PHYSICSAccess Research Paper
ISSN Online: 2756-3898, ISSN Print: 2714-500X https://doi.org/10.47514/phyaccess.2026.6.2.015

Indoor Radon Concentrations and Associated Radiological Risk in Selected Buildings at South-Eastern Kenya University, Kenya

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Received 08-07-2026
Accepted for publication 27-08-2026
Published 09-09-2026

Abstract

Radon is a naturally occurring radioactive gas and a major contributor to natural radiation exposure, with prolonged inhalation associated with an increased risk of lung cancer. This study evaluated indoor radon concentrations and associated radiological risks in selected buildings at South-Eastern Kenya University (SEKU), Kenya. Indoor radon concentrations were measured in six selected multi-storey buildings using a calibrated RAD7 electronic radon detector under standardized operating conditions. Measurements were conducted on the lowest floor of each building over 24 hours at each sampling location. Radiological risk parameters, including equilibrium equivalent concentration (EEC), annual effective dose (AED), excess lifetime cancer risk (ELCR), and lung cancer cases per million persons per year (LCC), were estimated using internationally established models and conversion factors. Indoor radon concentrations ranged from 8.18 ± 0.26 to 17.21 ± 0.77 Bq m^{-3}, with a mean of 12.84 ± 0.55 Bq m^{-3}, well below the reference levels recommended by the World Health Organization and the International Commission on Radiological Protection. The corresponding mean EEC, AED, ELCR, and LCC were 5.14 ± 0.22 Bq m^{-3}, 0.3239 ± 0.0140 mSv y^{-1}, (1.25 ± 0.05) × 10^{-3}, and 5.83 ± 0.25 cases per million persons per year, respectively. These values indicate a low estimated radiological risk for the monitored buildings. Because the measurements were limited to 24-hour active monitoring at six buildings, the findings are interpreted as a short-term baseline assessment rather than an estimate of annual average indoor radon exposure. Periodic and seasonal monitoring is recommended to better characterize long-term exposure variability.

Keywords: Indoor radon; RAD7 detector; South-Eastern Kenya University; radiological risk assessment.

I. Introduction

Radon (^{222}Rn) is a naturally occurring radioactive gas and an important environmental health concern because prolonged exposure to elevated concentrations increases the risk of lung cancer. ^{222}Rn is produced primarily through the radioactive decay of uranium and radium present in soils and rocks and can migrate from the subsurface into buildings through foundation cracks, gaps around service pipes, porous construction materials, and other entry pathways [1–2]. Although ^{222}Rn may also occur in groundwater, soil gas is generally regarded as the principal source of indoor ^{222}Rn, while certain building materials can also contribute to indoor concentrations [2]. Once inhaled, radon progeny, including

isotopes of polonium, lead, and bismuth, can deposit in the respiratory tract and emit alpha particles that damage lung tissue and increase the risk of lung cancer [3]. The carcinogenic risk associated with radon exposure is commonly evaluated within the linear no-threshold framework, while smoking can substantially amplify the risk of radon-induced lung cancer [4–5]. Consequently, assessment of indoor radon is an important component of environmental health and radiation protection.

Indoor radon concentrations are not static but vary spatially and temporally according to geological, meteorological, and building-related factors. The underlying geology determines the availability and generation of radon, while soil permeability, porosity, moisture content, fractures, and pressure gradients influence its migration toward buildings [6–7]. Building characteristics, including foundation construction, floor type, building materials, ventilation, and the integrity of structural joints, subsequently affect the rate at which radon enters and accumulates indoors [1–2]. Recent investigations in China and Latvia have demonstrated substantial geographical variation in indoor radon concentrations and associated public radiation doses [8–9]. Similarly, temporal studies have shown that indoor radon concentrations can fluctuate with seasonal conditions and other environmental and behavioural factors [10]. Research examining the combined influence of geology, housing characteristics, and season has further demonstrated that indoor radon levels result from interactions between environmental and building-related factors [11]. These variations emphasize the importance of site-specific assessment and, where possible, repeated or continuous monitoring rather than reliance on single measurements.

Consequently, appropriate measurement approaches have received increasing attention in recent indoor-radon research. Short-term measurements can provide useful screening information, whereas continuous monitoring can provide greater insight into temporal and diurnal changes in indoor radon concentrations [10], [12]. Continuous monitoring is particularly valuable for improving the characterization of indoor radon behaviour and exposure [12]. Comprehensive assessments have also emphasized the need to evaluate health risks associated with prolonged exposure and to implement appropriate remediation strategies where concentrations are elevated [13–14]. Measures such as improving ventilation and reducing pathways through which radon enters buildings can contribute to reducing indoor concentrations [1], [13]. These developments in indoor-radon research demonstrate the importance of combining reliable measurement techniques with radiological risk assessment when evaluating potential exposure in occupied buildings.

