integrity Research Journals

Applied Journal of Physical Science
Volume 6(3), pages 62-72, June 2025
Article Number: 9820BF792
ISSN: 2756-6684
https://doi.org/10.31248/AJPS2025.114
https://integrityresjournals.org/journal/AJPS

Full Length Research

Evaluation of indoor radon concentration and associated health risk factors in Port Harcourt City, Nigeria

Ikurite Tarinabo, Otugo Vivian Nkechinyelum* and Briggs-Kamara Margaret

Department of Physics, Faculty of Science, Rivers State University, Port Harcourt, Nigeria.

*Corresponding author. Email: vivian.otugo@ust.edu.ng, Tel: +234-7069924809.

Received 3rd April 2025; Accepted 7th May 2025

ABSTRACT: This study evaluates indoor radon concentration levels in Port Harcourt Metropolis using measurements from three locations: Rivers State University campus (RSU), Rumughalu, and Oyigbo. The Corentium Airthings Digital Radon Detector was used to assess radon levels in ventilated and non-ventilated spaces, with Global Positioning System (GPS) support for accurate location referencing. Ten sampling points were assessed per location. At the RSU campus, non-ventilated areas recorded concentrations ranging from 3 to 33 Bq/m³, with an average of 17.4 ± 2.99 Bq/m³, while ventilated areas averaged 9.0 ± 1.33 Bq/m³. In Rumughalu, a densely populated industrial area, non-ventilated spaces recorded significantly elevated levels (73 – 322 Bq/m³), averaging 118.8 ± 23.4 Bq/m³, whereas ventilated spaces averaged 13.4 ± 1.19 Bq/m³. Oyigbo recorded 81.2 ± 1.79 Bq/m³ in non-ventilated areas and 17.5 ± 2.43 Bq/m³ in ventilated ones. The Annual Effective Dose Rate (AEDR) in Rumughalu's non-ventilated areas was 0.57 ± 0.11 mSv/year, remaining below the International Commission on Radiological Protection (ICRP) recommended limit of 1.0 mSv/year. Excess Lifetime Cancer Risk (ELCR) values were location-specific: RSU (0.29 ± 0.05) × 10^{-3}, Rumughalu (2.39 ± 0.47) × 10^{-3}, and Oyigbo (1.36 ± 0.03) × 10^{-3} in non-ventilated areas, with values in Rumughalu and Oyigbo exceeding the ICRP reference value of 0.29 × 10^{-3}. The study concludes that proper ventilation significantly reduces indoor radon concentration, highlighting the need for regular monitoring and improved ventilation practices in residential areas within the Port Harcourt metropolis. It recommends increased public awareness and improved building practices to ensure safer indoor air quality.

Keywords: Annual effective dose rate, excess lifetime cancer risk, health risk parameters, radon concentration.

INTRODUCTION

Radon is a naturally occurring radioactive noble gas found in soil, water, and both outdoor and indoor air. It originates from the decay of uranium and radium, which are naturally present in rocks, bedrock formations, and groundwater worldwide. As a product of the earth's crust, radon gas is released into the atmosphere and can accumulate in buildings, including homes and workplaces (World Health Organisation, 2009).

Indoor radon concentrations vary widely due to geological conditions and factors affecting pressure differentials between the inside and outside of buildings. These include ventilation rates, indoor heating, and meteorological influences (Esan *et al*., 2024). Radon-222 (^{222}Rn), the most common isotope, is a radioactive gas with a half-life of 3.82 days, produced in the uranium-238 (^{238}U) decay series (Ruano-Raviña *et al.*, 2017). Indoor radon exposure is increasingly recognised as a public health concern in Nigeria. People are more exposed to high radon levels in small houses than in larger apartments (Aladeniyi, 2024). Usually, radon gas is released into the atmosphere from ground formation and significantly contributes to elevated indoor radon levels through some mechanisms, including convection via cracks and openings, diffusion from the soil via the pore space, an emanation from building materials, off-gassing of waterborne radon into the indoor environment, and entry of radon into the structure from outdoor air (Kumar *et al*., 2007; Pervin *et al*., 2018; Lee *et al*., 2020). The entry routes of indoor radon into the houses include the door, the windows, cracks on the walls, sinks, basements, and floors. Exposure to radon accounts for more than 50% of the annual effective dose of natural radioactivity (Ndubisi *et al*., 2021). Other influencing parameters are the radium content and mineralogy of the host rock and soil, porosity, grain size, moisture content, and permeability (Antoci *et al*., 2007).

Radon-222 releases an alpha particle with 5.49 MeV of energy when it decays to polonium-218. Polonium atoms are metals and tend to stick to surfaces when they come in contact with the dust particles in the air. Once the contaminated dust particles are inhaled, they damage the DNA of respiratory tissues, leading to respiratory functional changes, consequently increasing the risk of lung cancer (Turner *et al*., 2011). Unfortunately, radon was identified as a human lung carcinogen in 1986 by the WHO (ICRP, 2010). According to this organisation, radon gas is by far the most probable source of ionizing radiation among those that are of natural origin. It has been considered by the United Nations Environment Programme (UNEP) that radon is the second cause of lung cancer after smoking, and the combined effect of indoor radon and smoking is responsible for developing lung cancer (US EPA, 1999). Since radon is inert, almost all of the gas inhaled is then immediately exhaled. However, radon-222 decays into a series of solid, short-lived radioisotopes that, when inhaled, settle in the respiratory tract. Due to their short half-lives (less than 30 minutes), these radon progenies primarily decay in the lungs before being cleared (Darby *et al*., 2006). Two of these short-lived progenies, polonium-218 and polonium-214, emit alpha particles, and the energy from these alpha particles is the main contributor to the radiation dose to the lungs, and if decay occurs in the lungs, the resulting solid radioactive particles can settle onto bronchial epithelial cells causing DNA damage (ICRP, 2010). Studies have shown that radon-222 causes between 3% to 14% of all lung cancer cases throughout the world (World Health Organisation [WHO], 2009). This is the leading cause of lung cancer among non-smokers. However, another author (Sethi *et al*., 2012) states that the possibility of radon having a causative effect on other cancers has been explored but not yet proven. A possible correlation between radon exposure and skin cancer has been suggested. Hauri et al. (2017) reported an increased risk of malignant melanoma mortality associated with long-term exposure to elevated indoor radon levels. The health risk posed by radon depends largely on the concentration present and the duration of exposure. The relationship between the Amount of radon present and the health risk it poses depends on the length of time a person is exposed. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2008) states that the average yearly exposure of every individual is 1.15 mSv, which is attributed to radon.

