

DETERMINATION OF RADON-222 ACTIVITY CONCENTRATIONS IN GROUNDWATER SOURCES AT FELELE CAMPUS, FEDERAL UNIVERSITY LOKOJA, KOGI STATE, NIGERIA

Nakale Amos Jonathan¹, Omachi Immanuel Ojonugba², Ayua Kuma Joshua³
^{1,2,3}Department of Physics, Federal University Lokoja, P.M.B. 1154, Lokoja, Kogi State, Nigeria
Corresponding author: jonathanrex45@yahoo.co.uk

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Abstract

This study investigates the activity concentrations of radon-222 in groundwater sources within Felele Campus, Federal University Lokoja, Kogi State, Nigeria, and evaluates the associated radiological health risks to the university community. Ten groundwater samples comprising five boreholes and five hand-dug wells were collected and analysed using a Packard Tri-Carb 1000TR liquid scintillation counter at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria. The annual effective doses due to ingestion of radon-laden water were calculated for adult residents using established dose conversion factors, with a daily water intake of two litres per day explicitly assumed based on World Health Organization reference values. Radon concentrations in borehole water samples ranged from 11.02 to 15.51 Bq/L, with a mean of 13.96 plus or minus 2.16 Bq/L, and eighty per cent exceeding the United States Environmental Protection Agency maximum contaminant level of 11.1 Bq/L. Well water samples showed concentrations ranging from 7.48 to 11.14 Bq/L, with a mean of 9.65 plus or minus 1.44 Bq/L, and sixty per cent falling below international safety thresholds. The corresponding annual effective doses ranged from 0.080 to 0.113 mSv per year for boreholes and 0.055 to 0.081 mSv per year for wells. The mean annual effective dose for borehole water marginally exceeded the World Health Organization recommended reference level of 0.1 mSv per year, while well water samples remained below this threshold. The elevated radon levels in borehole water are attributed to the underlying Precambrian basement geology, characterised by granitic rocks containing uranium-bearing minerals. While well water sources appear safe for consumption, borehole water requires treatment through aeration or granular activated carbon filtration before use. This study provides baseline data for radon levels in the area and underscores the need for regular monitoring of groundwater quality in university campuses reliant on underground water sources.

Keywords: radon-222; groundwater; liquid scintillation counting; annual effective dose; Felele Campus; radiological health risk

1. Introduction

Water is the most abundant natural resource on Earth, covering approximately seventy-five per cent of the surface of the planet and serving as an essential component of all living organisms (Gleick, 1993). For human populations, water is indispensable for drinking, sanitation, agriculture, power generation, transportation, and various domestic and industrial activities. Consequently, the quality and safety of water sources with respect to radiological, chemical, microbiological, and other forms of contamination represent critical public health concerns requiring continuous monitoring and assessment (WHO, 2017).

Radon is a naturally occurring radioactive, colourless, odourless, and tasteless noble gas with an atomic number of eighty-six and a half-life of 3.8 days (USEPA, 2012). It is produced as an intermediate decay product in the uranium-238 decay series, specifically from the radioactive decay of radium-226 (UNSCEAR, 2000). Uranium and thorium, the parent elements of radon, are ubiquitous in the crust of the Earth, occurring in varying concentrations across different geological formations, particularly in granitic rocks, phosphate deposits, and shale formations (Appleton, 2007). The presence of radon in groundwater is governed by several factors, including the uranium and radium content of aquifer materials, rock permeability, porosity, and the geochemical conditions that facilitate the migration of radon from rock matrices into groundwater (Vinson et al., 2009). Groundwater typically exhibits higher radon concentrations than surface water because it remains in prolonged contact with uranium-bearing geological formations, allowing continuous accumulation of the gas (Przylibski, 2011).

The health implications of radon exposure have been extensively documented since its discovery. The International Agency for Research on Cancer classifies radon as a Group 1 human carcinogen, placing it in the same category as tobacco smoke, asbestos, and benzene (International Agency for Research on Cancer, 2012). When radon gas is inhaled, its short-lived progeny deposit in the bronchial epithelium, emitting alpha particles that can cause damage to deoxyribonucleic acid and initiate carcinogenesis (Darby et al., 2005). The World Health Organization estimates that radon exposure is responsible for between three and fourteen per cent of all lung cancer cases worldwide, making it the second leading cause of lung cancer after smoking (WHO, 2009). For the ingestion pathway, radon dissolved in drinking water delivers a radiation dose to the stomach and other gastrointestinal organs, and epidemiological evidence suggests an association between long-term ingestion of radon-contaminated water and increased risk of gastrointestinal cancers (Hopke et al., 2000).

