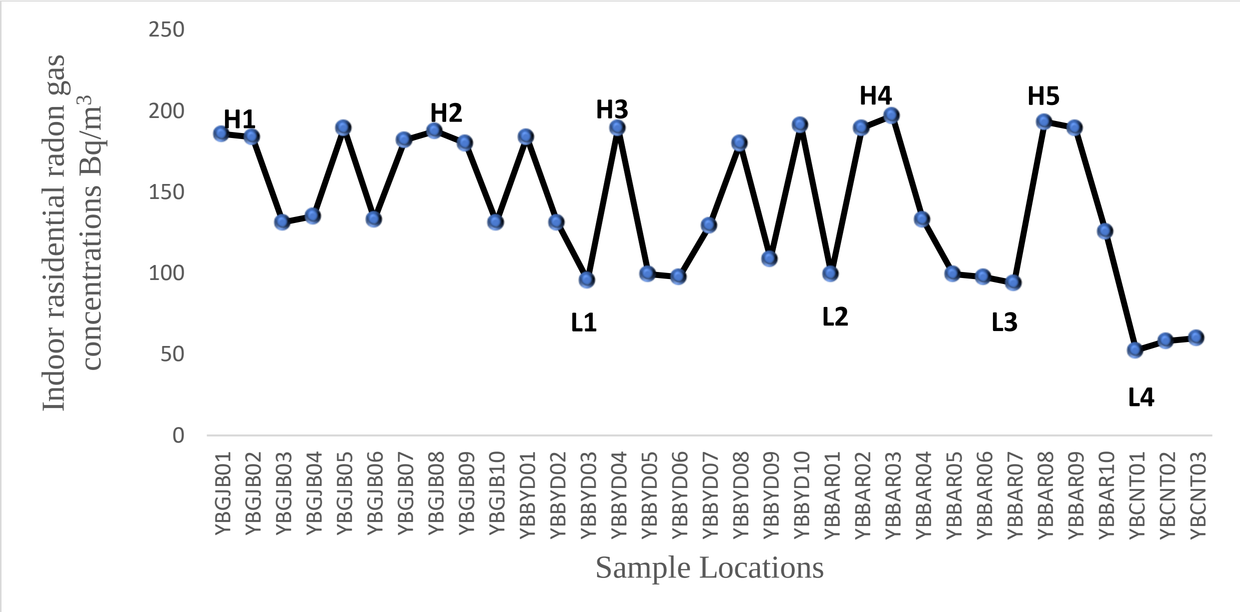


Figure 5: Yobe State Indoor Residential radon gas concentrations in Bq/m^3.
Radon concentration Guidelines for Residential Homes: *(WHO-100* Bq/m^3, Canadian Nuclear Safety Commission (CNSC)-100 Bq/m^3, ICRP- 300 Bq/m^3, US-EPA- 150 Bq/m^3, and Health Canada- 200 Bq/m^3.

Discussion

Indoor radon gas concentrations vary with temperature, humidity, ventilation, and building materials. Poorly ventilated and mud-built structures generally exhibit higher radon levels due to weak foundations allowing gas infiltration. Most locations in Gombe and Adamawa recorded radon levels above WHO and CNSC's recommended 100 Bq/m³, while some areas in Yobe had lower levels due to reduced underground radon emanation.

Figure 2 presented indoor Radon Concentration in Gombe State shows high radon concentrations in Ashaka and Tula which might be due to uranium-rich bedrock (Granite), almost all the values were obtained to be above the recommended limit set by WHO of 100 Bq/m^3 and the values obtained from other studies conducted by (Aladeniyi, 2024; Kolawole *et al*., 2023 and Maheso, 2021), this might be due to geological formation of the region (Granite bedrock). Talesse shows moderate levels due to its sedimented clay formation, which limits radon permeability. Control points with better ventilation and structural designs recorded acceptable radon levels (≤100 Bq/m³). Figure 3 presented indoor Radon Concentration in Adamawa State shows locations with high radon levels (H1-H5), these locations were associated with uranium-rich granite bedrock and velues obtained were above WHO recommended limit and the values obtained from other studies conducted by (Aladeniyi, 2024; Kolawole *et al*., 2023 and Maheso, 2021) this might be due to geological formation of the region (Granite bedrock), while locations with lower levels of indoor radon gas concentrations (L1-L4) were linked to better ventilation. Certain points, like ADCNT (L4), recorded safe levels (≤100 Bq/m³) due to improved building design and ventilation. Figure 4 presented indoor Radon Concentration in Yobe State revealed locations with high radon gas accumulation levels (H1-H5) with much deviations from the WHO recommended limit of 100 Bq/m^3 and the values obtained from other studies conducted by (Aladeniyi, 2024; Kolawole *et al*., 2023 and Maheso, 2021) this might be due to geological formation of the region (Granite bedrock), these locations were also attributed to uranium-rich shale and poor ventilation. Lower levels (L1-L3) were observed in areas with better ventilation and improved structural settings.

The average mean values of indoor radon gas concentrations, range and standard deviations from this study together with some studies in Nigeria and other countries across the world were presented in table (5). These statistical parameters shown a strong variations with changes in location, indoor temperature, indoor relative humidity, type of building materials and ventilation settings in the indoor radon gas measurements.

The average mean of indoor radon gas concentrations, range and Standard deviation of the sampling locations in Gombe State for Cement-type buildings were found to be 155.41 Bq/m^3, 58.18 Bq/m^3 to 202.7 Bq/m^3 and 50.11 Bq/m^3 respectively. For the case of Mud-type buildings the average mean concentrations of the indoor radon gas concentrations were obtained to be 200.86 Bq/m^3, with a range of 198.31 Bq/m^3 to 208.33 Bq/m^3 and standard deviation of 5.17 Bq/m^3. The average mean concentrations of the measured indoor radon gas in

Gombe State for both the Cement-type (155.41 Bq/m^3) and Mud-type (200.86 Bq/m^3) buildings have also indicated a strong deviations from (WHO) and (UNSCEAR) recommended limit of the average mean concentration in an indoor space of 40 Bq/m^3. This might be an indicator that almost all the locations have a common source (Bed rock Uranium) of radon gas irrespective of the type of building material used and ventilation settings.