A study at Obafemi Awolowo University reported that although most radon levels were below international limits, poorly ventilated areas still showed a measurable risk of lung cancer (Esan *et al.,* 2024). Despite the potential health risks associated with indoor radon exposure, there is a notable lack of comprehensive assessment, database on radon exposure, and mitigation efforts within Port Harcourt, Nigeria. The absence of systematic monitoring and evaluation of indoor radon levels leaves occupants vulnerable to potential health hazards without the necessary information to address them effectively (Oyelere, 2024). Furthermore, without an understanding of the extent of indoor radon contamination, it is challenging to implement targeted mitigation strategies to reduce exposure and ensure a safe living environment (Oyelere, 2024).

Therefore, this study aims to evaluate the concentration level of indoor radon in some selected residences in Port Harcourt metropolis and estimate the probable associated health risk of the residents. The findings of this research will be crucial for safeguarding the health and well-being of residents and for promoting a safe and healthy working environment in Port Harcourt City, Nigeria.

MATERIALS AND METHODS

The study area

The study was conducted in three residential communities within Port Harcourt, Rivers State, Nigeria: Rivers State University (RSU) campus, Oyigbo, and Rumughalu. These areas were purposively selected based on environmental characteristics and human activities likely to influence indoor radon levels, including construction work, industrial presence, and varying building types. A total of ten dwellings in each location, comprising both institutional accommodations and private residences, were surveyed.

Port Harcourt is an industrialized cosmopolitan city situated in the South-South geopolitical zone of Nigeria, within the core of the Niger Delta region. The city lies between latitudes 4°31'–4°40'N and longitudes 7°00'–7°10'E, with an elevation ranging from 10 to 15 meters above sea level. Its vegetation is predominantly tropical lowland rainforest, interspersed with mangrove swamps influenced by both salt and freshwater inundations. However, extensive urban development and industrial activities have significantly altered portions of the natural landscape. The city experiences a humid, semi-hot

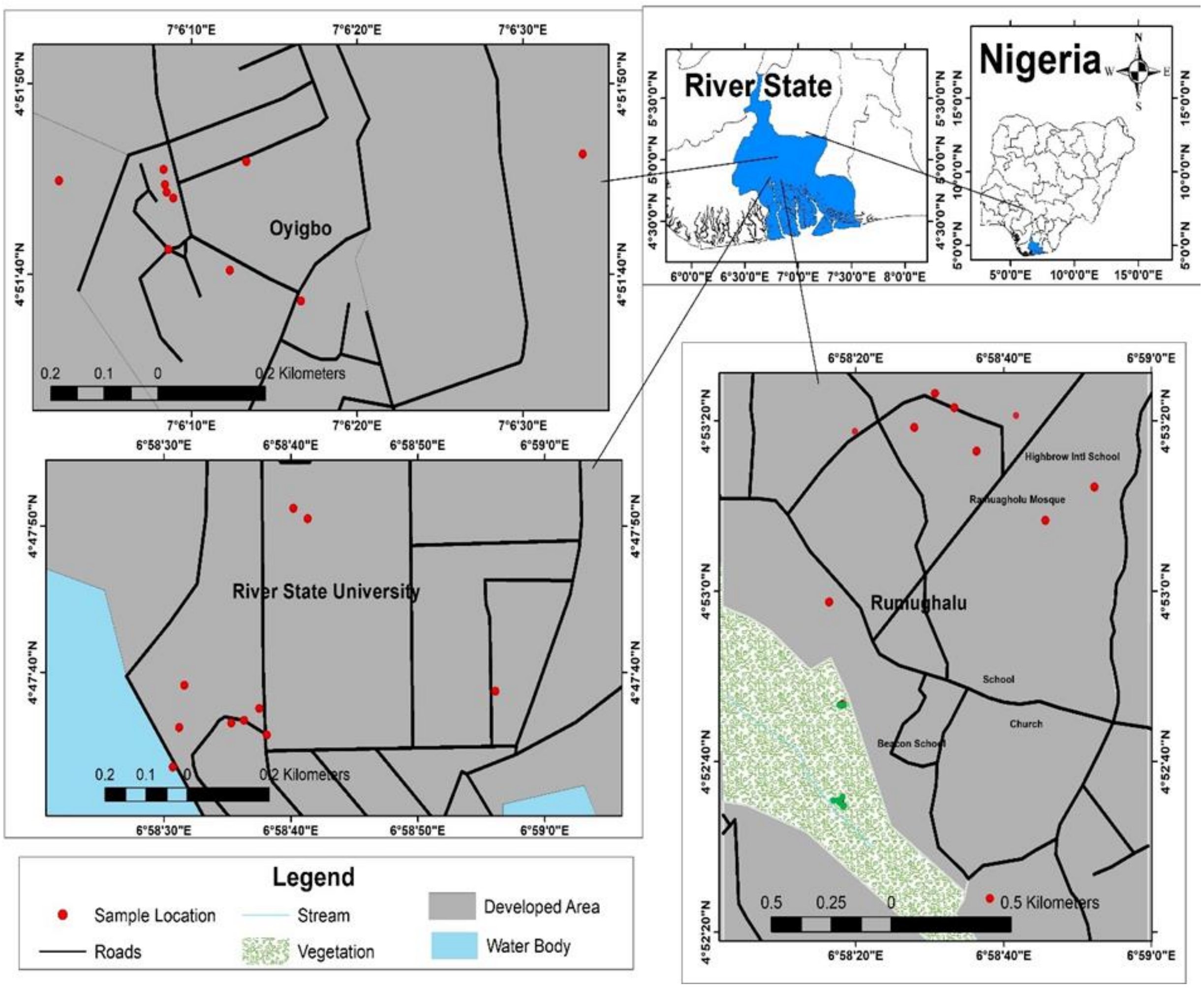

Figure 1. Map of study area (designed by the authors).

