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Radon Concentrations and Workers Exposure in Tanzanian Tourist Caves: A Field Assessment

Shovi Furaeli Sawe

shovisawe@yahoo.co.uk

Tanzania Atomic Energy Commission

Research Article

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Abstract

This study aimed to evaluate radon concentrations and potential exposure risks for workers, especially tour guides, in the Amboni caves near Tanga. Measurements of radon concentrations were carried out using an AlphaGUARD radon monitor at multiple locations over a three-month period in 2024. Data were collected during both the rainy and dry seasons to assess seasonal variation. Environmental parameters, including temperature and relative humidity, were also analyzed to determine their relationship with radon concentrations. The findings indicate that radon levels in the caves are relatively low, with maximum concentrations of 98 ± 5 Bqm^{-3} during the rainy season and 170 ± 6 Bqm^{-3} during the dry season. These values are below the reference levels of 300 Bqm^{-3} and 1000 Bqm^{-3} recommended by the ICRP and IAEA, respectively. Analysis of environmental factors showed weak and inconsistent correlations with radon levels, suggesting minimal seasonal influence on radon variability. Compared to studies from other regions, particularly in Africa and Europe, radon concentrations in the Amboni caves are significantly lower. Although radon concentrations in the Amboni caves are low, continued monitoring is important because of the confined nature of cave environments and the expansion of tourism activities. The study provides baseline radon data for Tanzania and supports the implementation of proactive radiation safety measures.

1. Introduction

Tourist caves in Tanzania are important natural attractions with geological, ecological, and cultural significance. Notable examples are the Amboni caves near Tanga which is the largest limestone cave system in East Africa and Nan'goma Cave in Kilwa District known for its extensive underground passages and historical importance. These caves typically form in karst landscapes and contain complex networks of chambers, stalactites, and stalagmites, as well as cave-dwelling fauna such as bats. However, their enclosed and poorly ventilated environments can allow radon gas to accumulate to elevated levels raising concerns for both visitors and workers. Therefore, as cave tourism expands, assessing environmental conditions particularly radon exposure has become increasingly important for safety and conservation. Karstic geology typically has low levels of uranium although concentrations may increase due to alluvial re-deposition because of uranium's water solubility (Bezuidenhout and Roux, 2024; Oufni and Misdaq, 2001). Enclosed cavities in this geology are therefore susceptible to radon accumulation due to inadequate ventilation.

Radon (^{222}Rn) is a naturally occurring, water-soluble inert gas formed in the decay chain of uranium-238 (^{238}U). It is widely distributed in soil and rocks and can be found in outdoor air, buildings, underground mines, and caves. With a half-life of approximately 3.8 days, radon decays by emitting alpha particles and produces radioactive progeny such as polonium-218 (^{218}Po), lead-214 (^{214}Pb), bismuth-214 (^{214}Bi), and polonium-214 (^{214}Po). These decay products can exist as unattached ions or attach to dust and other airborne particles, forming respirable radioactive aerosols (Abdo et al., 2024; Amrane et al., 2024). When short-lived alpha emitters particularly ^{218}Po and ^{214}Po are inhaled, they deliver radiation doses to

lung tissues significantly increasing the risk of lung cancer (Pavia et al., 2003; UNSCEAR 2000; William, 2018; WHO, 2009). Evidence from studies of underground miners strongly supports the link between radon exposure and lung cancer (ACS, 2026; ICRP 2014). Radon tends to accumulate in confined environments such as caves, raising concerns about exposure risks for workers and visitors. Studies have shown that radon levels in caves can exceed the outdoor levels thousand times (Papastefanou et al., 2003; Lichwa 2015), often exceeding the internationally recommended upper reference levels. For example, studies in Brazil and South Africa have reported radon concentrations in caves well above this guideline (Martins, 2022; le Roux et al., 2023).

Both passive and active detectors are used to perform radon measurements. The solid state nuclear track detectors (SSNTD) utilizing polymer of allil diglycol carbonate (CR-39), cellulose nitrate (LR-115 type II and CN-85), etc., are most widely used passive detectors (Hashim et al., 2021; Koç et al., 2018; Ramola et al., 1996; Sawe, 2025). One of the active methods for radon measurements utilizes AlphaGUARD radon monitor which is an ionization chamber-based instrument (Saphymol, 2017). In Tanzania, there are no specific studies focused on radon levels in Tanzanian tourist caves. This study therefore aims to preliminarily assess the exposure of workers (particularly tour guides) to radon and its progeny during their duties in the Amboni cave environments.