Recent investigations across Africa have demonstrated that indoor radon exposure remains an important environmental radiation issue, with concentrations varying considerably according to local geology, building characteristics, and environmental conditions. Studies conducted in Nigeria have reported that structural and environmental parameters significantly influence indoor radon accumulation [15–16]. Investigations in Ghana have examined the spatial distribution of indoor radon, mapped radon levels in the Greater Accra Region, assessed the effects of interior decorative materials, and applied statistical approaches to characterize radon variability [17–19]. In South Africa, indoor radon concentrations have been investigated in dwellings located around mining areas, with studies highlighting the contribution of geological and mining-related factors to indoor radon exposure [20]. Studies in Cameroon have similarly reported indoor radon and thoron concentrations and associated annual effective doses in regions characterized by naturally radioactive geological conditions [21–22], while investigations in Tanzania have also demonstrated the influence of geological and environmental settings on radon exposure in areas associated with mineralized formations [23], [24]. Collectively, these studies indicate that indoor radon concentrations across Africa are strongly influenced by local geological conditions, building construction and ventilation characteristics, and, in some settings, surrounding mining and other land-use activities.

In Kenya, systematic information on indoor radon remains comparatively limited. Previous investigations have demonstrated spatial variation in indoor radon concentrations and identified meteorological and environmental factors that can influence indoor radon levels [25–26]. Reference [25] particularly reported the influence of meteorological parameters on indoor radon concentrations in selected Kenyan dwellings, while [26] reviewed available radon and thoron studies in Kenya and highlighted the need for further research. Evidence from these African settings, including Ghana [17–19], South Africa [20], Cameroon [21–22], and Tanzania [23–24], further demonstrates the importance of geological and environmental variability in determining indoor radon exposure. In addition, [27] reported measurable natural radioactivity and associated radiological hazards in construction stones obtained from quarries in Machakos County, Kenya, demonstrating the relevance of both geological conditions and construction materials when evaluating natural radiation exposure in the Kenyan built environment.

SEKU, located in Kitui County in southeastern Kenya, provides an important setting for investigating indoor radon. The university lies within the Mozambique Mobile Belt, a geological terrain dominated by high-grade metamorphic rocks and associated geological structures that may influence the distribution and migration of naturally occurring radionuclides [28–29]. Such geological characteristics are therefore relevant to the potential generation and transport of radon from the subsurface into buildings. Despite the established health significance of indoor radon and increasing international attention to its spatial and temporal variability, localized information on radon exposure in Kenyan public institutions, particularly universities, remains scarce [26]. The

present study therefore evaluates indoor radon concentrations in selected SEKU buildings using a calibrated RAD7 electronic radon detector under standardized measurement conditions. The study further estimates associated radiological risk parameters, including equilibrium equivalent concentration (EEC), annual effective dose (AED), excess lifetime cancer risk (ELCR), and lung cancer cases per million persons per year (LCC). The findings provide a baseline assessment of indoor radon exposure in selected SEKU buildings and contribute to the limited evidence on indoor radon in southeastern Kenya. Given the short-term nature of the measurements, the findings are interpreted as a baseline assessment rather than an estimate of annual average exposure, thereby providing a basis for future long-term and seasonal monitoring.

II. Materials and Methods

A. Geology of the Study Area

The study was conducted at South-Eastern Kenya University (SEKU) in Kitui County, south-eastern Kenya, approximately 170 km from Nairobi along the Kitui–Machakos road near Kwa Vonza Market. Geographically, the study area lies between latitudes S1°18′10.51381″ and S1°21′47.0800″ and longitudes E37°45′4.21992″ and E37°47′23.8758″. Geologically, the area falls within the Neoproterozoic Mozambique Mobile Belt of southeastern Kenya, a Precambrian basement terrain dominated by high-grade metamorphic rocks intruded by granitic and pegmatitic bodies [28]. These lithologies are important in natural radioactivity studies because they may contain uranium-, thorium-, and potassium-bearing minerals. The area is further characterized by faults, folds, and shear zones associated with the Mozambique Orogeny, which may enhance radon migration through structural discontinuities [28–29]. To the west of SEKU, the Yatta Plateau is underlain by Tertiary phonolitic lava flows [30–31], which may also influence radon release through mineralogical variability and weathering [32–33]. Together with semi-arid climatic conditions, shallow weathering profiles, and relatively permeable soils, these geological conditions may contribute to spatial variability in radon occurrence and terrestrial radioactivity. Fig. 1 shows the study area and sampling points.