In response to these health concerns, various international and national regulatory bodies have established guidelines for radon in drinking water. The United States Environmental Protection Agency proposed a maximum contaminant level of 11.1 Bq/L for public water supplies (USEPA, 1999). The World Health Organization recommends a reference level of 100 Bq/L for individual water sources but emphasises that optimisation principles should be applied to reduce concentrations below 10 Bq/L where technically feasible (WHO, 2011). The Standards Organisation of Nigeria has adopted a more stringent limit of 0.1

Bq/L for radon in drinking water, although this value is considered impractically low for groundwater sources in uranium-rich geological terrains (SON, 2015).

Nigeria is underlain predominantly by Precambrian Basement Complex rocks in the western and northern regions and sedimentary formations in the south, exhibiting variable radon potential across its geological provinces (Obiora, 2005). Several studies have investigated radon concentrations in Nigerian groundwater. Garba et al. (2012) reported values ranging from 3.2 to 18.7 Bq/L for Zaria, while Aruwa et al. (2017) reported concentrations ranging from 11.2 to 45.6 Bq/L in parts of Kaduna State. Amodu et al. (2026) found that eighty per cent of groundwater samples from parts of Oyo and Osun States exceeded the maximum contaminant level, and Adebisi et al. (2025) reported a mean of 13.54 plus or minus 2.51 Bq/L for Igbesa, Ogun State. Federal University Lokoja, established in 2011, is situated in Felele, an area underlain by Precambrian basement rocks typical of the Lokoja region, and the campus relies exclusively on groundwater from boreholes and hand-dug wells for its water supply. The recent occupation of this environment, combined with the complete absence of baseline radon data, necessitates a comprehensive assessment of radiological water quality to safeguard the health of students, staff, and residents.

This study therefore aims to determine the activity concentration of radon-222 in groundwater sources within the campus, compare the measured values with international safety standards, calculate the annual effective doses due to ingestion of radon-contaminated water for adult residents, and identify water sources requiring intervention with appropriate mitigation measures. Given the complete dependence of the campus on groundwater and the potential health implications of chronic radon exposure, this research fills a critical knowledge gap and provides essential baseline data for regulatory decision-making and public health protection.

2. Materials and Methods

2.1 Study Area Description

Felele Campus of Federal University Lokoja is situated in Lokoja Local Government Area, Kogi State, north-central Nigeria. The campus is located at latitude 7 degrees 51 minutes north and longitude 6 degrees 43 minutes east, within the Guinea savanna ecological zone. The area experiences a tropical climate with distinct wet and dry seasons, mean annual rainfall of approximately 1,150 millimetres, and average temperatures ranging from 24 to 34 degrees Celsius. Geologically, the study area lies within the Precambrian Basement Complex of Nigeria, which comprises migmatites, gneisses, granites, and schists (Ayua et al., 2025; Rahaman, 1988). These crystalline rocks are known to contain uranium-bearing minerals, including zircon, monazite, and apatite, which serve as potential sources of radon production. The campus population relies exclusively on groundwater from boreholes and wells for domestic water needs, as municipal piped water supply is unavailable in this area.

2.2 Sample Collection

Ten groundwater samples were collected between February and March 2023, comprising five borehole samples designated B1 to

B5 and five hand-dug well samples designated W1 to W5. Samples were collected in 200 millilitre high-density polyethylene bottles, which were thoroughly washed, rinsed with distilled water, and dried before use, since the use of plastic containers minimises radon loss compared to glass containers (Jobbagy et al., 2019). For boreholes equipped with pumping systems, samples were collected after operating the pump for at least four minutes to ensure that stagnant water in the distribution system was flushed out. Hand-dug well samples were collected using a bailer lowered to approximately mid-depth of the water column. Sample bottles were filled completely to the brim and tightly capped to minimise headspace, and all samples were transported to the laboratory within twenty-four hours of collection and analysed within three days to minimise decay losses (ISO, 2014).