equatorial climate characterised by high rainfall and persistent moisture throughout the year (Ubong *et al.,* 2015). Figure 1 is a map of the study area

At the RSU campus, radon measurements were taken in student hostels and staff quarters to assess concentration levels in an institutional environment with diverse occupancy patterns and construction materials. In Oyigbo, a rapidly developing area near an extensive road construction project, dwellings were chosen to investigate the effect of soil disturbance and material displacement on radon emissions. Rumughalu was included due to its proximity to a gas processing facility. While gas plants do not directly emit radon, the geological formations and land disturbances associated with such infrastructure can enhance radon exhalation from the soil.

Residences were selected based on accessibility, willingness of occupants to participate, and their location relative to potential environmental radon sources. Measurements were conducted in the most frequently occupied indoor spaces, typically bedrooms, store rooms, garages, living rooms, and other areas of the houses to reflect actual exposure conditions.

Collection of data

Indoor radon concentrations were measured sequentially in 30 dwellings across three residential locations using the Corentium Home Radon Detector (Airthings), a digital passive device with factory calibration and certification under European Conformity (CE) and the American National Standards Institute (ANSI) in collaboration with the American Association of Radon Scientists and Technologists (AARST). The detector provides real-time readings in becquerels per cubic meter (Bq/m³). The device was sourced from the United Kingdom.

Figure 2. Faces of the Airthings Corentium detector (photograph by the Author, 2025).

Each dwelling was monitored over 48 hours, resulting in a cumulative sampling period of approximately 60 days. Detector was positioned in accordance with standard guidelines, maintaining a distance of approximately 25 cm from walls, 50 cm above the floor, and at least 150 cm from windows and doors (Ndubisi *et al*., 2021). This placement minimised the effects of ventilation and reflected typical indoor conditions. Measurements were conducted in the most frequently occupied rooms.

In addition to radon concentration data, the geographic coordinates of each sampling location were recorded using the GPS Coordinates mobile application installed on an iPhone XR. This ensured accurate documentation of latitude and longitude for each site. The instruments used in the course of this work include.

1. A pocket-sized Airthing Corentium Digital Radon detector.
2. The Geographical Positioning System.
3. Data collection spreadsheet.

The Airthings corentium home radon detector is the radon monitor suitable for family homes, public buildings, and workplaces. It is a simple and fast instrument that can be used by everyone. Operating on batteries, the detector can easily be moved through the building, thus allowing one to obtain a complete overview of the distribution of radon in the dwelling.

The radon detector monitors samples of indoor air through a passive diffusion chamber and uses alpha spectrometry to accurately calculate radon concentration. The detection is done using silicon photodiodes, both to count and to measure the energy of the alpha particles resulting from the chain of decomposition of the radon gas. When the alpha particle strikes the photodiode, it produces a small signal current. The signal current is changed into a large voltage signal by using a low-power amplifier stage. An analogue-to-digital converter measures and samples the voltage signal's maximum amplitude. The Corentium digital radon detector was chosen for its reliability and user-friendliness. It is not affected by temperature, humidity, or electromagnetic interference, making it ideal for varied indoor conditions. The device required no calibration and was used to obtain short-term radon concentration values during the study.

The Corentium Air Things Digital Radon Detector was used to measure indoor radon in residential homes on the RSU campus. The Arthings Corentium digital radon detector is installed in the room at a distance of 0.25 m from the walls, 1.5 m from the window, and 0.5 m from the door for 48 hours in each building (Ndubisi *et al*., 2021). Figure 2 shows the image of the radon measuring device, the Corentium Air Things detector.

For the concentration of radon gas measurements, the Corentium Air Things digital radon detector was placed inside each selected residential building for a minimum period of two days. To start the measurements, the device was reset by pressing the RESET function located on the back of the detector to erase the data from the device once inside the chosen house before starting a new measurement.

All results are given in a specific numerical value of becquerels per cubic meter (Bq/m^3). Concentration values will be read and copied onto a radon concentration data collection spreadsheet (Microsoft Excel) every 2 days. The values recorded were the short-term average (Corentium Airthing User Manual, 2024).

Data analysis

Annual absorbed dose from radon concentration

The absorbed dose (D) represents the amount of ionising radiation energy deposited per unit mass of tissue and is expressed in grays (Gy), where 1 Gy equals 1 joule per kilogram. It is a fundamental metric in radiation protection, used to assess potential tissue damage, particularly deterministic effects that arise beyond specific thresholds (Harrison *et al*., 2021; Sinnott *et al*., 2010). In this study, the annual absorbed dose due to indoor radon exposure was calculated using the International Commission on Radiological Protection (ICRP 2017) recommended equation. The calculation incorporated key assumptions: an equilibrium factor (F) of 0.4, an indoor occupancy time (t) of 7000 hours/year, a dose conversion factor (DCF) of 9× .0 10^{-6} mSv/h per Bq/m³, and measured radon concentrations (CRn) obtained from selected residential buildings in Port Harcourt metropolis. Equation 1 is given as:

$$D = C_{Rn} \times F \times t \times D_F \times Q \qquad (1)$$

Where: D = Annual absorbed dose (mSv/year), CRn = Radon concentration (Bq/m³), F = Equilibrium factor between radon and its progeny (0.4), t = Exposure time (7000 hours/year indoors) (0.8×24h×365), DF = Dose conversion factor ((9.0×10^{-6}mSv/h per Bq/m³), Q = Occupancy factor, which represents the fraction of time spent indoors (0.8)