The average mean of indoor radon gas concentrations, range and Standard deviations in some locations in Adamawa State for Cement-type buildings were obtained to be 151.05 Bq/m^3, 69.47 Bq/m^3 to 204.57 Bq/m^3, and 47.57 Bq/m^3 respectively. For the case of Mud-type buildings the mean concentrations of the indoor radon gas was found to be 201.19 Bq/m^3, with a range of 189.6 Bq/m^3 to 209.32 Bq/m^3 and standard deviation of 5.72 Bq/m^3. The mean concentrations of the measured indoor radon gas in Adamawa State both the Cement-type (151.05 Bq/m^3) and Mud-type (201.19 Bq/m^3) buildings have indicated strong deviation from (WHO), (US-EPA) and (UNSCEAR) recommended limits of the average mean concentration in an indoor space of 40 Bq/m^3. This might be an indicator that almost all the locations have a common source (Bed rock Uranium) of radon gas irrespective of the type of building material used and ventilation settings.

The average mean of indoor radon gas concentrations, range and Standard deviation in all locations in Yobe State for Cement-type buildings were obtained to be 105.99 Bq/m^3, 52.55 Bq/m^3 to 135.14 Bq/m^3 and 26.86 Bq/m^3 respectively. For the case of Mud-type buildings the mean concentrations of the indoor radon gas was found to be 147.42 Bq/m^3, with a range of 180.18 Bq/m^3 to 197.07 Bq/m^3 and standard deviation of 4.80 Bq/m^3. Also the Mean concentrations of the measured indoor radon gas in Yobe State for both the Cement-type (105.99 Bq/m^3) and Mud-type (147.42 Bq/m^3) buildings have indicated strong deviation from (WHO) and (UNSCEAR) recommended limit of the mean concentration in an indoor space of 40 Bq/m^3. This might be an indicator that almost all the locations have a common source (underground radon) of radon gas irrespective of the type of building material used and ventilation settings.

This study has shown a slight variation from the obtained average mean concentrations in an indoor space from Adamawa State (Cement-type 151.05 Bq/m^3 and Mud-type 201.19 Bq/m^3) and that of Gombe State (Cement-type 155.41 Bq/m^3 and Mud-type 200.86 Bq/m^3), this might be as a result of having some common geological formations. While that of Yobe State have shown a wide variation from those values obtained from Adamawa and Gombe States, the average mean values of indoor radon gas concentrations obtained in Yobe State were (Cement-type 105.99 Bq/m^3 and Mud-type 147.42 Bq/m^3), this variation might be due to its closeness to Sahara region, and was obtained to be below the mean average obtained by (Orlunta *et al.*, 2021).

The average mean of some other studies were compared with this study conducted by (Olaoye *et al*., 2021) at (Olososun) of Lagos State in Nigeria has shown a mean of indoor radon gas concentration (256 Bq/m^3) which is above all the mean of indoor radon gas concentrations found in this study. Some other studies conducted by (Chenko *et al*., 2019) in Plateau State (Barkin-Ladi), (Orlunta *et al*., 2021) in Rivers State (Port-hacourt), (Aladeniyi, 2024) in Ondo State (Akure) and Kolawole *et al*., 2023) in Cross-Rivers State (NOUN) has shown values of mean of indoor radon gas concentrations 167.43 Bq/m^3, 115 Bq/m^3, 76 Bq/m^3 and 83 Bq/m^3 respectively, these values were all found to be below the mean of indoor radon gas concentrations obtained in this study, but were all above the recommended limits sets by WHO, CNSC and UNSCEAR of 40 Bq/m^3.

Table 5: Comparison of this study's Average, Range and Standard deviation with other studies

S/N	Study Locations		Building Material	Number of Detectors	Mean (Bq/m^3)	Range (Bq/m^3)	Standard Deviation(Bq/m^3)	References
	Country	State						
1.	Nigeria	Adamawa State. *Michika, *Ganye *Mayo-Belwa.	Cement Mud	23 10	151.05 201.19	69.44 to 204.57 189.56 to 209.32	47.57 5.72	This Study
		Gombe State. *Ashaka, *Telasse *Tula.	Cement Mud	25 08	155.41 200.86	58.18 to 202.7 193.31 to 208.33	50.16 5.17	
		Yobe State. *Gujba *Buni-Yadi *Bara	Cement Mud	19 14	105.99 147.42	52.55 to 135.14 180.18 to 197.07	26.86 4.80	
		Plateau State. *Barkin-Ladi	Cement	08	167.43	173 to 222	7.42	Other Studues (Nigeria) Chenko *et-al*., (2019).
		Lagos State. *Olososun *Oke-Odo	Cement	50	257	656 to 131.2	51.4	Olaoye *et-al*., (2021).
		Rivers State. *Porthacourt	Cement	150	115	124 to 11.32	28.63	Orlunta, *et-al*., (2021).
		Ondo State. *Akure	Mud	56	76	17 to 174	36	Aladeniyi, (2024).
		Cross-Rivers. *NOUN Calabar.	Cement	30	83	4.89 to 84	5.59	Kolawole *et-al*., (2023).
		Country/State						
2.	Global Studies	Indonesia. *Bangka	Cement	135	41	22.4 to 46.6	6.03	Radhia *et-al*., (2024).
		Japan. *Fukushima.	Cement	70	374	93 to 405	22.54	Hosoda *et-al*., (2024)
		Cameroon. *Betare-Oya.	Mud and Cement	383	186	88 to 282	24.7	Louis & Hosoda, 2019
		Palestine. *Tulkarem province.	Cement	230	40.42	3.48 to 210.51	2.49	Al Zabadi *et-al*., (2015)