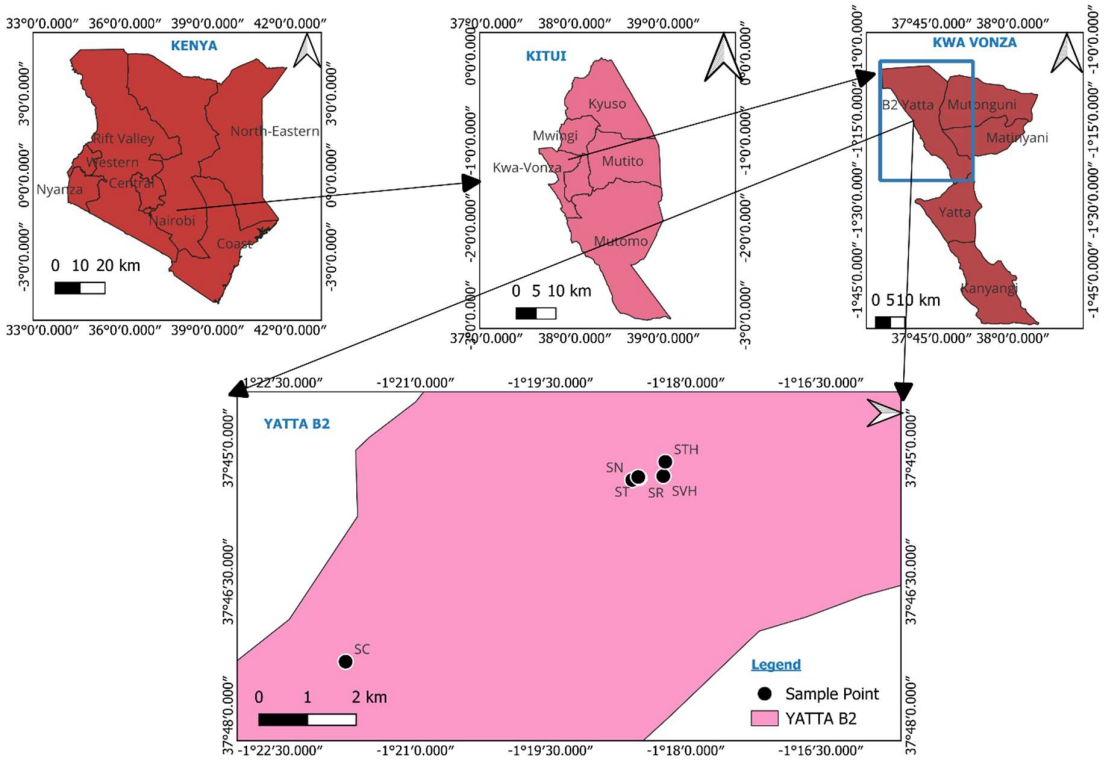

Fig. 1. Map of the study area with sampling points

B. Indoor Radon Measurements

Indoor radon measurements were conducted from 19 to 24 May 2025 in six selected buildings, as shown in Table I. The selected buildings encompassed the principal functional categories and predominant construction characteristics of the university. The six buildings, comprising three lecture buildings, two residential buildings, and one administrative building, were selected to represent indoor environments with the potential for substantial radon exposure.

Building selection was based on high occupancy, accessibility for uninterrupted 24-h monitoring, proximity to ground level where radon ingress from the underlying soil is expected to be greatest, representativeness of the predominant building construction on campus, and minimal disturbance during the measurement period. The selected buildings, constructed between 5 and 20 years ago, are typical of the university's infrastructure, with similar reinforced-concrete structural frames, masonry walls, and concrete floor slabs. The selected buildings were naturally ventilated, and a standardized pre-measurement and monitoring protocol was applied.

Doors and windows were kept closed for 12 h before and throughout the measurement period, except during normal entry and exit. This was adopted as a standardized screening condition to minimize short-term ventilation-related variation and improve comparability among buildings; it should not be interpreted as representing normal long-term ventilation or occupancy conditions. Radon measurements were performed on the ground floor of each building because indoor radon concentrations are generally expected to be higher at the lowest occupied level owing to direct infiltration of soil gas through building foundations.

Although only six buildings were investigated, the selected sites encompassed the principal functional categories, predominant construction characteristics, typical ventilation practices, and a representative range of building ages across the university, thereby providing a preliminary baseline assessment of indoor radon concentrations. Future investigations involving a larger number of buildings and repeated measurements across different seasons are recommended to evaluate the long-term spatial and temporal variability of indoor radon concentrations.

In the selected buildings, the RAD7 detector was placed at a height of 1.0 m above the floor, at least 0.5 m from walls and 1.5 m from doors, windows, ventilation openings, and heat sources, to minimize the influence of localized air movement. The detector was operated in Sniff Mode, which provides rapid detection of indoor radon by monitoring the short-lived decay product ^{218}Po. Each building was monitored continuously for 24 h using the RAD7 in Sniff Mode, with measurements recorded at 30-min intervals, resulting in 48 consecutive measurement cycles per location. Each reported concentration represents an average of 48 consecutive 30-min measurements.

After each measurement, the detector was purged with fresh ambient air for 15 min before deployment at the next location to remove residual radon from the measurement chamber. Throughout the monitoring period, the instrument continuously recorded radon concentration, temperature, relative humidity, and counting statistics. Measurements affected by excessive humidity or unstable operating conditions were repeated as part of the quality assurance and quality control procedures. The recorded concentrations were converted from pCi L^{-1} to Bq m^{-3} using the standard conversion factor of 1 pCi L^{-1} = 37 Bq m^{-3}.

C. Quality Assurance and Quality Control

Quality assurance and quality control procedures were implemented throughout the measurement period to ensure the reliability of the indoor radon measurements. The RAD7 electronic radon detector (Model RAD7-717, Serial No. 06234, Durridge Company Inc., USA) was calibrated on 30 August 2023 at the Durridge Radon Calibration Laboratory (Billerica, MA, USA; NRSB Accredited Radon Chamber Certificate No. NRSB TRC0003). The detector's calibration was established against primary reference units (Serial Nos. 504, 961, 1277, and 4232), providing traceability to absolute standards within an estimated uncertainty of ±5%.