Computed annual effective dose rate (AEDR) from radon concentration

The annual effective dose is a measure used to estimate the risk of radiation exposure to human health over the course of a year. It accounts for the type of radiation and the sensitivity of different tissues and organs to radiation. The annual effective dose provides a comprehensive measure of the radiation risk associated with radon exposure. The effective dose calculation converts the absorbed dose into a measure that reflects potential biological damage and risk, considering different sensitivities of organs. According to the International Commission on Radiological Protection (ICRP, 2017), the annual effective dose from radon exposure can be calculated using a specific equation (2) that incorporates several factors such as radon concentration, the equilibrium factor, the time spent indoors, and the dose conversion factor to estimate the potential health impact.

$$AED = C_{Rn} \times F \times t \times D_{CF} \qquad (2)$$

Where: AED = Annual effective dose (mSv/year), CRn = Radon concentration (Bq/m³), F = Equilibrium factor (0.4), t = Time of exposure (7000 hours/year), DCF = Dose conversion factor (mSv/(Bq·hm³)), 1.4 × 10^{-2} mSv/(Bq·m³· year). Dose per unit of radon concentration and exposure time (Tan and Nie, 2024).

Computed excess lifetime cancer risk from radon concentration

Excess lifetime cancer risk serves as a quantitative measure to estimate the potential likelihood of an individual developing cancer as a consequence of exposure to ionizing radiation. Excess Lifetime Cancer Risk (ELCR) from radon concentration quantifies the statistical probability of developing cancer over a lifetime as a result of chronic exposure to radon. This metric serves as an important indicator in assessing the long-term health impacts of radon exposure in environmental health studies. Determining this risk involves a complex analysis that considers an array of variables, such as the dose and type of radiation the individual has been exposed to, their age and gender, as well as the specific organ or tissue affected (Stewart and Kleihues, 2003). The United States National Research Council has defined low-dose radiation as ranging from approximately 0 mSv to 100 mSv of low-linear-energy-transfer radiation.Based upon calculated values of AEDE, Excess Life Cancer Risk (ELCR) is calculated using equation (3);

$$\text{ELCR} = \text{AEDE x (DL) x (RF)} \qquad (3)$$

Where: ELCR = Excess Lifetime Cancer Risk, AEDE = annual effective dose equivalent, DL = Average Duration of Life (typically assumed to be around 70 years), RF = Risk Factor (0.051 Sv^{-1}) (Dosunmu *et al.,* 2022).

Fatal cancer risk per sievert for low-dose background radiation is considered to produce stochastic effects; ICRP 60 uses values of 0.05 for public exposure (Taskin *et al*., 2009).

RESULTS AND DISCUSSION

The results of measurement of the indoor radon concentration across the three study locations, Rivers State University (RSU), Rumughalu, and Oyigbo, demonstrate significant variation influenced primarily by ventilation conditions. These variations highlight the critical role of ventilation in mitigating radon accumulation, which poses long-term health risks. The concentration data are summarised in Tables 1 to 3 for each location.

At the RSU campus, radon levels in non-ventilated spaces ranged from 3 to 33 Bq/m³, with an average of 17.4 ± 2.9 Bq/m³. In contrast, ventilated spaces recorded

Table 1. Indoor Radon concentration measurements in selected residences at RSU.

House	Position of the device	CRn (Bq/m^3) Non-ventilated	Position of Device	CRn (Bq/m^3) (Ventilated)
RSU HS 1	Store Room	10	Living Room	6
RSU HS 2	Locker Room	26	Sitting area	13
RSU HS 3	Garage	3	living room	3
RSU HS 4	Garage	12	Bed room	6
RSU HS 5	Store Room	27	Bed room	12
RSU HS 6	Store Room	33	Living Room	17
RSU HS 7	Store Room	23	Bed room	11
RSU HS 8	Garage	10	Living Room	6
RSU HS 9	Store Room	13	Sitting area	7
RSU HS10	Garage	17	Living Room	9
Range		3-33		3-17
Average		17.4±29.9		9.0±1.33

Table 2. Indoor Radon concentration measurements in selected residences at Rumughalu.

House	Position of Device	CRn (Bq/m^3) Non- ventilated	Position of Device	CRn (Bq/m^3) Ventilated
RUM HS 1	Pantry	322	Living Room	8
RUM HS 2	Locker Room	120	Dining Room	12
RUM HS 3	Store Room	85	Dining Room	20
RUM HS 4	Laundry Room	73	Living Room	10
RUM HS 5	Bathroom	130	Living Room	15
RUM HS 6	Pantry	105	Living Room	9
RUM HS 7	Store Room	90	Living Room	14
RUM HS 8	Store Room	80	Living Room	17
RUM HS 9	Store Room	110	Living Room	13
RUM HS 10	Pantry	73	Living Room	16
Range		73-322		8-20
Average		118.8±23.41		13.4±1.19

Table 3. Indoor radon concentration measurements in selected residences at Oyigbo.

House	Room placed	CRn (Bq/m^3) Ventilated	Room placed	CRn (Bq/m^3) Non-ventilated
OYI HS 1	Kitchen	14	Bed Room	84
OYI HS 2	Sitting area	12	Store Room	77
OYI HS 3	Kitchen	15	Bed Room	80
OYI HS 4	Bed Room	10	Store Room	75
OYI HS 5	Bed Room	25	Bed Room	82
OYI HS 6	Passage	14	Bed Room	78
OYI HS 7	Sitting Area	16	Kitchen	85
OYI HS 8	Bed Room	35	Kitchen	93
OYI HS 9	Kitchen	22	Bed Room	84
OYI HS 10	Living Room	12	Store Room	74
Range		10-35		74-93
Average		17.5±2.43		81.2±1.79

Table 4. Estimated average values of the radiological health risk parameters for ventilated areas.