Iraq. *Kurdistan.	Cement	90	189.41	99.94 to 360.11	9.26	Salih & Jaafar, (2013).
South Africa. *Stellenbosch University.	Cement	18	68.32	32.2 to 87.0	10.1	Maheso, (2021).
Ghana. *Dome.	Mud & Cement	120	466.9	214 to 496	2.9	Nsiah-Akoto *et-al*., (2011).
Cameroon. *Younde *Okola *Obala	Mud & Cement	140	41	15 to 140	5.33	Li *et-al*., (2024).
Burkina Faso. *Ouagadougou.	Mud & Cement	80	116	26.90 to 126	2.58	Luc *et-al*., (2021).
Sudan. *Omdurman, *Madeni *Sinnar	Mud & Cement	388	59	26 to 124	7.00	Elzain, (2015).
Tanzania. *Bahi District, *Dodoma	Mud & Cement	60	362	70 to 619	59	Mohammed & Focus, (2018).
Iran. *Tehran.	Cement	800	271	98 to 661	25.3	Mirdoraghi *et-al*., (2020).
Kenya. *Homa *Ruri.	Mud & Cement	86	66	43 to 87	8.2	Otieno *et-al*., (2021).
Palestine. *Western-Hebron.	Cement	240	76.8	32 to 91	18.5	Dabayneh, (2006).
*Hazara	Cement	344	128	41 to 254	63	Khan *et al*., (2012).
Turkey. *Giresun	Cement	252	130	52 to 360	78	Celik *et al*., (2008).
France. *Brittany.	Cement & Wood	386	155	43 to 185	21	Collignan, *et al*., (2016).
Saudi Arabia. *Jeddah.	Cement	544	36	21 to 52	8.4	Farid, (2016).

Type of building material significantly affect in Indoor radon gas accumulations and concentrations if proper ventilations settings are not provided. As described in figure (6), both in Gombe State, Adamawa State and Yobe State, almost all the Mud-type buildings have shown higher levels of indoor radon gas concentrations than the cement-type buildings, this might be as a result of poor ventilation settings, high indoor temperature or low radon gas trap by the humid indoor air of such buildings which are mostly rural standard. Perhaps, some of the cement-type buildings which has ventilation settings close to that of the mud-type buildings have also shown high level of indoor radon gas concentrations because of the poorly ventilation features and thermal stack of the structures. For the case of properly ventilated buildings (Structural and mechanical) the indoor radon gas concentrations were found to be at minimal as possible.

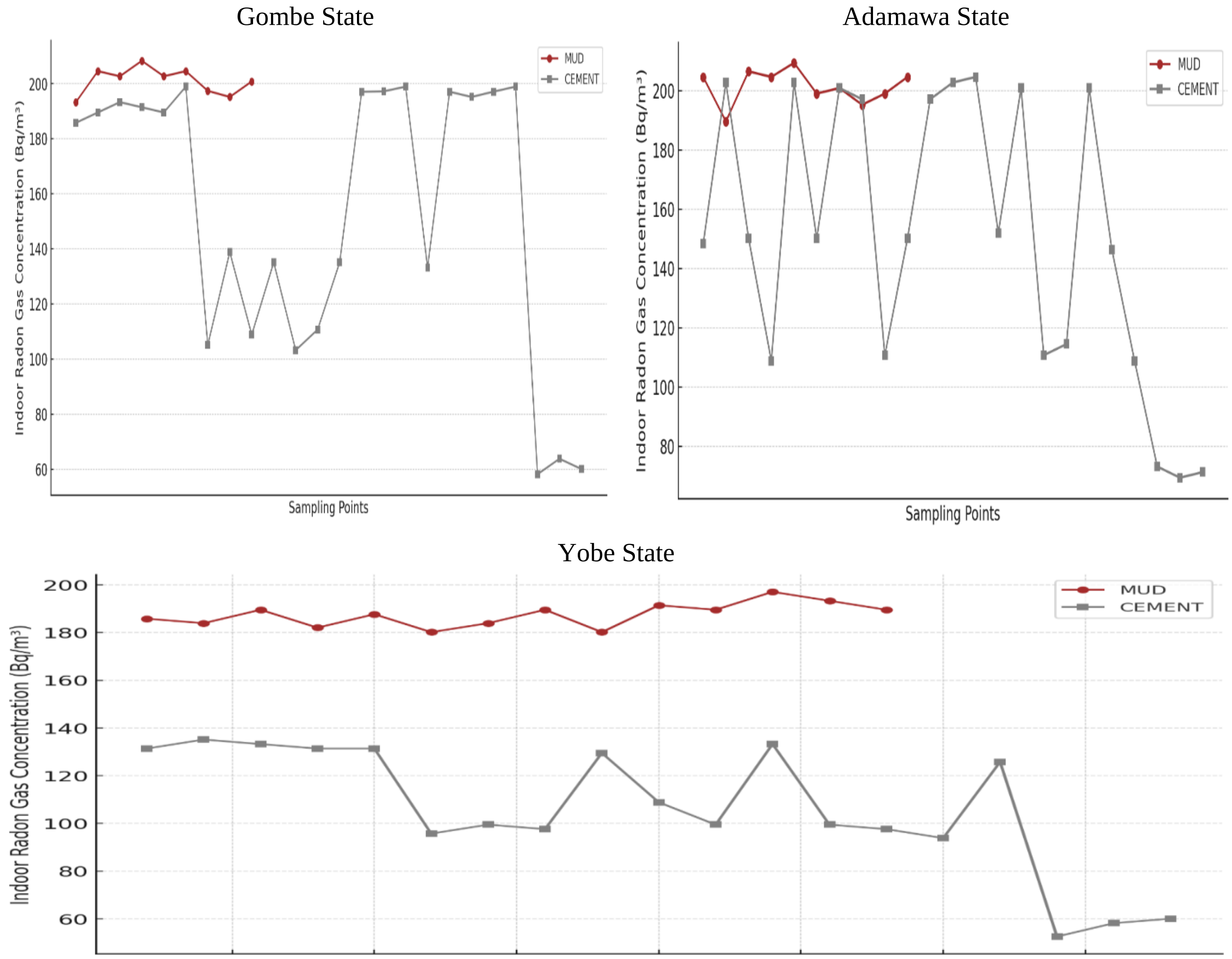


Figure 6: Relationship between Indoor Radon gas Concentrations and type of building material in Gombe, Adamawa and Yobe State

Figure (7) illustrate how indoor radon gas accumulation is influenced by ventilation settings. Proper ventilation significantly reduces radon concentration, regardless of building material, by lowering indoor temperature and limiting gas accumulation.