2.3 Principle of Liquid Scintillation Counting

Liquid scintillation counting is the standard laboratory method for quantifying radioactivity in low-energy beta-emitting and alpha-emitting radioisotopes, including radon-222 and its progeny (L'Annunziata, 2012). When a radioactive decay event occurs in a sample mixed with scintillation cocktail, the emitted radiation excites aromatic solvent molecules, and this excitation energy is transferred to scintillator molecules, which return to ground state by emitting photons of visible light. The light pulses are detected by photomultiplier tubes, which convert photons to electrical pulses whose intensity is proportional to the energy of the original radiation, allowing discrimination between different radionuclides (Goswami et al., 2025). The full sequence of the scintillation process is summarised in Figure 1.

Figure 1 traces the sequence of physical events that underpins the measurement technique. The radioactive decay excites the solvent, the excitation energy is transferred to the scintillator, light is emitted, and the photomultiplier converts the light into a measurable electrical pulse whose magnitude is proportional to the energy of the decay.

Schematic representation of the liquid scintillation counting process



Figure 1: Schematic representation of the liquid scintillation counting process, from radioactive decay through solvent excitation and energy transfer to light emission and photomultiplier detection.

Source: Authors' schematic after L'Annunziata (2012).

For radon analysis, a two-phase system is employed, in which the water sample is mixed with a lipophilic scintillation cocktail. Radon, being highly soluble in organic solvents, partitions preferentially into the cocktail phase, while more hydrophilic radionuclides such as radium-226 remain in the aqueous phase and do not interfere with counting (Stojkovic et al., 2021). The Packard Tri-Carb 1000TR liquid scintillation analyser used in this study, located at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria, features automatic sample changing, multiple counting windows, and alpha and beta discrimination capabilities based on pulse shape analysis, as represented in Figure 2.

Figure 2 represents the analytical instrument used for the measurements. The automatic sample changer and alpha and beta discrimination capabilities of the analyser permit the reliable counting of low-activity samples that characterise groundwater radon studies.

Liquid scintillation analyzer used for radon measurement

CERT, Ahmadu Bello University, Zaria

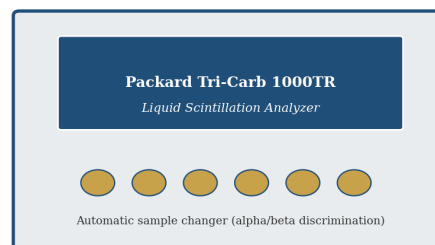


Figure 2: The Packard Tri-Carb 1000TR liquid scintillation analyser at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria, used for radon activity measurements.

Source: Authors' representation of the analytical instrument.

2.4 Sample Preparation and Counting

Sample preparation followed the standard method for radon in drinking water (ASTM International, 2009). Using a hypodermic syringe, ten millilitres of each water sample was carefully transferred to the bottom of a twenty millilitre glass scintillation vial to minimise agitation and radon loss, after which ten millilitres of scintillation cocktail was added using an automatic dispenser. Vials were immediately capped tightly, shaken vigorously for two minutes to ensure complete extraction of radon into the organic phase, and allowed to stand for three hours in the dark chamber to achieve secular equilibrium between radon-222 and its short-lived progeny before counting (Prichard and Gesell, 1977). Samples were counted for sixty minutes each using optimised counting windows for alpha particles, and the long counting time ensured statistical reliability for samples with low activity concentrations.

2.5 Activity and Dose Calculations

The radon-222 activity concentration in each sample was calculated using Equation 1 (Han and Pia, 1991).

$$R_n (\text{Bq L}^{-1}) = [100 \times (SC - BC) \exp(\lambda t)] / [60(CF) \times D] \quad (1)$$

In Equation 1, R_n denotes the radon-222 activity concentration in becquerels per litre, SC denotes the sample count rate, BC denotes the background count rate, λ denotes the decay constant for radon-222, taken as 0.181 per day, t denotes the time elapsed between sample collection and counting in days, CF denotes the calibration factor determined using standards of known activity, and D denotes the decay correction factor for ingrowth during the three-hour equilibration period. The exponential term corrects for radioactive decay occurring between sample collection and counting, while the factor of one hundred converts the result to becquerels per litre based on the ten millilitre sample volume. The annual effective dose due to ingestion of radon-containing water was calculated using the dose assessment methodology recommended by the European Commission (2001), expressed in Equation 2.