Location	CRn (Bq/m³)	DRn (mSv/y)	AEDR (mSv/y)	ELCR 70 Years	ELCR 60 Years	ELCR 50 Years	ELCR 40 Years	ELCR 30 Years
RSU	9.0	0.18	0.04	0.15	0.12	0.10	0.08	0.06
Rumughalu	13.4	0.27	0.81	2.83	2.43	2.02	1.62	1.21
Oyigbo	17.5	0.35	0.08	0.29	0.25	0.21	0.16	0.12

Table 5. Estimated average values of the radiological health risk parameters for non-ventilated areas.

Location	CRn (Bq/m³)	DRn (mSv/y)	AEDR (mSv/y)	ELCR 70 Years	ELCR 60 Years	ELCR 50 Years	ELCR 40 Years	ELCR 30 Years
RSU	17.4	0.35	0.08	0.29	0.25	0.20	0.16	0.12
Rumughalu	118.8	2.39	0.57	1.99	1.71	1.42	1.14	0.85
Oyigbo	81.2	1.63	0.38	1.36	1.16	0.97	0.77	0.58

significantly lower levels ranging from 3 Bq/m³ to 17 Bq/m³, averaging 9.0 ± 1.33 Bq/m³. These findings demonstrate the effectiveness of ventilation in dispersing radon gas and reducing indoor concentrations.

Rumughalu exhibited the highest radon levels among the three sites. In non-ventilated spaces, concentrations ranged from 73 to 322 Bq/m³, with an average of 188.8 ± 23.41 Bq/m³. One particularly high reading of 322 Bq/m³ was recorded in a non-ventilated pantry, surpassing the ICRP's upper safety threshold of 300 Bq/m³ and exceeding the reference level of 100 Bq/m³, indicating a potential health risk. The elevated levels suggest a higher concentration of natural radon-emitting materials and limited air circulation. Proximity to industrial activities and building materials may further contribute to radon accumulation. Ventilated areas in Rumughalu had significantly lower levels, ranging from 8 Bq/m³ to 20 Bq/m³, with an average of 13.4 ± 1.19 Bq/m³, reinforcing the importance of air movement in mitigating exposure.

In Oyigbo, radon concentrations also varied with ventilation. Non-ventilated spaces had concentrations ranging from 74 to 93 Bq/m³, averaging 81.2 ± 1.79 Bq/m³. Ventilated areas showed reduced levels, between 10 Bq/m³ and 35 Bq/m³, with an average of 17.5 ± 2.9 Bq/m³. Although radon levels here were higher than those in RSU, they remained below international safety limits. The highest average radon concentration recorded in this study (188.8 Bq/m³) was observed in non-ventilated Rumughalu, while the lowest (9.0 Bq/m³) occurred in ventilated RSU spaces. Importantly, all radon levels recorded in RSU and Oyigbo, both ventilated and non-ventilated, were within the ICRP-recommended safe range of 100-300 Bq/m³.

Health risk assessments were conducted by estimating radiological parameters, including the annual absorbed dose, annual effective dose rate, and excess lifetime cancer risk (ELCR), presented in Tables 4 and 5. The annual absorbed doses across all sites ranged from 0.06048 to 6.49152 mSv/year. Non-ventilated spaces generally exhibited higher doses than ventilated ones. The average absorbed doses were RSU (non-ventilated: 0.35 ± 0.60 mSv/year, ventilated: 0.18 ± 0.02 mSv/year), Rumughalu (non-ventilated: 2.39 ± 0.47 mSv/year, ventilated: 0.27 ± 0.02 mSv/year), and Oyigbo (non-ventilated: 1.63 ± 0.03 mSv/year, ventilated: 0.35 ± 0.04 mSv/year). All values fall below the ICRP's recommended limit of 10 mSv/year for the general public, indicating safe exposure levels.

The annual effective dose rate ranged from 0.08 ± 0.14 mSv/year in non-ventilated RSU rooms to 0.57 ± 0.11 mSv/year in non-ventilated Rumughalu rooms. Again, while within ICRP's 1.0 mSv/year limit, the elevated dose rates in Rumughalu suggest the need for improved ventilation or other mitigation strategies.

The ELCR calculated using a 70-year exposure model (with additional estimates for ages 30, 40, 50, and 60) based on Ndubisi *et al*. (2021), revealed higher risks in non-ventilated areas. Rumughalu had the highest non-ventilated ELCR value at 1.99 ± 0.39, exceeding the ICRP reference level of 0.29. ELCR values in non-ventilated areas were 0.29 ± 0.50 for RSU, 1.99 ± 0.39 for Rumughalu, and 1.36 ± 0.03 for Oyigbo. Ventilated areas showed reduced ELCRs: RSU (0.15 ± 0.02), Rumughalu (0.22 ± 0.02), and Oyigbo (0.22 ± 0.02), affirming that ventilation plays a vital role in reducing radon-related health risks.