In Gombe State, Ashaka showed high radon levels due to poor ventilation, while some buildings in Telesse with moderate ventilation had lower concentrations. Tula had high radon levels due to poor ventilation and underground radon emanation, whereas control locations with well-designed ventilation recorded safe levels below 100 Bq/m³.

In Adamawa State, most rural sampling locations had poor ventilation, leading to high radon concentrations, except for a few moderately ventilated areas (ADMCK07, ADGNY04, ADMBW04, ADMBW05) that stayed close to the recommended limit. Control locations ADCNT01, ADCNT02, and ADCNT03 recorded safe radon levels below 100 Bq/m³.

In Yobe State, high radon accumulation was observed in Gujba due to poor ventilation, while areas with moderate ventilation (YBGJB03, YBGJB04, YBGJB06, YBGJB10) showed lower radon concentrations. Similar trends were observed in Buni-Yadi and Bara, emphasizing the role of ventilation in mitigating radon accumulation.

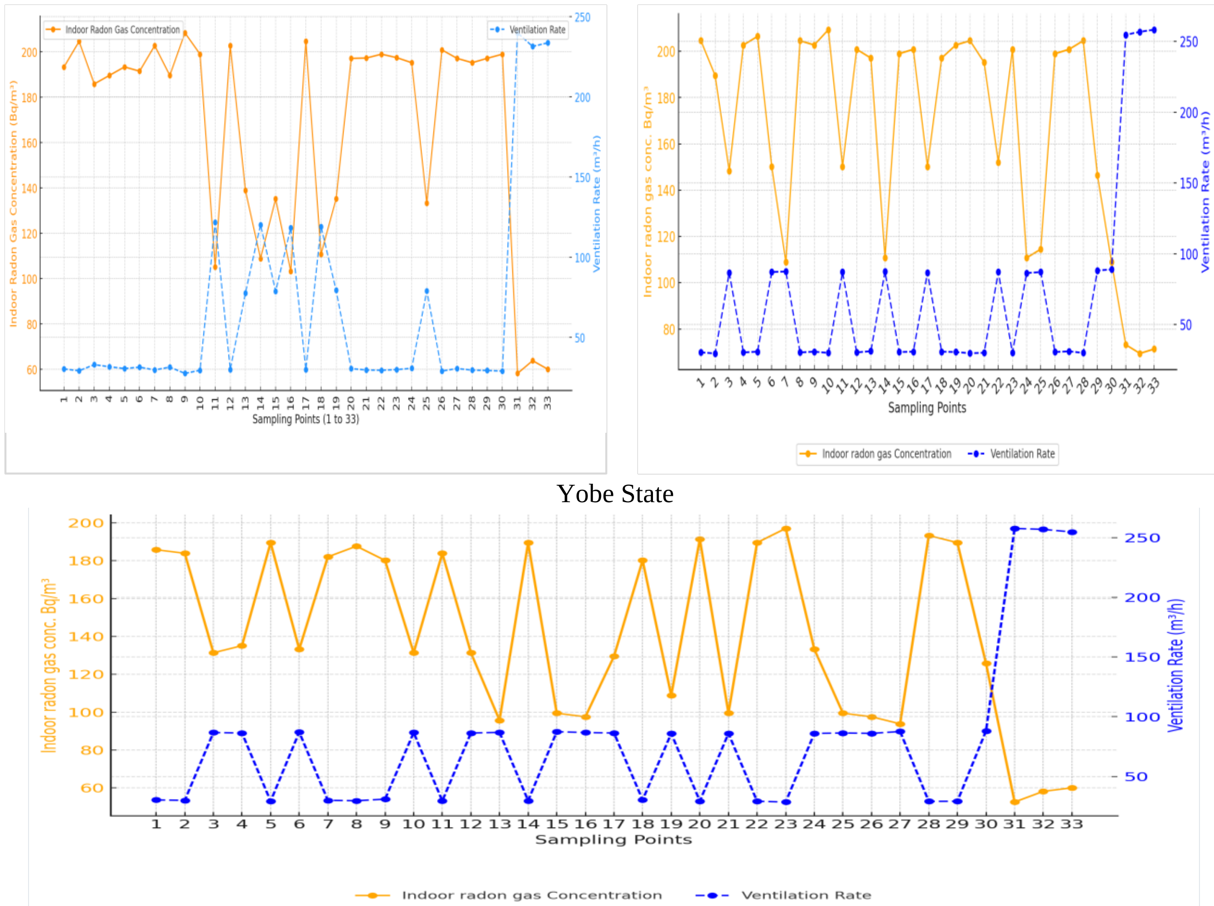
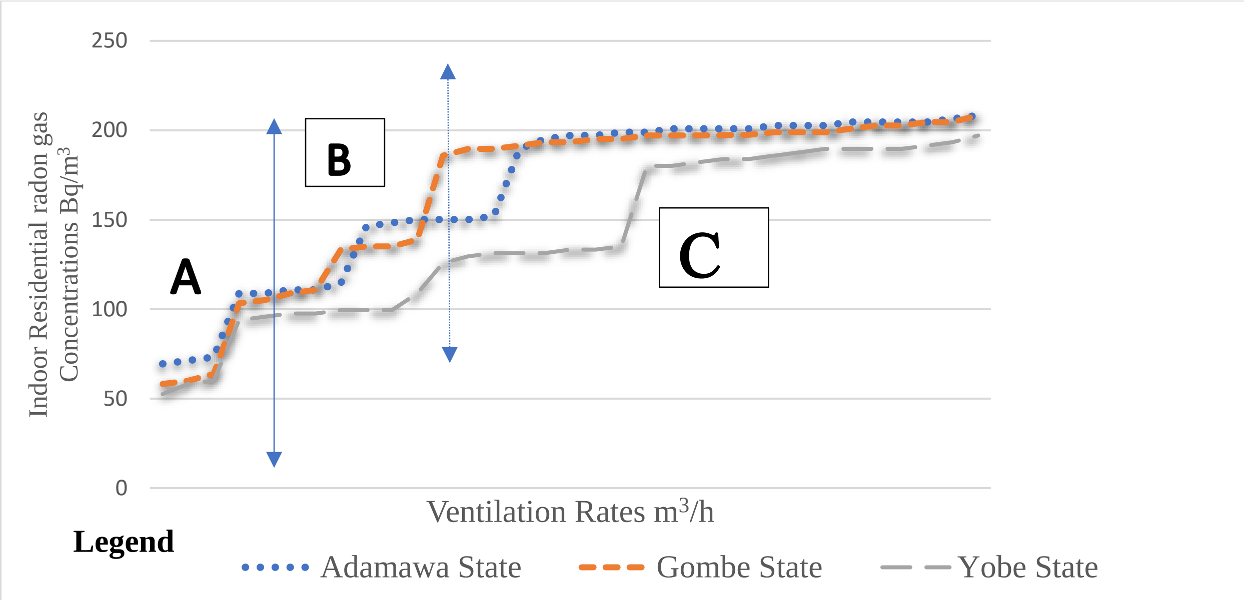