2. Materials and Methods

2.1.1 Description of the study site

The Amboni Caves, locally known as Mapango ya Amboni, are among the most extensive limestone cave systems in East Africa, located near Tanga along the northeastern coast of Tanzania (Fig. 1). It is the second limestone cave in the world after the Mammoth Cave of the United States of America (FEAT, 2026). These caves developed through the dissolution of limestone creating a complex network of chambers and passages approximately 150 million years ago (Wikipedia, 2026). The site is a popular tourist attraction known not only for its geological significance but also for its cultural and spiritual importance to local communities who associate the caves with traditional beliefs and rituals. Guided tours are offered to visitors allowing exploration of selected accessible sections while much of the cave system remains unmapped. Tourists typically spend about 30 minutes inside the caves, making radon exposure a significant concern for both visitors and workers. The caves also provide a habitat for various species including bats (NCAA, 2026) and their enclosed environment makes them a potential site for elevated radon concentrations (Cheng et al., 2017; Cigna, 2005), which is an important consideration for both visitors and workers. The caves are well maintained and lit with electricity for visitors (Fig. 2).

2.2 Measurement of radon concentrations

Radon concentrations (Bqm^{-3}) in Amboni caves were measured using a portable Professional Radon Monitor (AlphaGUARD) shown in Fig. 3. During operation, air diffuses into the instrument's ionization chamber through a large-surface glass fiber filter. Inside the chamber, alpha particles emitted by radon ionize the gas, and the resulting charges are collected at the electrodes, generating an electronic signal

that is converted into radon concentration through factory calibration as described in Saphymol (2017). Measurements were taken at multiple locations within the caves over a three-month period in 2024 using two equipment simultaneously, with measurements conducted during both rainy and dry seasons to assess seasonal variations influenced by meteorological conditions[25]. Measurement data were downloaded using DataEXPERT software. Measurement quality was ensured by verifying the instrument's calibration validity. In practice, the AlphaGUARD is calibrated by the manufacturer, with calibration stability guaranteed for five years, or alternatively by an accredited radiological calibration laboratory using a traceable, controlled radon atmosphere. This study relied on the manufacturer's calibration. Radon measurements were conducted at locations within the cave where tourists typically stop to receive explanations from guides. Therefore, the primary selection criterion for these locations was the duration of time visitors spend at each point. Measurement data were downloaded using DataEXPERT software.

3. Results and Discussion

Results of radon concentrations measured in Amboni caves are presented in Table 1. The highest radon concentration during the rainy season was 98 ± 5 Bqm^{-3} at location 6, while during the dry season it reached 170 ± 6 Bqm^{-3} at location 5. Both values are well below the upper reference level of 300 Bqm^{-3} recommended by International Commission on Radiological Protection[10] and far below the IAEA reference levels up to 1000 Bqm^{-3} for workplaces (IAEA, 2014). Radon concentration in these caves is low mainly because environmental and geological conditions prevent the gas from accumulating. A short airflow path length between the cave interior and the surface further enhances ventilation and reduces the time radon remains trapped inside the cave. In addition, caves formed in Karstic geology typically have low levels of uranium content (Bezuidenhout and Roux, 2024; Oufni and Misdaq, 2001). The mean temperature was 24°C in the rainy season and 26°C in the dry season, whereas the mean relative humidity was 96% and 98%, respectively. Pearson's correlation analysis showed no significant relationship ($p > 0.05$) between radon concentration and temperature in either the rainy season ($r = 0.11$) or the dry season ($r = 0.42$). A strong positive correlation between radon concentration and humidity ($r = 0.72$) was observed during the rainy season while a non-significant negative correlation ($r = -0.42$) was found in the dry season. Generally, environmental factors show inconsistent and limited influence, suggesting that seasonal effects on radon variation in this cave are minimal.