According to the manufacturer's calibration certificate, the calibration uncertainty based on counting statistics was ±2% (2σ), with demonstrated instrument sensitivities of 0.0146 cpm/Bq m^{-3} [0.541 cpm/pCi L^{-1}] in Normal Mode and 0.00703 cpm/Bq m^{-3} [0.260 cpm/pCi L^{-1}] in Sniff Mode. A valid calibration certificate accompanied the instrument throughout the study.

Before deployment, the detector was inspected and prepared in accordance with standard operating procedures. The instrument was connected to a desiccant unit to maintain internal relative humidity below 10%, thereby minimizing moisture effects on the electrostatic collection of radon progeny and ensuring stable detector performance. Operational and background checks were performed before each monitoring session to verify correct instrument operation.

Independent duplicate measurements and post-campaign intercomparison measurements were not performed; therefore, field-based estimates of reproducibility and detector drift could not be directly established. Instrument reliability was instead supported by strict adherence to the calibration schedule, pre-deployment operational checks, continuous humidity control, and ongoing monitoring of counting statistics.

D. Study Limitations

The present investigation employed 24-h active radon measurements, which are appropriate for baseline screening and comparison among buildings but do not necessarily represent annual average indoor radon concentrations. This is because radon levels vary seasonally with meteorological conditions, soil moisture, atmospheric pressure, and ventilation practices. Long-term measurements extending over several months are more appropriate for estimating annual exposure. Nevertheless, the standardized protocol adopted in this investigation provides reliable comparative information on indoor radon concentrations across the investigated buildings and establishes an important baseline dataset for southeastern Kenya.

Future studies should incorporate seasonal monitoring using passive detectors or other appropriate long-term measurement approaches and include a larger number of buildings to improve long-term exposure assessment and characterization of spatial and temporal variability.

E. Radiological Parameters

1) Equilibrium Equivalent Concentration (EEC)

The equilibrium equivalent concentration (EEC) of radon progeny was estimated from the measured indoor radon concentration using an equilibrium factor of 0.4 for indoor environments [1], [3], according to (1).

$$EEC = C_{Rn} \times F \quad (1)$$

where C_{Rn} is the measured indoor radon concentration (Bq m^{-3}) and $F$is the indoor equilibrium factor, taken as 0.4 for indoor environments [1], [3]. The uncertainty was propagated using (2).

$$u(EEC) = F \times u(C_{Rn}) \quad (2)$$

where $u(\mathrm{EEC})$ is the uncertainty in the equilibrium equivalent concentration, F is the equilibrium factor equal to 0.4, C_{Rn} is the measured indoor radon concentration, and $u(C_{\mathrm{Rn}})$ is the corresponding uncertainty in indoor radon concentration.

2) Annual Effective Dose (AED)

The annual effective dose (AED) due to indoor radon inhalation was calculated using (3) [2–3], [34].

$$AED\ (mSv\ y^{-1}) = C_{Rn} \times F \times Q \times D \quad (3)$$

where AED is the annual effective dose from indoor radon exposure (mSv y^{-1}), C_{Rn} is the measured indoor radon concentration (Bq m^{-3}), F is the equilibrium factor for indoor radon (0.4), Q is the indoor occupancy time (7008 h y^{-1}), and D is the dose conversion factor of 9×10^{-6}mSv h^{-1} per Bq m^{-3}.

The uncertainty was propagated using (4).

$$u(AED) = \frac{AED}{C_{Rn}}\, u(C_{Rn}) \quad (4)$$

where $u(\mathrm{AED})$ is the uncertainty in annual effective dose, $u(C_{\mathrm{Rn}})$ is the uncertainty in indoor radon concentration, AED is the annual effective dose, and C_{Rn} is the measured indoor radon concentration.

3) Excess Lifetime Cancer Risk (ELCR)

ELCR provides an estimate of the excess lifetime probability of cancer associated with the modelled radiation dose. It was estimated using (5) [35].

$$ELCR = AED \times DL \times RF \quad (5)$$

where ELCR is the excess lifetime cancer risk, AED is the annual effective dose from indoor radon exposure (mSv y^{-1}), DL is the assumed lifetime exposure duration (70 years), and RF is the detriment-adjusted nominal cancer risk coefficient. To maintain unit consistency when AED is expressed in mSv y^{-1}, the ICRP Publication 103 coefficient of 5.5×10^{-2} Sv^{-1} is converted to 5.5×10^{-5} mSv^{-1}. Thus, ELCR = AED × 70 × 5.5 × 10^{-5} [4]. The uncertainty was propagated using (6).

$$u(ELCR) = \frac{ELCR}{C_{Rn}} u(C_{Rn}) \quad (6)$$

Here, $u(\mathrm{ELCR})$ is the uncertainty in excess lifetime cancer risk; ELCR is the calculated excess lifetime cancer risk, C_{Rn} is the measured indoor radon concentration, and $u(C_{\mathrm{Rn}})$ is the corresponding uncertainty in indoor radon concentration.

4) Lung Cancer Cases per Million Persons per Year (LCC)

Following the terminology and assumptions of [35], a lung-cancer induction risk factor of 18×10^{-6} mSv^{-1} was adopted. This coefficient is used here as a model parameter for estimating the expected annual number of radon-associated lung-cancer cases under the assumptions of the cited study. It should not be interpreted as a directly observed incidence probability for an individual.