These findings align with previous research by Ndubisi *et al.* (2021), who analysed radon levels in Port Harcourt, and Sokari (2018), who examined residential radon risks in Okrika. Both studies, like the current one, underscore that non-ventilated environments consistently present

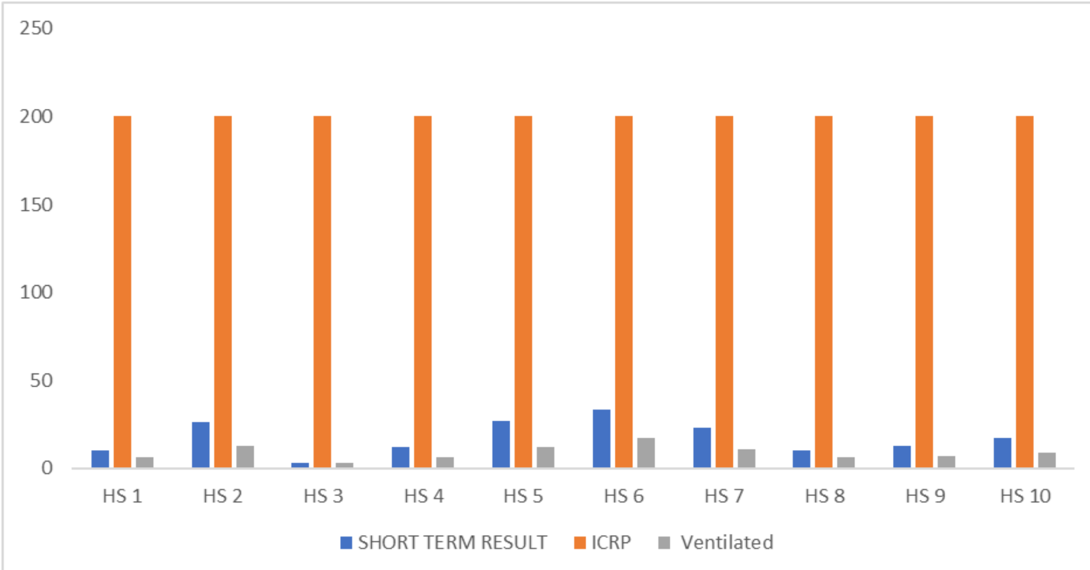

Figure 3. Concentration levels of ventilated and non-ventilated areas in RSU compared with the ICRP Reference level.

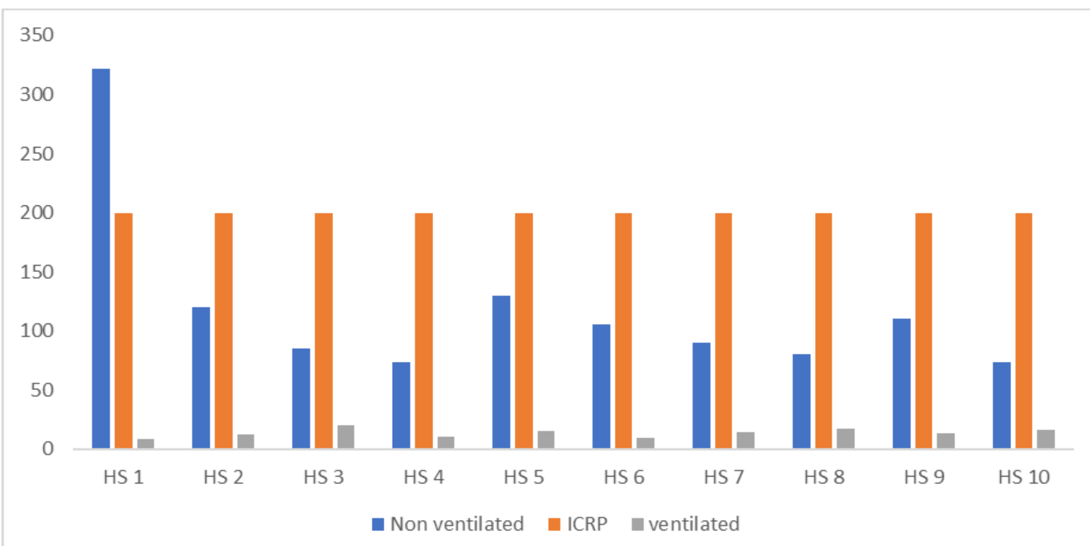

Figure 4. Radon concentration level of ventilated and non ventilated areas in Rumaughalu compared with the ICRP reference level.

higher radon concentrations and greater radiological health risks. Similarly, Oke and Ogunleye (2022) found lower radon concentrations in well-ventilated homes in Lagos, supporting the current study's results.

In comparison with other African studies, Moyo *et al.* (2020) in South Africa and Chikunguru et al. (2021) in Zimbabwe also observed higher radon levels in non-ventilated residential spaces, further emphasising the role of ventilation in reducing radon exposure.

Figures 3 to 5 illustrate the radon concentration levels in ventilated and non-ventilated areas across the study sites. At the RSU campus (Figure 3), none of the sampled rooms exceeded the ICRP recommended reference level, indicating this location as the safest among the study areas. In Rumughalu (Figure 4), one non-ventilated room slightly surpassed the ICRP reference level, suggesting a

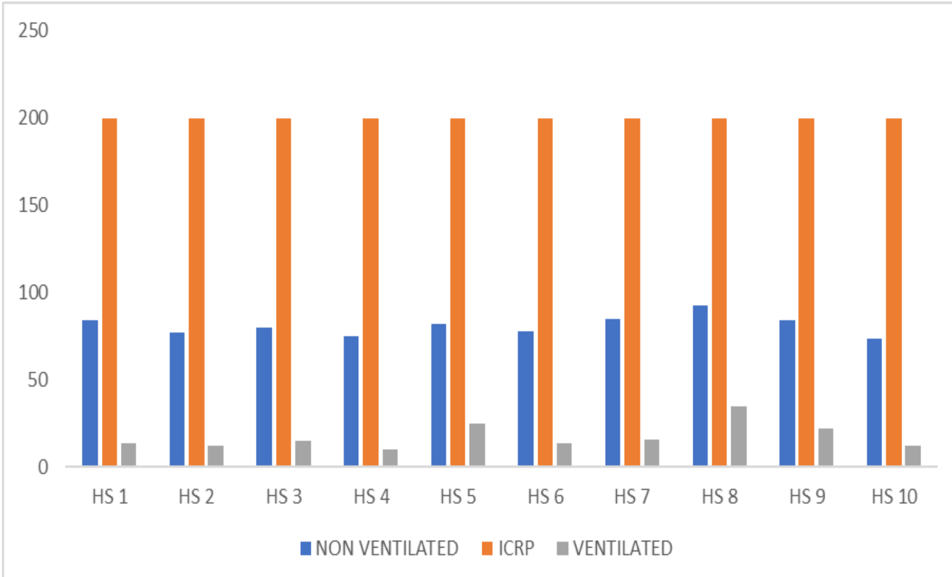

Figure 5. Radon concentration level of ventilated and non-ventilated areas in Oyigbo compared with the ICRP reference level.

localized radon accumulation likely influenced by nearby industrial activity and insufficient ventilation. At Oyigbo (Figure 5), radon levels in both ventilated and non-ventilated areas remained within safe limits; however, concentrations were generally higher than those at the RSU campus, indicating a moderate exposure risk.