$$E = K \times G \times C \times T \times 1000 \quad (2)$$

In Equation 2, E denotes the annual effective dose in millisieverts per year, K denotes the dose conversion coefficient for radon-222 ingestion, taken as ten to the power of minus eight sieverts per becquerel based on ICRP Publication 119, G denotes the daily water consumption rate in litres per day, C denotes the radon-222 concentration in water in becquerels per litre, T denotes the annual consumption period of three hundred and sixty-five days, and the factor of one thousand converts sieverts to millisieverts. For adult residents, a daily water consumption rate of two litres per day was assumed, consistent with World Health Organization reference values (WHO, 2011). The dose conversion coefficient represents the committed effective dose per unit intake of radon-222 via ingestion, accounting for the distribution of radon in body tissues and its decay before elimination (Harrison and Marsh, 2021).

2.6 Quality Assurance

Several measures were implemented to ensure data quality and reliability. Field blanks of radon-free distilled water were transported to the sampling sites and processed in the same manner as the field samples to check for contamination, and duplicate samples were collected at ten per cent of the sampling locations to assess sampling and analytical precision. The liquid scintillation counter was calibrated using certified radium-226 standards traceable to international reference materials, background counts were determined using fresh scintillation cocktail and radon-free water counted under identical conditions for each batch of samples, and all results were decay-corrected to the time of sample collection. The detection limit for the method, determined from background count rates and counting efficiency, was 0.12 Bq/L for a sixty-minute counting time, and all sample concentrations were well above this detection limit, confirming the reliability of the measurements.

3. Results

3.1 Radon-222 Activity Concentrations

The radon-222 activity concentrations measured in groundwater samples from Felele Campus are presented in Table 1. Concentrations ranged from 7.48 to 15.51 Bq/L across all samples, with distinct differences between borehole and well water sources.

Table 1. Radon-222 activity concentrations and annual effective doses for groundwater samples from Felele Campus

S/N	Sample ID	Water source	Longitude (°E)	Latitude (°N)	²²² Rn concentration (Bq/L)	Annual effective dose (mSv/y)
1	B1	Borehole	7.5110	6.4312	15.51 ± 1.24	0.113 ± 0.009
2	B2	Borehole	7.5124	6.4310	12.70 ± 1.02	0.093 ± 0.007
3	B3	Borehole	7.5120	6.4310	11.02 ± 0.88	0.080 ± 0.006
4	B4	Borehole	7.5122	6.4311	15.09 ± 1.21	0.110 ± 0.009
5	B5	Borehole	7.5135	6.4310	15.49 ± 1.24	0.113 ± 0.009
	Borehole mean				13.96 ± 2.16	0.102 ± 0.016
6	W1	Well	7.5012	6.4456	9.93 ± 0.79	0.073 ± 0.006
7	W2	Well	7.5019	6.4450	9.15 ± 0.73	0.067 ± 0.005
8	W3	Well	7.5015	6.4455	7.48 ± 0.60	0.055 ± 0.004
9	W4	Well	7.5032	6.4452	11.14 ± 0.89	0.081 ± 0.006
10	W5	Well	7.5021	6.4449	10.55 ± 0.84	0.077 ± 0.006
	Well mean				9.65 ± 1.44	0.070 ± 0.011
	Overall mean				11.81 ± 2.72	0.086 ± 0.020

Uncertainties represent one standard deviation from counting statistics. Detection limit = 0.12 Bq/L. Source: Authors' field measurement, 2023.

The detection limit for the liquid scintillation counting method, determined from background count rates and counting efficiency, was 0.12 Bq/L for a sixty-minute counting time. All sample concentrations were well above this detection limit, confirming the reliability of the measurements. The overall mean uncertainty was 2.72 Bq/L for radon concentration and 0.020 mSv per year for annual effective dose.

3.2 Borehole and Well Water Results

The radon concentrations in the five borehole samples ranged from 11.02 Bq/L in sample B3 to 15.51 Bq/L in sample B1, with a mean value of 13.96 plus or minus 2.16 Bq/L. Four of the five borehole samples, equivalent to eighty per cent, exceeded the maximum contaminant level of 11.1 Bq/L, while sample B3 was marginally below this threshold. The radon concentrations in the five well water samples ranged from 7.48 Bq/L in sample W3 to 11.14 Bq/L in sample W4, with a mean value of 9.65 plus or minus 1.44 Bq/L. Three well samples, equivalent to sixty per cent, had concentrations below the maximum contaminant level, while two samples exceeded this limit. The contrast between the two source types is displayed in Figure 3.

