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REVIEW ARTICLE

Review of radon research in Tanzania

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Abstract

In this paper, nine researched studies of radon concentrations in Tanzania were reviewed by searching specified databases from various search engines, such as Web of Science, Scopus, Google Scholar, Science Direct and PubMed for the studies published between the years 2010 and mid-April 2024 in English language to establish baseline data for the current research, which focused on Tanzania's national radon survey and radon mapping strategy. The radon prediction map was created using well-known GIS software, ArcGIS 10.3. The results show that studies were conducted in central Tanzania close to Bahi and Manyoni uranium deposits, the Northern part of Tanzania at the Buhemba Gold mine and Tanzanite mines, and southern highlands at the Mkuju uranium project and Kiwira Coal mine. From the results of this review, the highest level of indoor radon concentration of 619 ± 59 Bq/m^3 was recorded in Bahi Makulu, whilst the lowest average level of 19 ± 3 Bq/m^3 was observed in Manyoni town. Radon in soil was conducted in Dodoma city only, and the mean was 59.8 kBq/m^3. The average mean of radon in building materials is 74.6 Bq/m^3, whilst no study has been found in the literature for radon in water. The lowest and highest radon concentration levels found in mining pits are 36 ± 5 and 4171.6 Bq/m^3 reported from the Kiwira coal mine and Tanzanite Merelani mine, respectively. The results of this study emphasise the need for additional research on radon across the nation and raise awareness of the dangers and causes of radon exposure. Furthermore, this paper's results will help develop the national indoor radon database and establish a regulatory framework for radon in buildings, soil, underground mines, building materials and water.

Keywords: *radon*; *uranium*; *mining*; *GIS*; *Tanzania*; *regulatory framework*

Introduction

Our environment contains radioactive elements of naturally occurring radioactive material (NORM). NORM primarily contains uranium, thorium and potassium. Radon gas, a member of the uranium and thorium part of NORM, contributes 55% of the entire amount of natural ionising radiation that the general public is exposed to (1, 2). Radon is an invisible, colourless, odourless and tasteless radioactive gas. Radon has three isotopes of ^{222}Rn, ^{220}Rn and ^{219}Rn come from the decay of radium ^{226}Ra, ^{224}Ra and ^{223}Ra, which are members of the natural uranium (^{238}U), thorium (^{232}Th) and uranium (^{235}U), respectively (2–4). ^{220}Rn and ^{219}Rn have a short half-life of 56 s and 4 s, respectively, compared to ^{222}Rn, a half-life of 3.8 days. Therefore, due to the half-life, many studies were interested in ^{222}Rn compared to other isotopes. ^{222}Rn decays to form short-lived decay products, which are called radon daughters or radon progenies. These radon progenies are polonium (^{218}Po and ^{214}Po), which decay by emitting alpha (α) particles, whilst lead (^{214}Pb) and bismuth (^{214}Bi) decay by emitting beta (β) particles. These radon progenies are connected to dust, which we are mainly exposed to by breathing it. ^{222}Rn decays to several α and β emissions before finally reaching a stable form of lead (^{206}Pb). Outdoor radon is often present in tiny amounts, whilst inside houses, schools and office buildings have the potential to contain higher indoor radon concentrations. The nature of concrete construction materials and cracks in the basement or foundation of a home may allow elevated levels of radon in the building. High radon levels can be found in areas with elevated levels of thorium or uranium. This can also be found in most mining or milling operations involving phosphates or metals. Drinking water derived from surface and groundwater sources is likely to include radon. They are also present in drinking water drawn from radon-contaminated wells. Water containing radon has the potential to release particles into the atmosphere, particularly when used for showering or cooking.