This study's strength lies in its thorough assessment of indoor radon concentrations across three distinct locations in Port Harcourt Metropolis, using the portable and reliable Corentium Airthings Digital Radon Detector for accurate measurements. By including both ventilated and non-ventilated spaces, the study effectively demonstrates the impact of ventilation on radon accumulation.

However, there are some limitations. The sample size is relatively small, with only 20 sample points per location, which limits the ability to generalise the findings. Additionally, the study is confined to three locations in Port Harcourt, which restricts its representation of radon exposure across Nigeria and the wider African context. A broader study, encompassing both rural and urban areas, would provide a more comprehensive understanding of radon risks. Furthermore, the study does not account for seasonal variations in radon levels, which could fluctuate due to changes in ventilation and atmospheric conditions, warranting further exploration in future research.

Estimated radiological health risk parameters of the measured indoor radon concentration

The radiological health risk from indoor radon exposure was assessed by calculating the annual absorbed dose (AD), annual effective dose rate (AEDR), and excess lifetime cancer risk (ELCR) over different exposure durations of 30, 40, 50, 60, and 70 years. This approach reflects how longer exposure periods increase the potential health risk.

The results showed that with increasing exposure time, the estimated ELCR values also increased, indicating a greater lifetime cancer risk for residents exposed for longer periods. Houses with radon levels above the WHO (2009) guideline of 100 Bq/m³ presented notably higher risks. These findings agree with previous studies, such as Dosunmu *et al*. (2022) and Arogunjo et al. (2005), which also reported elevated risks related to prolonged radon exposure in Nigerian dwellings.

Compared to the global average risk reported by UNSCEAR (2000), many of the calculated ELCR values in this study were higher, highlighting the potential health impact for residents living in high-radon environments, especially when combined with factors like poor ventilation.

Conclusion and Recommendation

The analysis of indoor radon concentration levels has been carried out in 3 locations within Port Harcourt metropolis. In each of the 3 locations, measurement was done at 20 sample points. 10 ventilated spaces and 10 non-ventilated spaces, making it a total of 60 sample points. The evaluation of indoor radon concentration level confirms that radon levels are generally manageable with adequate ventilation, but certain areas, especially non-ventilated and naturally radon-rich locations, present higher health risks due to elevated concentrations. Rumughalu stands out as a high-risk area, with radon concentrations and ELCR values above safety thresholds. This underscores the importance of regular monitoring, especially in poorly ventilated spaces, where radon concentrations may accumulate beyond safe limits. This implies a direct need for mitigation strategies, particularly in enclosed spaces with high occupancy rates.

Enhanced ventilation systems should be encouraged, especially in enclosed spaces where radon levels were found to exceed recommended limits, as improved airflow can significantly reduce indoor radon accumulation. Regular radon testing should also be implemented, particularly in high-risk areas or structures with poor ventilation, to ensure that concentrations remain within safe limits over time. Furthermore, the government and relevant agencies should launch educational campaigns to raise public awareness about radon risks, safe building practices, and the health implications of long-term exposure. These campaigns should promote periodic radon testing and encourage building designs that prioritise ventilation. Lastly, there is a need to develop local guidelines and policies that align with international standards on radon exposure, including mandatory testing in residential and public buildings.

CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

REFERENCES

Aladeniyi, K. (2024). *Health risk evaluation of radon progeny exposure in Nigerian traditional mud houses*. *Journal of the Nigerian Society of Physical Sciences*, *6*(3), 2128.

Antoci, C., Immè, G., La Delfa, S., Nigro, S. L., Morelli, D., & Alessandro, G. P. G. (2007). Indoor and soil radon measurements in the Hyblean Foreland (South-East Sicily). *Annals of Geophysics, 50(4), 493-500.*

Arogunjo, A. M., Afolabi, M. A., & Akinloye, M. K. (2005). Assessment of indoor radon concentrations and dose in dwellings of Ondo and Ekiti States, southwestern Nigeria. *Radiation Protection Dosimetry*, *113*(3), 243-247.

Chikunguru, T. S., Mudzengerere, J., & Mudzingwa, L. (2021). Indoor radon concentrations in residential buildings in Zimbabwe: Implications for public health. *Journal of Environmental Health, 35*(1), 47-52.

Corentium by Airthings. (2024). User manual: Corentium Home radon detector. Airthings. Retrieved from https://www.airthings.com

Darby, S., Hill, D., Deo, H., Auvinen, A., Barros-Dios, J. M., Baysson, H., Bochicchio, F., Falk, R., Farchi, S., Figueiras, A., & Doll, R. (2006). Residential radon and lung cancer—detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14,208 persons without lung cancer from 13 epidemiologic studies in Europe. *Scandinavian Journal of Work, Environment & Health*, 1-84.

Dosunmu, G. O., Ademola, A. K., Jidele, P. A., Ajayi, K. F., & Olowofila, I. O. (2022). Measurements of radon and estimation of excess lifetime cancer risk in water-well samples along Iwaraja-Ifewara faults, Southwestern Nigeria. International *Research Journal of Public and Environmental Health*, *9*(4), 120-124.