Figure 3 sets the borehole and well concentrations side by side for each sampling location. The consistent elevation of the borehole values above those of the corresponding wells, and their position relative to the regulatory thresholds, conveys the systematic difference between the two aquifer types.

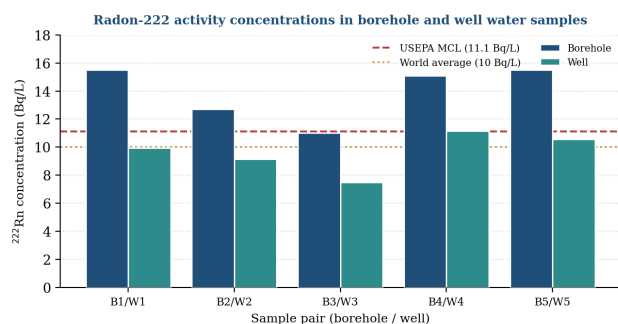


Figure 3: Comparison of radon-222 activity concentrations in borehole and well water samples from Felele Campus, with the USEPA maximum contaminant level and world average value indicated.

Source: Authors' field measurement, 2023.

The individual borehole and well results are displayed in Figures 4 and 5 respectively, which show each sample relative to the maximum contaminant level and the respective source mean.

Figure 4 presents the five borehole samples individually. The majority of the samples lie above the maximum contaminant level, and the borehole mean sits clearly above the regulatory threshold, confirming the elevated radon status of the borehole sources.

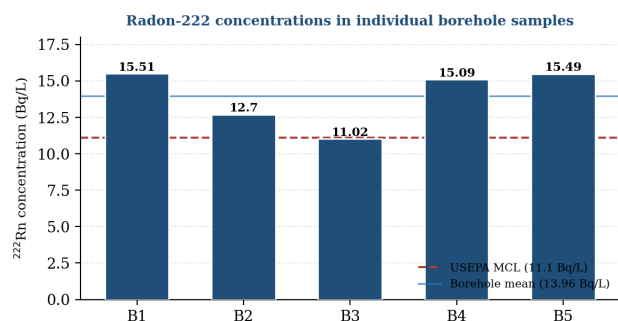


Figure 4: Radon-222 activity concentrations in individual borehole water samples from Felele Campus.

Source: Authors' field measurement, 2023.

Figure 5 presents the five well samples individually. Most of the well samples fall below the maximum contaminant level, and the well mean lies below the threshold, indicating the generally

safer radiological status of the well sources.

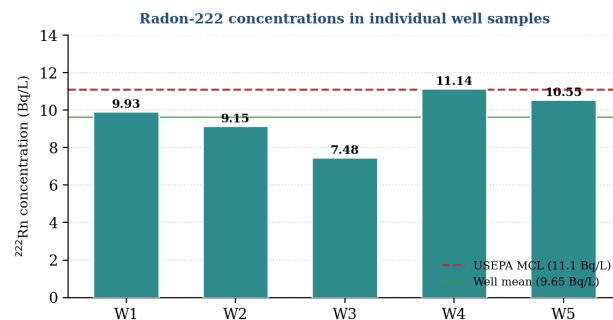


Figure 5: Radon-222 activity concentrations in individual well water samples from Felele Campus.

Source: Authors' field measurement, 2023.

3.3 Annual Effective Doses

The annual effective doses due to ingestion of radon-containing water, calculated for adult residents consuming two litres per day, are presented in Table 1 and displayed in Figure 6. For borehole water samples, the annual effective dose ranged from 0.080 mSv per year in sample B3 to 0.113 mSv per year in samples B1 and B5, with a mean of 0.102 plus or minus 0.016 mSv per year, which marginally exceeded the World Health Organization recommended reference level of 0.1 mSv per year. For well water samples, the annual effective dose ranged from 0.055 to 0.081 mSv per year, with a mean of 0.070 plus or minus 0.011 mSv per year, all below the reference level.

Figure 6 presents the annual effective doses for each sample pair against the World Health Organization reference level. The borehole doses cluster around and above the reference line, while the well doses remain consistently below it, mirroring the pattern observed in the underlying concentration data.