Radon is the second leading cause of lung cancer death in the world, behind the tobacco cigarette smoking. Due to health concerns, radon has been classified as a human carcinogen by several public health bodies, including the World Health Organization (WHO) and the International

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Agency for Research on Cancer (IARC). For this reason, different international organisations have set radon limits that are recommended for indoor and outdoor radon, radon in water, soil, building materials and underground mining. The upper limit recommended for indoor radon concentrations is 100 and 300 Bq/m^3, set by the WHO and the International Commission on Radiological Protection (ICRP), respectively (5). The limit ICRP sets for underground mining is 500–1,500 Bq/m^3 (6). The Swedish risk threshold for soil is (10–50 kBq/m^3) and (> 50 kBq/m^3) for the normal risk range and high radon risk zones, respectively (7). The world average mean for outdoor radon is in the range of 5–15 Bq/m^3 (8). Many international countries that are members of the International Atomic Energy Agency (IAEA) have radon maps (9–12). However, Tanzania has never conducted a thorough national radon survey for indoor radon and other types of radon. As a result, the nation lacks a radon map that shows potential radon hotspots. Currently, Tanzania lacks adequate radon statistics and a regulated framework for protecting the public from the risk posed by radon. This study examines the data on radon that is already accessible in the nation to begin developing the Tanzania program for radon mapping and surveying. The review's findings will be useful in creating the nation's radon database and establishing a regulatory framework for radon in homes and other buildings frequently occupied by the general public, such as offices, kindergartens, above-ground and underground working places.

Material and methods

Data sources and search strategy

This paper's information is based on data gathered from radon investigations carried out in Tanzania between 2010 and mid-April 2024 for indoor radon, outdoor, mining, soil, building materials and water, to mention a few. The available data that focus on radon measurements are very few studies that have primarily been carried out by independent researchers for academic purposes and a few by consultants for the Tanzania Atomic Energy Commission (TAEC). The radon concentration levels were obtained mainly using an Alpha Guard radon monitor, as shown in Table 1. Table 1 also shows the calibration, sample size, measurement period and mean concentration that were obtained. The search targeted articles published in English between 2010 and mid-April 2024. The researcher utilised search engines such as Web of Science, Scopus, Science Direct, Springer, Google Scholar, PubMed and Research Gate to obtain the data. Two essential keywords which are 'radon Tanzania' and 'radon measurements in Tanzania' were employed to search for the required information. The English versions of all studies pertaining to radon measurements between 2010 and mid-April 2024 were acquired. This study considered the radon measurement in soil, building materials, indoor and outdoor spaces, and water. The review is based on nine (9) radon studies, including those on indoor and outdoor radon, radon in the soil, radon from building materials and radon from underground mining. Table 1 presents the publications' complete information. The radon prediction maps were created using well-known GIS software, ArcGIS 10.3, as shown in Fig. 1.

Results and discussion

Results

Data on the nationwide distribution of radon levels in homes, soil and water, as well as the variables influencing environmental radon levels, are obtained via radon monitoring programs. The results of radon monitoring serve as the foundation for creating a plan for protecting the environment from radon exposure and taking appropriate preventative measures. This review aims to map the nation's radon levels and identify areas with elevated levels in soil, water and homes to regulate radon levels in newly constructed buildings and water sources. The following subsections are the investigations that served as the foundation for this review study conducted in various regions of Tanzania. The mean radon concentrations discussed are in geometric mean unless otherwise stated and are presented together with standard deviation.

Mara region

Focus *et al.,* 2022 conducted a Risk Assessment of Natural Radionuclides and Radon Gas in the Artisanal and Small-Scale Gold Mine of Buhemba, Tanzania (17). Twelve mining pits at the Buhemba Artisanal and Small-Scale Gold Mine had their radon levels measured, whilst five measurements from five offices at Mwalimu J. K. Nyerere University served as the control area. Radon concentrations in the pits ranged between 66 ± 11 and 698 ± 54 Bq/m^3 with a geometric mean of 124.2 ± 2 Bq/m^3, whilst the control area had a range of 28 ± 3–62 ± 7 Bq/m^3 with a geometric mean value of 41.7 ± 1.4 Bq/m^3.