Esan, D. T., Ajiboye, Y., Obed, R., Olubodun, B. B., & Tobih, J. E. (2024). Seasonal Indoor Radon Assessment and Estimation of Cancer Risk: A Case Study of Obafemi Awolowo University Nigeria. *Environmental Health Insights*, *18*, 11786302241271536.

Harrison, J., Balonov, M., Bochud, F., Martin, C., Menzel, H., Ortiz-Lopez, P., Smith-Bindman, R., Simmonds, J., & Wakeford, R. (2021). *ICRP Publication 147: Use of dose quantities in radiological Protection. Annals of the ICRP, 50*(1), 9-82.

Hauri, D., Huss, A., Zimmermann, F., Kuehni, C. E., & Röösli, M. (2017). A geospatial analysis of radon exposure and malignant skin cancer mortality in Switzerland. *Environmental Health Perspectives*, *125*(6), 067006.

International Commission on Radiological Protection (1993). Protection against radon-222 at home and at work. *ICRP Publication 65. Ann. ICRP 23(2).*

International Commission on Radiological Protection (ICRP) (1994). Human respiratory tract model for radiological protection. *ICRP Publication 66. Ann. ICRP, 24*(1–3).

International Commission on Radiological Protection (ICRP) (2005). Recommendations of the International Commission on Radiological Protection. *ICRP Publication 60. Annals of the ICRP, Pergamon Press, Oxford. Vol. 21*

International Commission on Radiological Protection (ICRP) (2010). Lung Cancer Risk from Radon and Progeny and Statement on Radon. *ICRP Publication 115, Ann. ICRP 40*(1).

International Commission on Radiological Protection (ICRP) (2017). *Radiological protection against radon exposure* (ICRP Publication 137). Elsevier.

International Commission on Radiological Protection (ICRP). (2010). Lung Cancer Risk from Radon and Progeny and Statement on Radon. *ICRP Publication 115. Ann. ICRP 40*(1).

Kumar, R., Mahur, A. K., John, J. P., & Prasad, R. (2007). Study of Radon and its Progeny Levels Dwellings of Thankassery, Kerala, India. *Indian Journal of Pure and Applied Physics, 45,* 877-879.

Lee, K. Y., Park, S. Y., & Kim, C. G. (2020). Effects of radon on soil microbial community and their growth. *Environmental Engineering Research*, *25*(1), 29-35.

Moyo, S., Hlongwane, J., & Ndlovu, T. (2020). *Assessment of indoor radon exposure in residential areas in South Africa and its impact on public health*. *African Journal of Environmental Science and Technology*, 14(6), 245-251.

Ndubisi, O. A., Briggs-Kamara, M. A., Sigalo, F. B., & Tamunobereton-Ari, I. (2021). Analysis of indoor radon level and its health risks parameters in three selected towns in PortHarcourt, Rivers State, Nigeria. *Journal of Nigerian Society of Physical Sciences, 3*(3),181-188.

Oke, S. O., & Ogunleye, O. (2022). *Radon concentration levels* *in Lagos: A comparative study of ventilated and non-ventilated residential areas*. Nigerian Journal of Environmental Research, 8(2), 134-139.

Oyelere, M. (2024, September 29). Radon exposure and lung cancer risk in Nigeria: The urgent need for a national database and public health action. *Tribune Online*. https://tribuneonlineng.com/radon-exposure-and-lung-cancer-risk-in-nigeria-the-urgent-need-for-a-national-database-and-public-health-action/

Pervin, S., Yeasmin, S., Ferdous, J., & Begum, A. (2018). A Study of Radon Concentration in Tap Water of Dhaka City. *Journal of Environmental Pollution and Management*, *1*, 205.

Ruano-Raviña, A., Kelsey, K. T., Fernández-Villar, A., & Dios, J. M. B. (2017). Action levels for indoor radon: different risks for the same lung carcinogen? *The European Respiratory Journal, 50*(5), 1701609.

Sethi, T. K., El-Ghamry, M. N., & Kloecker, G. H. (2012). Radon and lung cancer. *Clinical Advances in Hematology and Oncology, 10*(3), 157-164.

Sinnott, B., Ron, E., & Schneider, A. B. (2010). Exposing the thyroid to radiation: A review of its current extent, risks, and implications. *Endocrine Reviews, 31(6), 756-773.*

Sokari, S. A. (2018). Estimation of radiation risks associated with radon within residential buildings in Okrika, Rivers State, Nigeria. *Asian Journal of Physical and Chemical Sciences, 6*(3), 1-12.

Stewart, B. W., & Kleihues, P. (2003). *World Cancer Report.* International Agency for Research on Cancer Press.

Tan, W., & Nie, Y. (2024). Radon Concentration in Air and Evaluation of the Radiation Dose in Villages near Shizhuyuan, Southern Hunan, China. *Atmosphere*, *15*(7), 786.

Turner, M. C., Krewski, D., Chen, Y., Pope, C. A., Gapstur, S. M., & Thun, M. J. (2011). Radon and lung cancer in the American Cancer Society cohort. *Cancer Epidemiology, Biomarkers & Prevention, 20*(3), 438-448.

U.S. Environmental Protection Agency (EPA) (1999). *Methods, occurrence, and monitoring document of radon in drinking water*. Office of Ground Water and Drinking Water.

Ubong, U. I., Ideriah, T. J. K., Igbara, J., & Ubong, E. U. (2015). Ambient air quality assessment of the RSUST campus air basin, Port Harcourt. *International Journal of Advanced and Innovative Research, 4(8), 208.*

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2000). *Sources and effects of ionizing radiation.* Volume I. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes. United Nations.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2008). *Sources and effects of ionizing radiation: Annex B – Exposure of the public and workers from various sources of radiation.* United Nations.

World Health Organisation (2009). *WHO handbook on indoor radon: A public health perspective*. WHO Press.