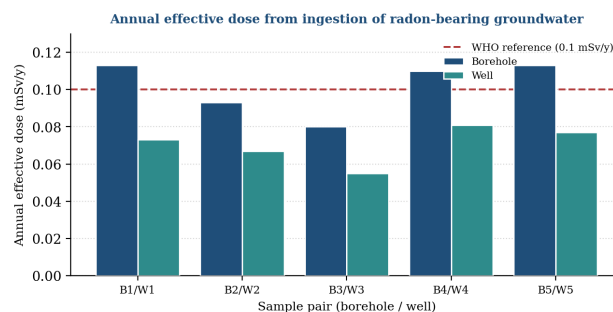


Figure 6: Annual effective doses due to ingestion of radon-containing water from borehole and well samples at Felele Campus, with the WHO reference level indicated.

Source: Authors' field measurement, 2023.

4. Discussion

4.1 Interpretation of Radon Concentrations

The radon concentrations measured in this study fall within the range of values previously reported for groundwater in the Nigerian Basement Complex terrain, comparable to those reported by Garba et al. (2012) for Zaria and Oni and Adagunodo (2019) for Ogbomoso, and lower than the extreme values reported by Adebisi et al. (2025) for Igbesa, suggesting moderate radon potential in the Lokoja area. The higher radon concentrations in borehole water compared to well water reflect fundamental differences in the

hydrogeological characteristics of the two aquifer types. Boreholes at Felele Campus typically extend to depths of thirty to sixty metres, penetrating fractured basement rocks where uranium-bearing minerals are present and groundwater circulation is restricted, allowing radon to accumulate to higher concentrations (Andrews and Wood, 1972). In contrast, hand-dug wells are shallow and draw water from the weathered regolith, where higher porosity, greater groundwater flux, and reduced uranium content result in lower radon concentrations (Folkesson and Lindgren, 2019).

4.2 Comparison with Safety Standards

The proportion of samples exceeding regulatory limits depends critically on the standard applied. Using the maximum contaminant level of 11.1 Bq/L, forty per cent of all samples exceeded the limit, while using the world average value of 10 Bq/L, sixty per cent of samples exceeded this threshold. However, all samples fell well below the World Health Organization reference level of 100 Bq/L for individual water sources. The Nigerian standard specifies a limit of 0.1 Bq/L, which all samples exceeded by factors of seventy-five to one hundred and fifty-five, highlighting the impracticality of this standard for groundwater sources in uranium-bearing geological terrains (Farai and Sanni, 2018). The discrepancy between international and national standards underscores the need for context-specific, risk-informed guidelines that consider local geological conditions, available treatment technologies, and socioeconomic constraints.

4.3 Radiological Health Risk Assessment

The annual effective doses calculated in this study represent only the ingestion pathway for radon exposure, and the total effective dose from waterborne radon would be substantially higher when inhalation exposure from radon released during household water use is considered. According to the National Research Council (1999), inhalation of released radon contributes approximately seventy to ninety per cent of the total effective dose from waterborne radon. Applying a water-to-air transfer factor and an equilibrium factor between radon and its progeny, the estimated total effective dose for borehole water users would range from 0.34 to 0.48 mSv per year, and for well water users from 0.23 to 0.34 mSv per year (UNSCEAR, 2000). These total dose estimates remain below the reference level of three to ten mSv per year recommended for intervention in existing exposure situations (ICRP, 2007), but they exceed the reference level of 0.1 mSv per year for drinking water alone, indicating that optimisation measures should be considered, particularly for borehole water sources.

The excess lifetime cancer risk can be estimated using the risk coefficient for radon in drinking water proposed by Hopke et al. (2000). For the mean borehole concentration, the excess lifetime cancer risk is approximately 7.96×10^{-5} , meaning that among one hundred thousand people consuming this water for seventy years, approximately eight excess cancer cases might occur. For well water, the corresponding excess lifetime cancer risk is 5.50×10^{-5} . These values fall within the acceptable risk range of 10^{-6} to 10^{-4} typically used in radiation protection (IAEA, 2014). It is important to note that

this study focused exclusively on the ingestion pathway, and future studies should include air radon measurements in buildings served by the borehole water to provide a more comprehensive health risk assessment.