Table 1
Radon concentrations measured in Amboni caves

Location	Radon concentration. (Bqm^{-3})		Temperature (^0C)		Relative humidity (%)	
	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season
1	60 ± 4	74 ± 4	25	26	99	99
2	72 ± 4	170 ± 64	26	26	97	99
3	98 ± 5	112 ± 6	25	26	99	99
4	51 ± 3	85 ± 5	19	26	90	99
5	46 ± 3	154 ± 8	26	27	91	92
6	62 ± 5	133 ± 10	20	26	97	99
Mean	**65** ± 2	**121** ± 11	**24**	**26**	**96**	**98**

Since no radon studies have been conducted in Tanzanian caves, direct comparison with previous findings is not possible. However, data from other regions provide useful context (Table 2). In Africa, studies from South Africa report relatively high radon concentrations. Mean levels of 1,265 Bqm^{-3} were recorded in Cango Cave (Bezuidenhout and Rikus, 2024), 750 Bqm^{-3} in Sudwala Cave (Ramola et al., 1996), and 427 Bqm^{-3} in Sterkfontein Cave Bezuidenhout and Rikus, 2024). In Europe, radon concentrations vary widely. In the Czech Republic, values in show caves range from 1,000 to 7,000 Bqm^{-3} (Thinova et al., 2025). In Greece, reported levels range from 0.19 to 88.06 $kBqm^{-3}$(Papastefanou et al., 2003). Romanian caves show concentrations between 400 and 2,178 Bqm^{-3} with mean values of 1,167 Bqm^{-3} in one study and 1,527 Bqm^{-3} in another (Bican-brişan et al., 2016). In these European studies, seasonal variation was significant. In Postojna Cave, Slovenia, radon levels ranged from about 200 Bqm^{-3} in winter to approximately 3,000 Bqm^{-3} in summer (Gregorič et al., 2011). Similarly, in Spain, radon concentrations ranged from 39 to 627 Bqm^{-3} (mean 449 Bqm^{-3}) during summer, and from 8 to 185 Bqm^{-3} (mean 29 Bqm^{-3}) in winter. Generally, these studies indicate that radon concentrations in caves can vary substantially depending on location, geological conditions, and seasonal factors.

Table 2
Radon concentrations in caves reported from different parts of the world

Cave / Location	Country	Mean Radon Concentration (Bqm^{-3})	Reference
Postojna Cave	Slovania	25,020	Gregorič et al., 2014
Various caves	Switzerland	25,000	Surbeck, 1990
Shawan Cave	China	47,419	Wang et al., 2019
Petralona Cave	Greece	25,179	Papastefanou et al., 1986
Jenolan Cave	Australia	4,578	Waring et al., 2025
Altamira Cave	Spain	3,564	Lario et al., 2005
Altamira Cave	Spain	3,286	Sainz et al., 2018
Big Bone Cave	USA	11,678	Bashor 2004
Various Caves	Poland	1,166	Przylibski, 1999
Various Caves	Great Britain	35,890	Gunn, et al., 1991
Various Caves	Great Britain	9,306	Gillmore et al., 2000
Various Caves	Hungary	3,300	Somogyi et al., 1989
Amboni Caves	Tanzania	93	This study

4. Conclusions

This study assessed radon concentrations in the Amboni caves, one of Tanzania's tourist cave systems with the aim of evaluating potential exposure risks to workers, particularly tour guides. The measured radon concentrations were low with maximum values of 98 ± 5 Bqm^{-3} during the rainy season and 170 ± 6 Bqm^{-3} during the dry season. These values are well below the ICRP and IAEA maximum reference levels for occupational exposure, indicating that, under current conditions, the caves do not pose a significant radiological health risk to workers or visitors. Analysis of environmental parameters showed no consistent or statistically significant relationship between radon concentration and temperature, while the relationship with humidity varied between seasons. This suggests that short-term meteorological factors may have limited influence on radon variability within the cave system, and that other factors such as cave geometry and ventilation may play a more important role. When compared with international studies, radon levels in Amboni caves are considerably lower than those reported in many caves in Africa and Europe, where concentrations often exceed recommended upper reference levels. This difference may be attributed to geological characteristics, ventilation conditions, and local environmental factors. Despite the relatively low concentrations observed, continuous monitoring is recommended, especially as cave tourism continues to grow. Long-term assessments covering different seasons and additional cave systems in Tanzania would provide a more comprehensive understanding

of radon exposure. Furthermore, implementing routine monitoring and awareness programs for cave workers would support proactive management of potential health risks. Although the current dataset is limited, this study provides the first baseline data on radon levels in Tanzanian tourist caves and highlights the importance of ongoing environmental assessment to ensure the safety and sustainability of cave tourism.