Manyara region

In the Manyara region, two studies have been conducted on radon concentrations in the underground Merelani Tanzanite Mines over different years. Kahuluda and Makundi, 2014, conducted a study on the determination of radon gas and respirable dust concentrations in the Underground Merelani Tanzanite Mines and found radon concentrations in 13 pits ranging from 40.1 to 4171.6 Bq/m^3 with the geometric mean of 118.4 Bq/m^3 (6). After 10 years, Mbuya *et al.*, 2024's study explored respirable crystalline silica and radon concentrations amongst the tanzanite mining communities in Mererani, Tanzania (18).

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Table 1. The information on radon concentrations documented in Tanzania

S/N	Year	Title of the study	Techniques used for radon detection	Calibration	Sample size	Measurement period	Geometric mean concentration (Bq/m^3)	Reference
1	2010	Environmental assessment of uranium exploration projects: a case study of Mkuju river uranium exploration project, Ruvuma – Tanzania	Polycarbonate track edge devices (Radon Gas Monitors)	Non-degradable calibration	30	3 months	11.9	(13)
2	2010	Determinant of Radon Gas and Respirable Coal Dust Concentrations in the Working Environments of Kiwira Coal Mine, SW Tanzania	AlphaGuard radon monitor	NA	NA	NA	NA	(14)
3	2014	Determination of Radon Gas and Respirable Dust Concentrations in the Underground Merelani Tanzanite Mines	AlphaGuard radon monitor	NA	13	NA	118.4	(6)
4	2015	Radon Mass Exhalation Rates of Selected Building Materials in Tanzania	Radon meter Pylon AB5™	NA	9	1 month	74.6	(15)
5	2018	Assessment of Indoor Radon-222 Concentrations in the Vicinity of Manyoni Uranium Deposit, Singida	AlphaGuard radon monitor	Factory calibration	32	2 months	140.1	(5)
6	2018	Indoor Radon Concentration Levels and Annual Effective Doses for Residence of Houses Near Uranium Deposit in Bahi District, Dodoma, Tanzania	AlphaGuard radon monitor	NA	60	NA	221.5	(16)
7	2022	Risk Assessment of Natural Radionuclides and Radon Gas in the Artisanal and Small-Scale Gold Mine of Buhemba, Tanzania	AlphaGuard radon monitor	NA	12	NA	124.2	(17)
8	2023	Levels of Radon in Soils of Dodoma City, Central Tanzania	AlphaGuard radon monitor	NA	32	NA	59.8	(7)
9	2024	Concentrations of respirable crystalline silica and radon among tanzanite mining communities in Mererani, Tanzania	AlphaGuard radon monitor	NA	44	3 months	NA	(18)

NA, Not available.

The results from 22 underground mining pits had a median radon concentration of 169.5 Bq/m^3, whilst 22 community houses had a median indoor radon concentration of 88 Bq/m^3.

Dodoma region

In the Dodoma region, two studies have been conducted on indoor radon and radon in soil. Mohammed and Focus, 2018, study 'Indoor Radon Concentration Levels and Annual Effective Doses for Residence of Houses Near Uranium Deposit in Bahi District, Dodoma, Tanzania' (16) explored 32 houses in Bahi Makulu and 28 houses in Bahi Sokoni villages. In Bahi Makulu, the study observed that the minimum and maximum indoor radon levels were recorded as 70 ± 15 and 619 ± 59 Bq/m^3, respectively, with a geometric mean of 320.8 ± 1.6 Bq/m^3. The radon level in Bahi Sokoni houses ranged between 29 ± 8 and 398 ± 38 Bq/m^3 with a geometric mean of 140.1 ± 2.1 Bq/m^3. The geometric mean of indoor radon concentration for this study in Bahi is 221.5 ± 2.0 Bq/m^3. In another study, Sawe,