The LCC values were calculated from the annual effective dose (AED) using (7a), while the resulting values were converted to cases per million persons per year by multiplying by 10^6, as in (7b).

$$\left.\begin{aligned} LCC &= AED \times 18 \times 10^{-6} \quad (a) \\ LCC &= AED \times 18 \quad (b) \end{aligned}\right\} \quad (7)$$

This parameter represents a model-based annual population-rate estimate under the assumed exposure conditions and should not be interpreted as an observed incidence rate or a lifetime number of lung-cancer cases. The uncertainty in LCC was propagated using (8).

$$u(LCC) = \frac{LCC}{C_{Rn}} u(C_{Rn}) \quad (8)$$

where $u(\mathrm{LCC})$ is the uncertainty in lung cancer cases per million persons per year; LCC is the calculated lung cancer cases per million persons per year, C_{Rn} is the measured indoor radon concentration, and $u(C_{\mathrm{Rn}})$ is the corresponding uncertainty in indoor radon concentration.

III. Results and Discussion

A. Indoor Radon Concentrations

Table I summarizes the measured indoor radon concentrations and corresponding radiological risk parameters. The measured indoor radon concentrations ranged from 8.18 ± 0.26 to 17.21 ± 0.77 Bq m^{-3}, with a mean value of 12.84 ± 0.55 Bq m^{-3}. All measured concentrations were below the WHO-recommended reference level of 100 Bq m^{-3} [1] and the ICRP reference level of 300 Bq m^{-3} [4].

The relatively low indoor radon concentrations measured across the investigated buildings may be associated with the geological characteristics of the study area together with the prevailing building and ventilation conditions. SEKU is situated within the Precambrian Mozambique Belt, a high-grade metamorphic terrane composed predominantly of gneisses, schists, migmatites, and quartzites [28]. These geological materials may contain uranium-bearing minerals capable of producing ^{222}Rn through the radioactive decay of ^238U. Such geological characteristics are relevant to the potential generation and migration of radon.

The migration of radon from the subsurface is influenced by factors such as rock weathering, fracture density, soil permeability, and moisture content, which affect the transport of radon from its source towards the ground surface [6–7]. Consequently, local geological conditions and building

characteristics may contribute to the observed differences in indoor radon concentrations. However, because soil radon potential, soil permeability, and ventilation rates were not directly measured, their individual contributions cannot be quantitatively established from the present dataset.

Table I: Monitoring dates, mean indoor radon concentrations, and derived radiological risk parameters expressed as mean ± measurement uncertainty.

Site code	Monitoring Date	C_{Rn} (Bq m^{-3})	EEC (Bq m^{-3})	AED (mSv y^{-1})	ELCR (×10^{-3})	LCC (cases per 10^6 persons y^{-1})
SC	19/05/2025	17.21 ± 0.77	6.88 ± 0.31	0.4342 ± 0.0194	1.67 ± 0.07	7.82 ± 0.35
SN	20/05/2025	08.18 ± 0.26	3.27 ± 0.11	0.2064 ± 0.0066	0.79 ± 0.03	3.71 ± 0.12
SR	21/05/2025	15.12 ± 0.66	6.05 ± 0.26	0.3815 ± 0.0167	1.47 ± 0.06	6.87 ± 0.30
ST	22/05/2025	12.94 ± 0.54	5.17 ± 0.22	0.3265 ± 0.0136	1.26 ± 0.05	5.88 ± 0.25
STH	23/05/2025	08.61 ± 0.43	3.44 ± 0.17	0.2172 ± 0.0108	0.84 ± 0.04	3.91 ± 0.20
SVH	24/05/2025	14.97 ± 0.66	5.99 ± 0.26	0.3778 ± 0.0167	1.45 ± 0.06	6.80 ± 0.30
Minimum		08.18 ± 0.26	3.27 ± 0.11	0.2064 ± 0.0066	0.79 ± 0.03	3.71 ± 0.12
Maximum		17.21 ± 0.77	6.88 ± 0.31	0.4342 ± 0.0194	1.67 ± 0.07	7.82 ± 0.35
Average		12.84 ± 0.55	5.14 ± 0.22	0.3239 ± 0.0140	1.25 ± 0.05	5.83 ± 0.25

Note: The ± values represent propagated measurement uncertainties associated with the measured indoor radon concentrations.

The spatial variation in indoor radon concentration is shown in Fig. 2. Buildings located on relatively permeable soils generally experience greater radon entry because interconnected pore spaces facilitate soil-gas transport, whereas compact or fine-grained soils tend to restrict gas migration [7]. Soil moisture can also influence radon transport: moderate moisture may enhance radon emanation into pore spaces, whereas excessive moisture can reduce soil-gas permeability and limit radon migration towards building foundations [3]. In addition, well-ventilated buildings can dilute indoor radon more effectively than poorly ventilated structures, resulting in lower indoor radon concentrations [36].

These combined effects may explain the differences observed among the investigated buildings. Nevertheless, the present measurements do not permit the individual contributions of these factors to be quantified.