Declarations

Declaration of competing interest

The author declares no conflict of interest related to this work.

All authors have read, understood, and have complied as applicable with the statement on “Ethical responsibilities of Authors” as found in the Instructions for Authors”

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Declaration

The author declares that no funding was received for this study

Author Contribution

SFS played role in conceptualization, field work, original draft preparation, and review and editing

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Figures



Figure 1

Entrance to Amboni Caves in Tanga, Tanzania

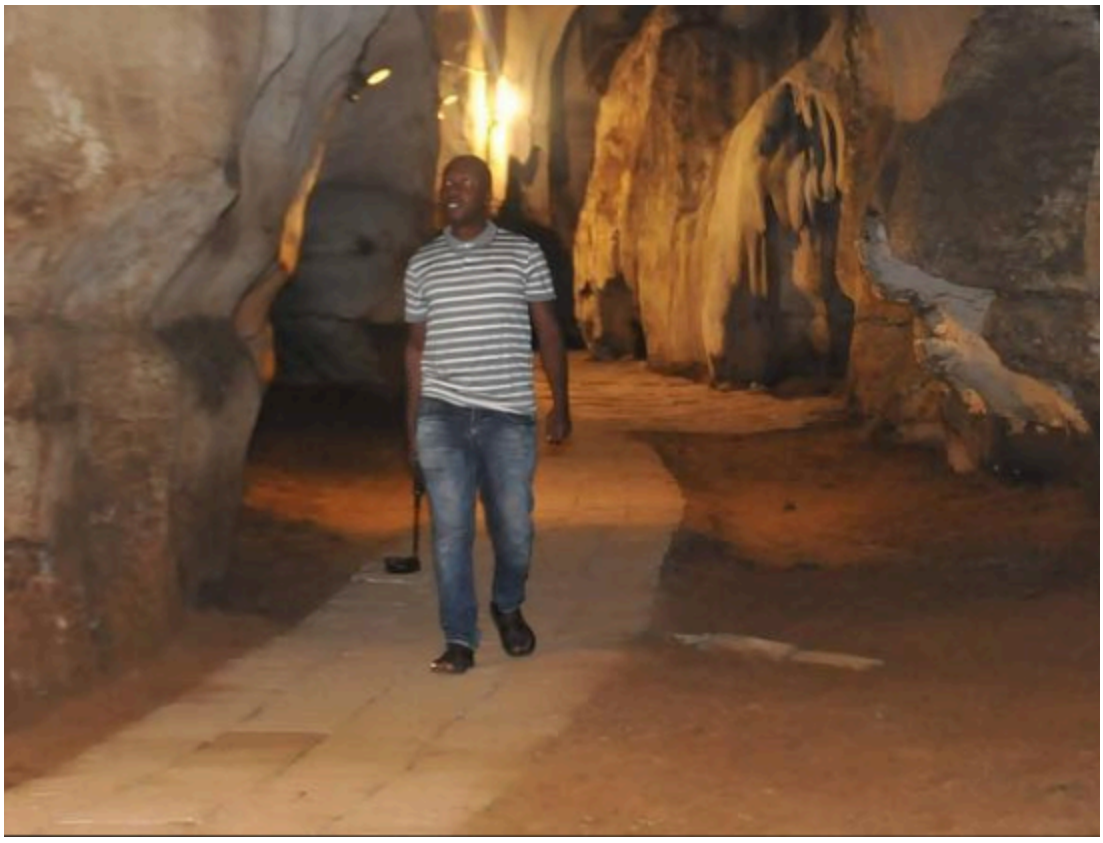


Figure 2

Interior of Amboni Caves in Tanga, Tanzania



Figure 3

Front view of Professional Radon Monitor (AlphaGUARD)