Figure 7: Relationship between Indoor Radon gas Concentration and Ventilation rates in Gombe, Adamawa and Yobe State

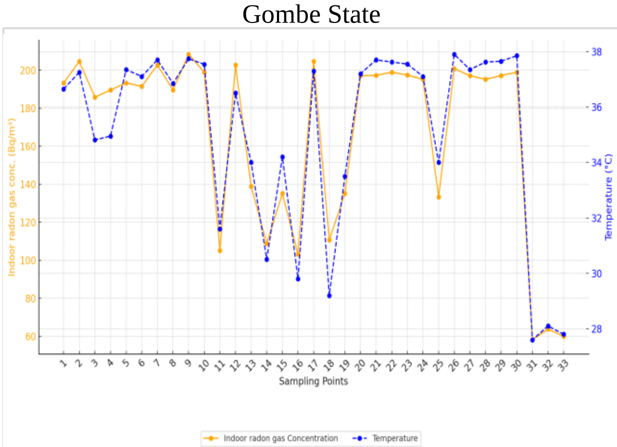
This study found that indoor radon gas concentrations are more significantly affected by ventilation rates than by building materials. Figure (8) illustrates this, showing that properly ventilated structures (Region A) had radon levels within the WHO, CNSC, and UNSCEAR limits of 100 Bq/m³. Moderately ventilated structures (Region B) had slightly elevated levels, while poorly ventilated dwellings (Region C) exceeded the recommended limits. The distribution pattern was consistent across Adamawa, Gombe, and Yobe States, confirming that ventilation is a key factor in indoor radon accumulation.



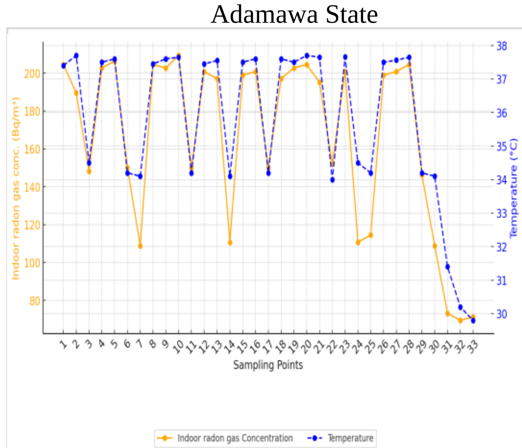
Key: A= Properly Ventilated region, B= Averagely Ventilated region and C= Poorly Ventilated region.
Figure 8: Relationship between Indoor Residential Radon Gas Concentration and Ventilation Rates in Adamawa State, Gombe State and Yobe State

Indoor radon gas concentration is influenced by environmental factors, with temperature playing a critical role in radon emanation, diffusion, and transport. Data from Gombe, Adamawa, and Yobe States show a strong positive correlation between indoor temperature and radon levels, with Pearson correlation coefficients of 0.948, 0.959, and 0.9621, respectively. Higher indoor temperatures (above 36°C) correspond to elevated radon concentrations, while lower temperatures (around 25–29°C) result in reduced levels. The "stack effect" enhances radon infiltration during high temperatures by increasing soil gas flow into buildings. Maintaining moderate indoor temperatures could help control indoor radon levels, especially in radon-prone areas.