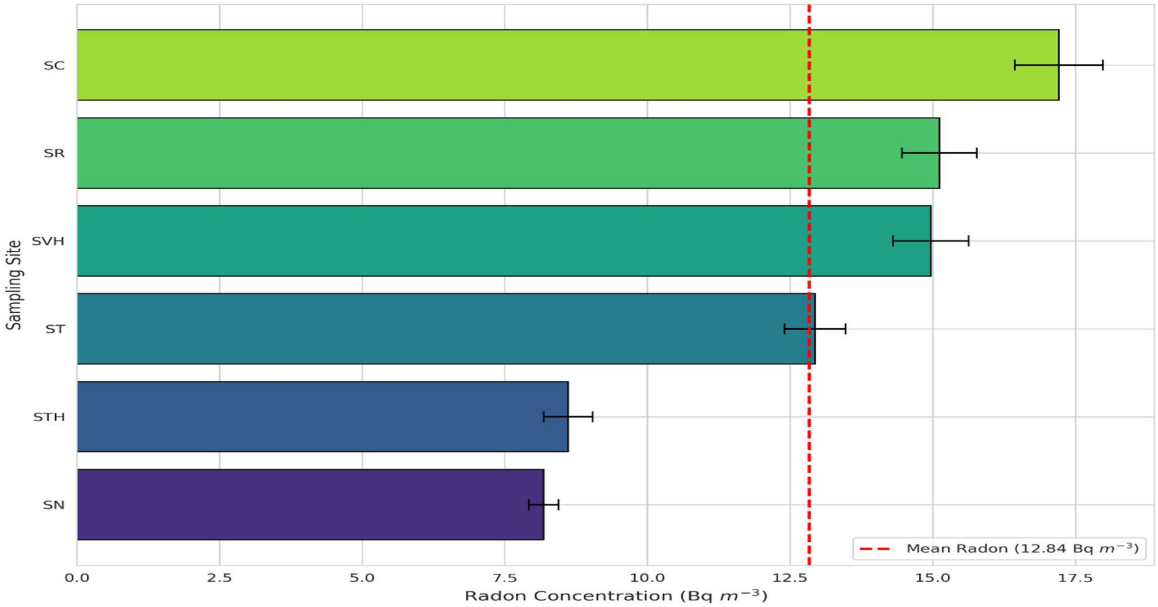

Fig. 2. Horizontal bar chart illustrating the spatial variation of indoor radon concentrations across the investigated buildings with corresponding uncertainties.

B. Statistical Description of Indoor Radon Concentrations

The descriptive statistics of the building-level mean indoor radon concentrations and the derived radiological parameters are presented in Table II. The mean indoor radon concentration was 12.84 ± 3.70 Bq m^{-3}, with a median of 13.96 Bq m^{-3}, a minimum of 8.18 Bq m^{-3}, and a maximum of 17.21 Bq m^{-3}. The coefficient of variation was 28.82%, while the 95% confidence interval for the mean was 8.96–16.72 Bq m^{-3}.

The derived parameters exhibited similar variability. The EEC had a mean of 5.13 ± 1.48 Bq m^{-3}, with a median of 5.58 Bq m^{-3} and a coefficient of variation of 28.85%. The AED had a mean of 0.3239 ± 0.0933 mSv y^{-1}, with a 95% confidence

interval of 0.2259–0.4219 mSv y^{-1}. The mean ELCR was $1.247 \pm 0.359 \times 10^{-3}$, while the mean LCC was 5.830 ± 1.680 cases $\times 10^{6}$ persons^{-1} y^{-1}. The corresponding coefficients of variation were approximately 28.82%.

Table II: Descriptive statistics of building-level mean indoor radon concentrations and derived radiological parameters.

Parameter	Mean ± SD	Median	MIN – MAX	CV (%)	95% CI
C_{Rn} (Bq m^{-3})	12.84 ± 3.70	13.96	8.18 – 17.21	28.82	8.96 – 16.72
EEC (Bq m^{-3})	5.13 ± 1.48	5.58	3.27 – 6.88	28.85	3.58 – 6.69
AED (mSv y^{-1})	0.3239 ± 0.0933	0.3521	0.2064 – 0.4342	28.82	0.2259 – 0.4219
ELCR ($\times 10^{-3}$)	1.247 ± 0.359	1.355	0.795 – 1.672	28.82	0.870 – 1.624
LCC (cases $\times 10^{6}$ persons^{-1} y^{-1})	5.830 ± 1.680	6.337	3.715 – 7.815	28.82	4.067 – 7.593

The building-level mean radon concentrations showed measurable variability across the six monitored buildings. The coefficient of variation indicates a moderate level of variability, while the mean and median values suggest that the observations were not strongly influenced by extremely high or low values. The observed differences may be related to variations in ventilation, building characteristics, occupancy patterns, and local radon-entry conditions. The confidence intervals provide an indication of the uncertainty associated with the estimated mean values. These estimates should be interpreted as applying to the selected buildings rather than to the entire university. Because the radiological risk parameters were calculated directly from the measured radon concentrations, they followed a similar pattern of variability.