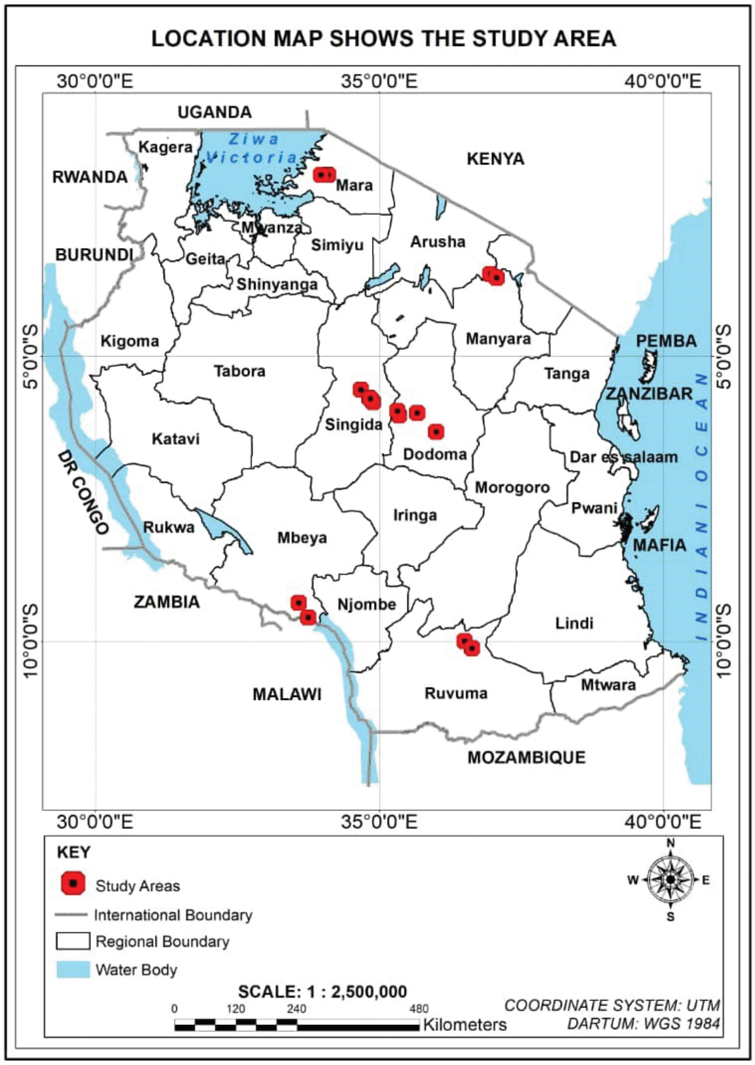

Fig. 1. Location map shows the study areas of radon in Tanzania.

2023, conducted a study on 'Levels of Radon in Soils of Dodoma City, Central Tanzania' (7). He found that radon levels vary between 18.8 and 233.5 kBq/m^3, with a geometric mean of 59.8 ± 1.8 kBq/m^3.

Singida region

Mlay and Makundi, 2018, conducted a study on the Assessment of Indoor Radon-222 Concentrations in the Vicinity of Manyoni Uranium Deposit, Singida (5). Indoor radon measurements were conducted in 32 houses in 8 villages surrounding the locality's uranium deposit. The results of indoor radon level for minimum and maximum in Bq/m^3 are (27 ± 3 and 74 ± 6), (31 ± 3 and 125 ± 8), (35 ± 3 and 52 ± 4), (98 ± 6 and 303 ± 19), (286 ± 19 and 442 ± 26), (83 ± 7 and 518 ± 28), (242 ± 16 and 512 ± 29) and (156 ± 12 and 182 ± 12) from Agondi, Kamenyanga, Mkwese, Muhalala, Mitoo, Mwanzi, Majengo and Kipondoda villages, respectively. Their mean indoor concentrations in Bq/m^3 are 52 ± 17, 69 ± 19, 43 ± 7, 177 ± 16, 325 ± 21, 287 ± 13, 377 ± 23 and 169 ± 13 from Agondi, Kamenyanga, Mkwese, Muhalala, Mitoo, Mwanzi, Majengo and Kipondoda villages, respectively. The geometric mean of indoor radon concentration in Manyoni uranium deposit is 140.1 ± 2.4 Bq/m^3. The results for outdoor radon concentrations from Agondi, Kamenyanga, Mkwese, Muhalala, Mitoo, Mwanzi, Majengo and Kipondoda villages are 16 ± 2, 15 ± 3, 15 ± 3, 47 ± 4, 33 ± 4, 32 ± 4, 24 ± 3 and 24 ± 3 Bq/m^3, respectively. The same study also measured indoor radon in 9 houses in Manyoni town as a control. The indoor radon concentrations recorded for minimum and maximum were 19 ± 3 and 164 ± 10 Bq/m^3, respectively, with the geometric mean value of 47 ± 2 Bq/m^3.