Gombe State



Adamawa State



Yobe State

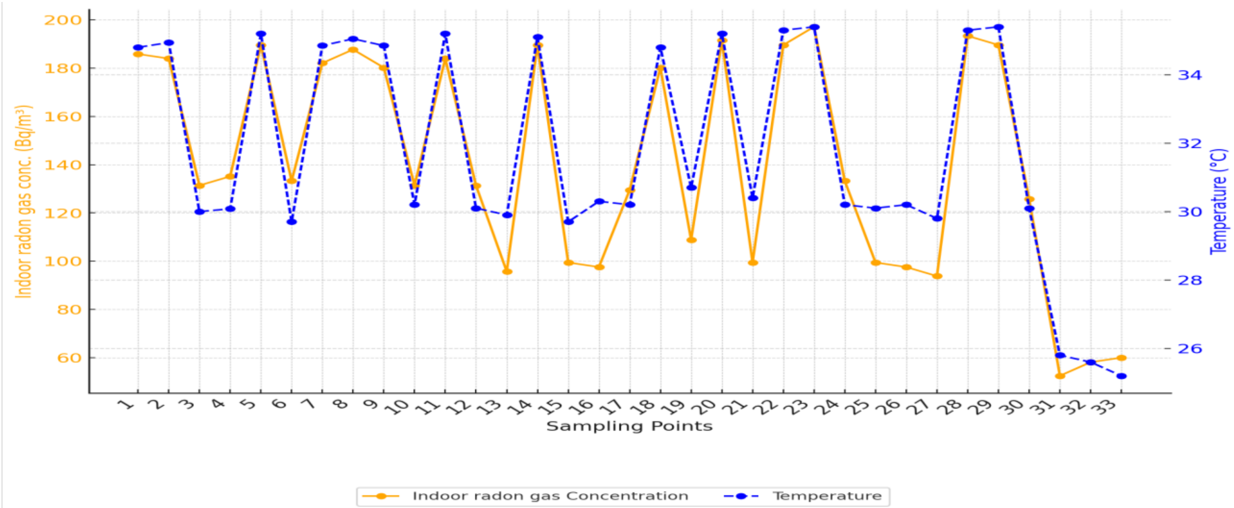


Figure 9: Relationship between Indoor Residential Radon Gas Concentration and indoor temperature in sampling locations from Gombe, Adamawa and Yobe State

The relationship between indoor relative humidity (RH) and radon gas concentration is critical in environmental and health research, as radon poses health risks when concentrations exceed safe thresholds. Indoor RH, the moisture content in air, influences radon accumulation, with higher RH making air denser and trapping radon gas, which may decay before reaching the breathing zone (1.5 m height).

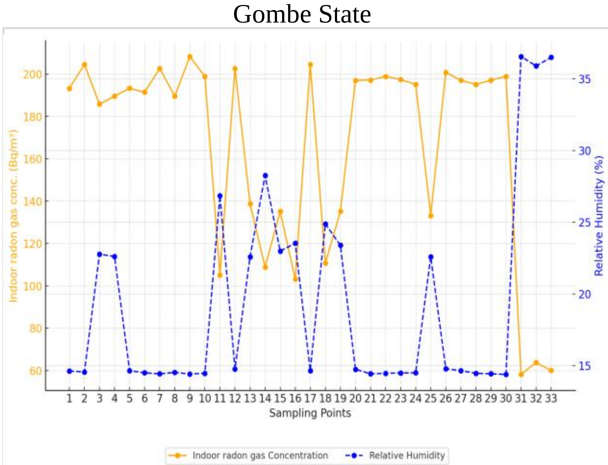
In Gombe State, RH levels ranged from 14.4% to 31.9%, with moderate RH (22–28%) linked to radon concentrations of 108.85–208.33 Bq/m³, while low RH (~14%) coincided with higher radon levels (~202.7 Bq/m³). A strong negative correlation (Pearson coefficient: -0.870) between RH and radon concentration in Gombe suggests that higher RH reduces radon levels.

In Adamawa State, RH ranged from 14.5% to 31.5%, with low RH (~15%) associated with high radon concentrations (202.7–209.32 Bq/m³) and higher RH (>27%) linked to lower radon levels (<100 Bq/m³). A very strong negative correlation (Pearson coefficient: -0.963) in Adamawa reinforces the inverse relationship between RH and radon concentration.

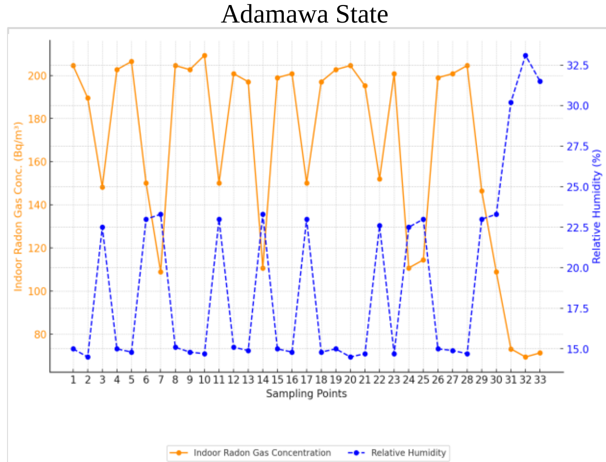
In Yobe State, RH values ranged from 15.4% to 38%, with low RH (15–16%) corresponding to moderate-to-high radon levels (180.18–191.44 Bq/m³). A strong negative correlation (Pearson coefficient: -0.921) in Yobe further supports the inverse relationship, indicating that higher RH reduces radon concentrations.

Dry conditions (low RH) enhance radon diffusion from soil or building materials, increasing indoor radon levels, while higher RH acts as a barrier to radon gas flow. The findings highlight the need for mitigation strategies, such as improved ventilation, to reduce radon exposure in high-humidity environments, where radon concentrations are higher and pose greater health risks.