Inferential statistical comparisons among the buildings were not performed because only one 24-hour monitoring campaign was conducted per building, resulting in six independent building-level observations. Although each building generated 48 consecutive 30-minute measurements, treating these repeated measurements as independent observations would constitute pseudoreplication and could artificially inflate the effective sample size. Therefore, the analysis was restricted to descriptive statistics and building-level uncertainty estimates. This approach provides a conservative interpretation of the observed between-building variability and avoids overstating the statistical significance of differences among the monitored buildings.

C. Comparison with Previous Studies

Table III compares the indoor radon concentrations obtained in the present study with values reported from similar investigations conducted in Kenya and other countries. Such comparisons provide a basis for evaluating the relative magnitude of the measured concentrations and the geographical variability of indoor radon associated with differences in geological setting, soil characteristics, building construction materials, ventilation conditions, and climatic factors.

Table III: Comparison of mean indoor radon concentrations reported in the present study with previous investigations conducted in Kenya and other countries.

Region	Study area	Mean indoor radon (Bq m^{-3})	Comparison with the present study	Reference
Kenya	Traditional dwellings	170.3 ± 39.6	Much higher than the present study, mainly due to poorly ventilated traditional huts and meteorological influences.	[25]
Kenya	Review of Kenyan radon studies	30-300 (depending on location)	Confirms substantial spatial variability of indoor radon in Kenya; the present study is below the reported range.	[26]
Tanzania	Manyoni Uranium Deposit	166 ± 12	Higher than the present study.	[37]
Tanzania	Residential houses	Most houses >100 Bq m^{-3}, especially near uranium deposits	Higher than the present study.	[24]
Nigeria	Dwellings	39 ± 7	Considerably higher than the present study.	[38]
World average	Indoor environments	40	Approximately three times higher than the present study.	[39]

The mean indoor radon concentration obtained in the present study was lower than the 170.3 ± 39.6 Bq m^{-3} reported for traditional dwellings in Kenya [25]. The present value was below the 30–300 Bq m^{-3} range reported in a review of Kenyan radon studies [26], indicating substantial spatial variability in indoor radon concentrations across Kenya.

In Tanzania, a mean concentration of 166 ± 12 Bq m^{-3} was reported for the Manyoni uranium-deposit area [37], while another study reported that most residential houses had concentrations above 100 Bq m^{-3}, particularly in areas close to uranium deposits [24]. Both reported values are higher than the mean concentration obtained in the present study.

The mean concentration reported for Nigerian dwellings was 39 ± 7 Bq m^{-3} [38], while the reported global average indoor radon concentration was approximately 40 Bq m^{-3} [39]. Both values are higher than the mean concentration measured

in the present study.

The differences among the reported studies may reflect variations in geological setting, uranium content of underlying rocks, soil permeability, building construction materials, ventilation characteristics, and climatic conditions. However, differences in measurement periods and study designs should also be considered when comparing reported indoor radon concentrations.

D. Radiological Analysis

1) Equilibrium Equivalent Concentration (EEC)

The equilibrium equivalent concentration (EEC) of radon progeny reflects the physical balance between radon gas and its short-lived decay products, which emit the alpha radiation responsible for damaging lung tissue. The EEC ranged from 3.27 ± 0.11 to 6.88 ± 0.31 Bq m^{-3}, with an average of 5.14 ± 0.22 Bq m^{-3} (Table I). The EEC values were low, consistent with the low measured indoor radon concentrations and the adopted equilibrium factor of 0.4.

2) Annual Effective Dose

As shown in Fig. 3, the annual effective dose (AED) attributable to indoor radon ranged from 0.2064 ± 0.0066 to 0.4342 ± 0.0194 mSv y^{-1}, with a mean of 0.3239 ± 0.0140 mSv y^{-1}. The dose pattern across the investigated buildings was consistent with the measured indoor radon concentrations, indicating correspondingly low modelled radiological exposure under the adopted exposure assumptions.