Mbeya region

Sawe, 2010, carried out a study on the 'Determination of Radon Gas and Respirable Coal Dust Concentrations in the

Working Environments of Kiwira Coal Mine, SW Tanzania' (14). The lowest and highest mean radon concentrations recorded were 36 ± 5 and 305 ± 29 Bq/m^3, respectively.

Ruvuma region

In the Ruvuma region, only the Wilfred, 2010, study 'Environmental assessment of uranium exploration projects: a case study of Mkuju river uranium exploration project, Ruvuma-Tanzania' was conducted (13). The results for 30 public outdoor radon concentration measurements ranged from 0.5 to 82.9 Bq/m^3 with a geometric mean value of 11.9 ± 3.1 Bq/m^3.

Discussion

The next sub-section deals with a review of radon concentrations in Tanzania, which involves evaluating radon levels and examining radon using international guidelines.

Radon in houses

Exposure to ^{222}Rn and their daughter is allegedly related to the rising risk of promoting lung cancer. From the results of this review, the highest level of indoor radon concentration of 619 ± 59 Bq/m^3 was recorded in Bahi Makulu (16), whilst the lowest average level of 19 ± 3 Bq/m^3 was observed in Manyoni town (5). These places are in central Tanzania at Bahi uranium deposit and Manyoni town, respectively. The primary factors contributing to this significant variation are the building materials used in each residence and the local geological composition. The houses in Bahi Makulu with high radon levels are close to the Bahi uranium deposit. Additionally, the rooms are poorly designed for the environment due to their small size, inadequate ventilation and occupants' lifestyles. Most places that have been studied have mean values of indoor ^{222}Rn that are well below the limit of 300 Bq/m^3 recommended by ICRP, except a few places located near Manyoni and Bahi uranium deposits. However, some sites have significantly higher values than the recommended limit set by WHO, 100 Bq/m^3, and the worldwide average radon concentration is 40 Bq/m^3, as reported by UNSCEAR. The indoor radon concentrations of 325 ± 21 and 377 ± 23 Bq/m^3 were recorded at Mitoo and Majengo villages, respectively, in the vicinity of the Manyoni uranium deposit that exceeded the limit set by ICRP. Other areas with the highest average mean of the radon concentration level of 362 ± 22 Bq/m^3 exceeding the limit proposed by ICRP were observed in Bahi Makulu near the Bahi uranium deposit. This study proposes that the indoor radon action level in Tanzania be set at 100 Bq/m^3, in line with the guidelines established by the WHO. This recommendation will remain in place until a comprehensive national radon survey is conducted, at which point the national radon level may be reassessed and adjusted as necessary.

Radon in soil

The assessment of radon level in the soil is very important in environmental engineering for ^{222}Rn exhalation studies in building materials. This study's review found that only one study conducted radon in the soil in Tanzania by Sawe (2023). According to the Swedish risk threshold, the Dodoma soil results show that the indoor radon concentration of 71 kBq/m^3 is a high-risk range and hence requires construction protective measures against radon. According to the study, 41% and 59% of the evaluated sample sites fell under the normal risk range (10–50 kBq/m^3) and high radon risk zones (> 50 kBq/m^3), respectively.