Gombe State



Adamawa State



Yobe State

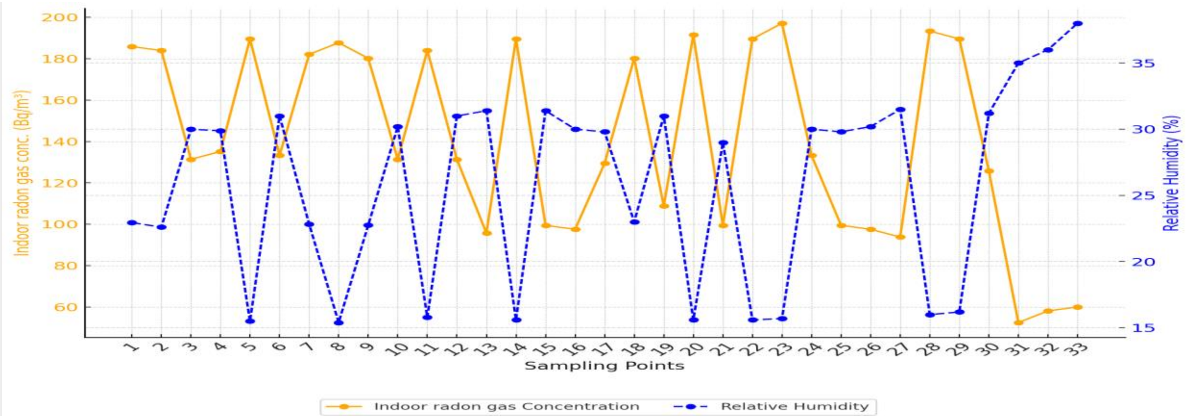


Figure 9: Relationship between Indoor Residential Radon Gas Concentration and Relative Humidity in sampling locations from Gombe, Adamawa and Yobe State

CONCLUSION

This study demonstrates that structural and environmental parameters significantly influence indoor radon concentrations. Poor ventilation, small room volumes, thin foundation floors, high indoor temperatures, and high humidity exacerbate radon accumulation. Mitigation strategies, including improved ventilation, larger room designs, and thicker foundation floors, are recommended to reduce radon levels and associated health risks.

REFERENCES

Abba H. T, Dahiru U. (2018). Evaluation of Radon Concentration and Annual Effective Dose in Sachet Drinking water in Gujba Local Government, Yobe S. *Dutse Journal of Applied Science 6(2), 85–94.*

Afolabi, O. T., Esan, D. T., Banjoko, B., Fajewonyomi, B. A., Tobih, J. E., & Olubodun, B. B. (2015). Radon level in a Nigerian University Campus. *BMC Research Notes*, *8*(1), 677. https://doi.org/10.1186/s13104-015-1447-7

Aladeniyi, K. (2024). Health risk evaluation of radon progeny exposure in Nigerian traditional mud houses. *Journal. Nig. Soc. Phys. Sci. 6 (2024) 2128.*

Al Zabadi, H., Mallah, K., & Saffarini, G. (2015). Indoor exposure assessment of radon in the elementary schools, Palestine. *International Journal of Radiation Research*, *13*(3), 221–228.

Celik, N. U. Çevik, A. Çelik, and B. Kucukomeroglu. (2008). Determination of indoor radon and soil radioactivity levels in Giresun, Turkey. *Journal of Environmental Radioactivity*, vol. 99, no. 8, pp. 1349–1354.

Chenko G. Y. Nimchang, Mangset W. E and Joyce K.D. (2019). Comparative Survey of Radon-222 Level in Some Residential Houses in Barkin-Ladi Local Government. *International Journal of Trend in Research and Development*, *6*(4), 5–7.

CNSC Canadian Nuclear Safety Commission. (2011). Radon and Health. Minister of Public Works and Government Services Canada 2011 Catalogue number CC172-67/2011- PDF ISBN 978-1-100- 17765-6 Published by the Canadian Nuclear Safety Commission (CNSC) Catalogue number: INFO-0813.

Collignan, B. E. Le Ponner, and C. Mandin. (2016).Relationships between indoor radon concentrations, thermal retrofit, and dwelling characteristics. *Journal of Environmental Radioactivity*, vol. 165, pp. 124–130.

Dabayneh K (2006) Indoor radon concentration on measurements in Tarqumia girl schools at Western Hebron Region-Palestine. *Isotope and Rad Res*, 38: 1067-1077.

Elzain, A. A. (2015). Assessment of Indoor Radon Doses Received by the Students and Staff in Schools in some Towns in Sudan. *International Journal of Science and Research* (IJSR) *4*(1), 2566–2571.

Farid. S. M. (2016). Indoor radon in dwellings of Jeddah city, Saudi Arabia and its correlations with the radium and radon exhalation rates from soil. *Indoor and Built Environment*, vol. 25, no. 1, pp. 269–278.

Gewali, J. P., & Tripathi, P. K. (2019). Advantage of Solid-State Nuclear Track Detection (SSNTD)Technique. *6*(1), 552–555. *Journal of*

Emerging Technologies and Innovative Research. www.jetir.org

Health Canada. (2017). Guide for Radon Measurements in Residential Dwellings. *Health Canada*, 1–22. https://www.canada.ca/content/dam/hc sc/documents/services/publications/health-risks-safety/guide-radon-measurements-residential-dwellings/radon-measurements-homes-eng.pdf

Hosoda, M., Oda, Y., Kranrod, C., Sampei, A., Kiso, M., & Taira, Y. (2024). Dose Assessments Due to Inhalation of Radon and Thoron at 70 Dwellings in the Coastal Area of Fukushima. *Radiation Environment and Medicine 13*(2), 51083.

ICRP, The 2007 Recommendations of the International Commission on radiological Protection. *ICRP Publication 103*. Ann. ICRP 37, 2007. pp. 2-4.