4.4 Geological Controls on Radon Levels

The elevated radon concentrations observed in this study, particularly in borehole samples, are consistent with the known geology of the Lokoja area, since the geology of an area is important in understanding the source of background radiation (Nakale et al., 2025). The Precambrian Basement Complex in this region consists predominantly of migmatites, granitic gneisses, and older granites, all of which contain uranium-bearing accessory minerals such as zircon, apatite, sphene, and monazite (Ayua et al., 2025; Dada, 2006). Radioelement mapping by the Nigeria Geological Survey Agency (2009) indicates that uranium concentrations in basement rocks of Kogi State range from 1.5 to 4.2 parts per million, with localised enrichments in shear zones and pegmatitic bodies, sufficient to generate significant radon production through continuous decay. The mechanism of radon release from these rocks involves both alpha recoil and diffusion along microfractures and grain boundaries, and in fractured basement aquifers groundwater circulating through open fractures can accumulate radon from a large rock surface area, leading to the elevated concentrations observed in boreholes (Oni et al., 2025).

4.5 Implications for Public Health and Water Management

The findings of this study have significant implications for public health and water management at Federal University Lokoja. Borehole water sources, which serve as the primary water supply for most campus facilities, should be prioritised for radon mitigation, since the mean annual effective dose for boreholes marginally exceeds the World Health Organization reference level. Aeration treatment should be installed at borehole supply points to reduce radon concentrations before distribution, since simple spray aeration systems have been shown to achieve removal efficiencies of seventy to ninety per cent and can be constructed at relatively low cost using locally available materials. A regular monitoring programme should be established to track radon levels over time and assess the effectiveness of any implemented treatment measures, with seasonal variations evaluated through quarterly sampling. Well water samples generally meet international safety guidelines and can be considered acceptable for consumption without treatment, though regular monitoring and proper well maintenance remain essential. Finally, a clear and accurate communication strategy should be developed to inform the university community about radon and the measures being taken to ensure water safety, providing necessary information without causing undue alarm.

4.6 Study Limitations

This study has several limitations that should be acknowledged. The primary limitation is the small sample size of ten samples, which limits the statistical power of the study and the generalisability of the findings, and which arose from the absence of funding given that liquid scintillation counting analysis involves significant costs. The samples were also collected during a single field campaign, offering only a snapshot of radon concentrations, whereas groundwater levels and recharge are subject to seasonal

variation. The study estimated the inhalation dose using generic transfer factors rather than directly measuring indoor radon concentrations, and the lack of detailed hydrogeochemical data limits the interpretation of the specific factors influencing radon variability. Future research should address these limitations through larger sample sizes, multi-season sampling, direct indoor air measurements, and detailed aquifer characterisation.

5. Conclusion and Recommendations

This study successfully measured the activity concentrations of radon-222 in groundwater sources at the Felele Campus of Federal University Lokoja using liquid scintillation counting. Radon concentrations in borehole water samples ranged from 11.02 to 15.51 Bq/L, with a mean of 13.96 plus or minus 2.16 Bq/L, and eighty per cent of the borehole samples exceeded the maximum contaminant level of 11.1 Bq/L. The mean annual effective dose for borehole water was 0.102 mSv per year, marginally exceeding the World Health Organization reference level. In contrast, radon concentrations in well water samples were lower, ranging from 7.48 to 11.14 Bq/L, with a mean of 9.65 plus or minus 1.44 Bq/L, and all well water samples yielded annual effective doses below the reference level. The higher radon levels observed in borehole water can be attributed to the underlying Precambrian basement geology, characterised by fractured aquifers and greater depth that result in prolonged rock-water contact time. The excess lifetime cancer risks were estimated at 7.96 times ten to the power of minus five for borehole water consumers and 5.50 times ten to the power of minus five for well water consumers, both within the acceptable risk range used in radiation protection. This research provides the first baseline data on radon concentrations in groundwater at Federal University Lokoja.

On the basis of these findings, it is recommended that the university administration install aeration treatment systems at borehole supply points, with priority given to boreholes serving student hostels, staff quarters, and cafeterias, and establish a quarterly groundwater quality monitoring programme that includes radon analysis. Indoor air radon measurements should be conducted within campus buildings, particularly in poorly ventilated spaces, and risk communication materials should be developed to inform the community accurately. Regulatory authorities are encouraged to review the Nigerian standard for radon in drinking water to establish a more realistic and risk-informed guideline that considers geological context and treatment feasibility, and to develop national monitoring protocols tailored to different hydrogeological settings. Future research should conduct comprehensive seasonal studies, investigate the relationship between bedrock geology and radon potential, assess the effectiveness of various aeration designs, and extend the work to other radionuclides and to comparative studies across federal university campuses in Nigeria.

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