Radon in building materials

Some of the main modifiers of indoor air radon levels are buildings, including how they are constructed and, more rarely, the materials that they are made of. As a result, to advance radioecology and environmental protection, the radon level and ^{222}Rn exhalation rate from building materials must be evaluated. Only one study has been conducted in Tanzania to evaluate the radon concentration levels in building materials (15). The study assessed the four cement brands of Tembo, Simba, Rhino and Kilwa that are sold in Tanzania and obtained from the local market. Other building materials used were sandstone and clay for fired and unfired bricks, gypsum as thin (1–3 cm) gypsum boards for walls and ceilings, and pozzolan, which is occasionally used for plastering in nearby settlements. Pozzolan, clay, sandstone and gypsum were obtained from their quarries in Songwe and Kilwa, located in the Mbeya and Lindi areas, respectively. The calculated indoor radon concentrations for a tightly closed standard room ranged from 3.1 to 1012.3 Bq/m^3 witha geometric mean of 74.6 ± 4.6 Bq/m^3. These results are within the recommended limit of the ICRP for potential radon health concerns in homes and workplaces.

Radon in underground mines

Most workers' exposure to radon is associated with underground uranium mining operations. However, underground uranium miners are not the only workers who may be exposed to radon at work; other underground works that are not usually linked to radiological risks may be carried out with minimal consideration for the possibility of radon exposure. These workers typically lack awareness of the health concerns of radon and associated health risks. There is also a chance that radon levels in open-pit mines could be hazardous to workers. In Tanzania, four studies have been conducted in underground mines: the Tanzanite Merelani mine (6, 18), the Kiwira coal mine (14) and the Buhemba gold mine (17). The lowest and highest radon concentration levels of 36 ± 5 and 4171.6 Bq/m^3 were reported from the Kiwira coal mine and Tanzanite Merelani mine, respectively. Many underground pits surveyed are well below the value of 500–1,500 Bq/m^3 recommended by ICRP for workplaces.

Outdoor radon

Outdoor radon typically dilutes to extremely low levels quickly and poses no threat. Two studies (5) and (13) were conducted near the Manyoni uranium deposit and the Mkuju River uranium mine, respectively. The results from many locations show an average of 5–15 Bq/m^3 worldwide, except for a few cases.

Radon in water

Drinking water that is contaminated with radon can pose health risks for developing internal organ cancers, which are likely to cause stomach cancer. However, the chance of getting cancer from radon dissolved in water is less than getting cancer from indoor radon. In Tanzania, no study has focussed on radon in water.

Conclusion

This review paper reviewed nine studies on radon conducted in Tanzania from 2010 to April 2024. It was found that (as the GIS map in Fig. 1 reveals) studies were conducted in three parts of Tanzania, mainly in the central, northern and southern parts. The result of indoor radon shows that many researched areas were well below the limit of 300 Bq/m^3 set by ICRP. However, in some areas, the indoor radon is higher than the 100 Bq/m^3 recommended by WHO. The soil analysis results and the analysis of underground mines and building materials show that radon is well below the standard limits of different international organisations. This review found no study conducted on radon in water. From the data presented in Table 1 and Fig. 1, further research and integrated, long-term indoor radon measurements are needed. This need is especially important in discovering and alerting potential radon hotspots like residential areas near gold or uranium mining areas and mine dumps. With enough information, a national radon database and, eventually, a national radon map can be created, and trend between the variables that affect indoor radon can be established. Furthermore, this will further direct future epidemiological and environmental effect research and help identify the sources of indoor radon in various regions. This review article concludes that more investigation and data gathering are necessary to guide the creation of regulations on managing conditions in current radon exposure scenarios.

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Data availability

Data will be made available on request.

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