Khan, F. N. Ali, E. U. (2012). Study of indoor radon concentrations and associated health risks in the five districts of Hazara division, Pakistan," *Journal of Environmental Monitoring*, vol. 14, no. 11, pp. 3015–3023

Kitson-Mills, D., Sovoe, S., Opoku-Ntim, I., Kyei, K. A., Marnotey, S., Anim-Sampong, S., Kwabeng, M. A., Otoo, F., & Baiden, F. (2019). An assessment of indoor radon level in a suburb of ghana. *Environmental Research Communications*, *1*(6). https://doi.org/10.1088/2515-7620/ab2af7

Kolawole M. L, Etido P. I, Efiong A. I, Funmilayo A. (2023). Assessment of indoor radon gas concentration in national open university of nigeria: a case study of calabar study centre. *East European Journal of Physics*. 4. 371-375 (2023). https://doi.org/10.26565/2312-4334-2023-4-47

Li, J. E. N. N., Yerima, A. H., Bobbo, M. O., Nugraha, E. D., Ipan, A. S., Najam, L. A., Navarro, J. A. S., & Yoho, B. (2024). Lithological Impact on Radon Levels : A Study of Indoor and Soil Gas Radon in the Centre Region of Cameroon. Thorium 232, 1–15. *Journal of Geophysical Research: Atmospheres*. https://doi.org/10.1029/2024JD040843

Louis, N. E., & Blanchard, D. G. (2022). Public exposure to natural radiation and related excess lung cancer risk in Betare-Oya gold mining areas, eastern-Cameroon. *Journal of Radiation Protection*. Vol(5). 82–85

Luc, B. T., Karim, K., Moumouni, D., Cedric, B., Cisse, O. I., & Zougmore, F. (2021). Assessment of Indoor Radon Concentration in Residential Buildings at Ouagadougou and Estimation of the Annual Effective Dose. *Radiation Science and Technology 7*(2), 41–46. https://doi.org/10.11648/j.rst.20210702.14

Lusimbo, I. R. (2019). Assessment Of Radiological Hazards Associated With Indoor Norm Dose Exposure In Residential Houses In Nairobi, Kenya. *Kenyan Journal of Radiatio Protection*. http://erepository.uonbi.ac.ke/handle/11295/109664

Ma'aji, A. A, Olanrewaju, A. I, Onifade, Y. S, Bello, R. (2024). Evaluation of radon gas concentration in soil samples from Boheholes in Kaltungo local Government Area of Gombe State, Nigeria. *Nigerian Journal of Physics*, Vol(33). No.1

Maheso, A. M. (2021). Radon levels in South African homes - design elements for a national survey and initial results from directed sampling. *International Journal of Radiation Oncology*. Vol(7) 123-132.

Meludu, O.C., Catherine, I., Idowu, O. P., Dolapo, S. O., Adesina, K. E. (2023). Assessment of Radionuclides distribution and associated radiological hazards of soil in Mayo-Belwa, Adamawa State. *Recent Advances in Natural Sciences* I (2023) 25. https://doi.org/10.61298/rans.2023.1.2.25

Mirdoraghi, M., Einor, D., Asghari, F. B., Esrafili, A., Heidari, N., Mohammadi, A. A., & Yousefi, M. (2020). Assess the annual effective dose and contribute to risk of lung cancer caused by internal radon 222 in 22 regions of Tehran , Iran using geographic information system. *Journal of Environmental Health Science and Engineering* 211–220.

Mohammed, N. K., & Focus, E. (2018). Indoor Radon Concentration Levels and Annual Effective Doses for Residence of Houses Near Uranium Deposit in Bahi District, Dodoma, Tanzania. *Tanzania Journal of Science*, *44*(1), 159–168. www.tjs.udsm.ac.tz

Nader AF. (2015). Theoretical and Experimental Study to Evaluate Radioactivity Applied on a Selected Area in Basra Governorate. Basra, Iraq: University of Basra, Iraq; [thesis].

Nsiah-Akoto, I., Fletcher, J. J., Oppon, O. C., & Andam, A. B. (2011). Indoor Radon Levels and the Associated Effective Dose Rate Determination at Dome in the Greater Accra Region of Ghana. *Research Journal of Environmental and Earth Sciences*, *3*(2), 124–130.

Olaoye, M. A., Ademola, A. K., & Jegede, O. (2021). Residential Indoor Radon Assessment in the Vicinity of some Dumpsites in Lagos, Nigeria. *Journal of Applied*

Sciences and Environmental Management, *25*(1), 15–19. https://doi.org/10.4314/jasem.v25i1.2

Orlunta AN, Briggs Kamara MA, Sigalo FB, Iyeneomie T (2021) Analysis of Indoor Radon Level and its Health Risks Parameters in Three Selected Towns in Port Harcourt, Rivers State, Nigeria. *J Nig Soc Phys Sci* 3: 181- 188.

Otieno, W., Odongo, G., Chege, M., Tokonami, S., Hashim, N., Kranrod, C., & Nyambura, C. (2021). Radon and thoron exhalation rates from earthen building materials used in high background radiation areas of Homa and Ruri , Kenya. *Journal of Nuclear and Radiation Medicine*. Vol (3) 1–7

Radhia, P., Nugraga, E. D., Sharah, N. S., Omori, Y., & Wahyudi, W. (2024). The Effective Dose from Inhalation of Radon and Thoron in the Dwelling around the Tin Mine and Smelter Area in Bangka , Indonesia. *Radiation Environment and Medicine*. *13*(2), 51083.

Salih, N. F., & Jaafar, M. S. (2013). Higher levels of radon affect women's fertility in Iraqi Kurdistan Original research. *Polish Journal of Environmental Studies*, *22*(4), 1163–1169.

Shehu, F., C., & Way, S. (n.d.). *Lung Cancer risk in Nigeria, radon context*. *International Journal of Environmental Science and Technology*, *12*(2), 43–58. https://doi.org/10.1007/s17562-013-9352

Taufiq, M. (2022). National and Regional Surveys of Radon Concentration in Dwellings. Nigerian Nuclear Regulatory Authority Annual Report. Vol.(1) *33*.

UNSCEAR, 2000. Exposure of the public and workers from various sources of radiation, ANNEX B, 2008, pp. 223-293.

unscear - Google Search. (2023). Retrieved May 24, 2023, from https://www.google.com/search?q=unscear&oq=unscear&aqs=chrome..69i57.22230j0j7&sourceid=chrome&ie=UTF-8

USEPA. (1999). United States Environmental Protection Agency, Office of Water: 40 CFR Parts 141, and 142: *National Primary Indoor and Drinking Water Regulations*; radon-222: proposed rule.

WHO, G. (2011). Guidelines for air and drinking-water quality. World Health Organization, 216, 303- 304.