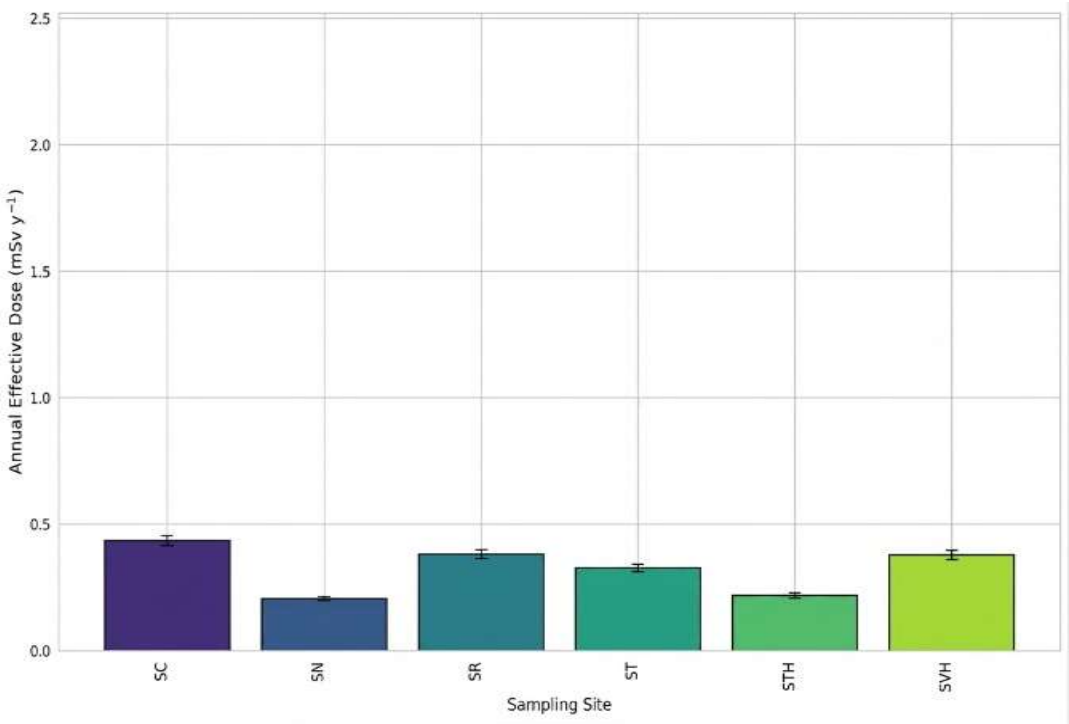

Fig. 3. Annual effective dose (mSv y^{-1}) calculated for each investigated building with corresponding measurement uncertainties.

3) Excess Lifetime Cancer Risk

The excess lifetime cancer risk (ELCR) attributable to indoor radon exposure ranged from $(0.79 \pm 0.03) \times 10^{-3}$ to $(1.67 \pm 0.07) \times 10^{-3}$, with a mean of $(1.25 \pm 0.05) \times 10^{-3}$. The calculation incorporated the ICRP Publication 103 cancer-risk coefficient of 5.5×10^{-2} Sv^{-1}, together with the appropriate conversion between millisieverts and sieverts.

The variation in ELCR among the sampling sites followed the pattern of the measured indoor radon concentrations and the corresponding annual effective doses. The estimated values represent model-based lifetime excess cancer probabilities under the assumed exposure conditions and should not be interpreted as directly observed cancer incidence.

4) Lung Cancer Cases per Million Persons per Year

The estimated lung cancer cases per million persons per year (LCC) attributable to indoor radon exposure ranged from 3.71 ± 0.12 to 7.82 ± 0.35 cases per 10^6 persons y^{-1}, with a mean of 5.83 ± 0.25 cases per 10^6 persons y^{-1}. The variation in LCC followed the pattern of the annual effective dose and, consequently, the measured indoor radon concentration.

Because this indicator is calculated from the annual effective dose, it should not be described as a lifetime lung cancer case count. Rather, the results represent model-based annual population rates under the assumed exposure conditions.

5) Overall Radiological Interpretation

Under the standardized short-term measurement conditions used in this study, the monitored buildings exhibited low indoor radon concentrations and correspondingly low modelled radiological-risk indicators. Nevertheless, because the measurements represent a single short-term monitoring campaign, they should be interpreted within the context of the study design and should not be taken as a definitive representation of long-term exposure.

The results indicate that continued periodic monitoring of indoor radon concentrations and the maintenance of adequate building ventilation remain important preventive measures. These measures are particularly relevant where changes in land use, building characteristics, or geological conditions could alter indoor radon accumulation. The potential health significance of radon exposure is also influenced by cumulative exposure and cigarette smoking.

IV. Conclusion

This study evaluated indoor radon concentrations and associated radiological risk parameters in six selected buildings at SEKU. The measured indoor radon concentrations ranged from 8.18 ± 0.26 to 17.21 ± 0.77 Bq m^{-3}, with an overall mean of 12.84 ± 0.55 Bq m^{-3}. All measured concentrations were below the World Health Organization (WHO) reference level of 100 Bq m^{-3} and the International Commission on Radiological Protection (ICRP) reference level of 300 Bq m^{-3}. The estimated annual effective dose, excess lifetime cancer risk, and lung cancer cases per million persons per year were likewise low under the adopted exposure assumptions. Overall, the findings indicate that the monitored indoor environments exhibited low radon concentrations and correspondingly low modelled radiological-risk indicators under the standardized measurement conditions and exposure assumptions used in this study.

The observed variation in radon concentrations among the monitored buildings indicates that differences in local geological conditions, building characteristics, and ventilation may contribute to variations in indoor radon levels. However, these factors were not measured independently, and their individual contributions could therefore not be quantitatively established. The results provide a useful baseline assessment of indoor radon levels at SEKU but should not be considered representative of all university buildings because the study was limited to six selected buildings, each monitored for a single 24-hour period. Future studies involving a larger number of buildings, longer monitoring durations, and repeated measurements across different seasons are recommended to better characterize the spatial and temporal variability of indoor radon across the university. In the interim, maintaining adequate ventilation, inspecting and sealing potential radon entry pathways such as foundation cracks and service penetrations, and conducting periodic indoor radon monitoring would provide practical measures for maintaining low indoor radon levels and supporting radiation protection at SEKU.

Acknowledgement

The authors gratefully acknowledge the laboratory technicians of Karatina University and South-Eastern Kenya University for their technical assistance throughout the research.

Conflict of Interest

The authors declare no conflict of interest.

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