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LEVELS OF RADON IN SOILS OF DODOMA CITY, CENTRAL TANZANIA

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ABSTRACT

Purpose: Humans receive radiation doses exceeding fifty percent (50%) of the total dose from natural sources as a result of inhaling radon and thoron gases and their daughters. Radon occurs naturally in soils and can diffuse into indoor environments leading to adverse health effects for inhabitants. In this study, measurement of levels of radon gas in soils was performed with the purpose of categorizing areas and highlighting the likelihood of high levels of radon in indoor environments.

Design/Methodology/ Approach: The study targeted the environs of Dodoma where the rapid expansion of human settlements is ongoing or anticipated**.** For easy access and convenience, the study was conducted in areas located along main roads leading to the nearby towns/cities. Sampling was done by inserting the drilling rod to a depth of approximately one meter (1 m) below ground level with the aid of a heavy hammer. The alpha pump was used to suck the soil gas from the ground through a metallic tube (the capillary probe) and pressed it into the ionization chamber of the measuring instrument (AlphaGUARD). Radon concentration was read directly from the instrument's display.

Findings: It was found that radon concentrations in soil vary from 18.8 to 233.5 kBq.m^{-3}. Based on the radon risk criterion, surveyed areas range from normal to high radon risk categories.

Research Limitation/Implication: The study only covered a limited area in Dodoma City, and therefore the results may not be representative of the entire city or even the surrounding regions.

Practical Implications: This study is useful in categorizing building areas based on radon risk criterion with the purpose of reducing possibilities of radon-related health risks; mainly lung cancer to the population.

Social Implications: Radon is a proven cause of lung cancer in humans. Therefore, knowledge of radon levels in the study area will help in setting the mitigation measures necessary for public health protection.

Originality / Value/ Novelty: The study demonstrates an approach for estimating radon levels in soils which is beneficial to current and future researchers, environmentalists and regulators, among others.

Keywords*: *Health risk. radon. risk criterion. soil. Tanzania.

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INTRODUCTION

Our planet earth contains naturally occurring radioactive materials, and around 90 % of radiation exposure to humans arises from such sources which include cosmic radiation, radon gas (^{222}Rn), and terrestrial radiation (Singh, et al., 2011). ^{222}Rn occurs naturally in the uranium-238 (^{238}U) decay chain (Figure 1). The half-life of ^{222}Rn is approximately 3.8 days and decays to daughter product polonium (^{218}Po) by emitting alpha particles. It is a water-soluble inert gas that is widespread in soil and rocks at varying concentrations. Radon emanation from soil, water and rocks are of substantial concern since they are the sources of radon in houses (Iskandar, et al., 2005). Radon concentration in soil gas (C_{Rn})which is the main focus of this study is given by the relation below assuming no transportation of radon (UNSCEAR 2000). Representative values of the parameters used in Eqn. 1 can be found in UNSCEAR 2000.

$$C_{Rn} = C_{Ra} \times k \times \rho_s \times \varepsilon^{-1}(1-\varepsilon) \times (m[K_T - 1] + 1)^{-1} \text{ ……………………….……… (Eqn. 1)}$$

where C_{Ra} is the concentration of ^{226}Ra in soil (Bq.kg^{-1}), "k" is the emanation factor, ρ_s is the soil density (kg m^{-3}), ε is the total soil porosity, "m" is the fraction of saturation, and K_T is the partition coefficient for radon between the water and air phases. Factor "m" is zero for dry soil and the last term on the right side of the equation is negligible. Generally, a warm moist soil will have higher concentration of radon in pore air compared to the same soil under cold and dry conditions (UNSCEAR 2000).

According to UNSCEAR 2000 report, the main mechanism for radon entry into the atmosphere is the molecular diffusion. In this case, the diffusive entry rate of radon into the atmosphere can be estimated using an expression available in UNSCEAR Reports of 1988 and 1993. According to the UNSCEAR, the flux density of radon at the surface of dry soil J_D (Bq.m^{-2}s^{-1}) is given by the expression

$$J_D = C_{Ra} \times \lambda_{Rn} \times k \times \rho_s (1-\varepsilon) L \text{ ……………………………………..…… (Eqn.2)}$$

where C_{Ra} is the activity concentration of ^{226}Ra in earth material (Bq.kg^{-1}), λ_{Rn} is the decay constant of ^{222}Rn, "k" is the emanation fraction for earth material, ρ_s is the soil grain density (kg.m^{-3}), ε is the porosity of dry earth material, and L is the diffusion length. Equation (2) is valid only for dry soil (UNSCEAR 2000).

The main factor responsible for radon entry into the building is advection (Mishra and Ramu 1988). This advection is driven by the pressure differential between the area covered by the building (the shell) and the ground around the foundation, produced by the higher temperatures within the shell, mechanical ventilation, and to some degree also by wind blowing on the building. The permeabilities of both the building foundation and the adjacent earth highly influence the effectiveness of the pressure differential in pulling radon-loaded soil gas through the foundation. Wind and atmospheric pressure fluctuations can also represent an important mechanism of radon entry (Riley et al. 1996, Robinson et al. 1997). Once radon is in the indoor environment, the inhabitants are exposed to ionizing radiation from both radon and its decay products. The evidence available in the literature indicates that humans receive radiation doses exceeding fifty percent (50%) of the total dose from natural sources as a result of inhaling radon and thoron gases and their daughters (UNSCEAR, 2000). Whenever radon is inhaled, its progenies get deposited in the lungs which in turn receive a dose from alpha particles emitted during the following decays (Figure 1). The internal exposure of the lungs to ionizing radiation from short-lived decay products of radon is known to be a cause of lung cancer (NAS, 1988; UNSCEAR, 2006). Therefore, investigating the level of radon in the soil is imperative due to its radiological effects. Studies have shown that ^{222}Rn measurements in soil gas can be used as a method of assessing the possibility of elevated indoor ^{222}Rn concentrations (Markkanen and Arvela, 1992; Iskandar, et al., 2005). Other studies by Varley and Flowers (1992) and Sundal et al. (2004) also reported the usefulness of soil gas radon data in determining levels of indoor radon. In addition, the USEPA (1993) and Neznal et al. (2004) have recommended the use of indoor radon measurements or soil gas radon concentration measurements to identify radon-affected areas.

Investigation of soil radon emanation potential in Dodoma and the surroundings is necessary for two main reasons: the first one is the proximity of Dodoma to Bahi and Manyoni areas where commercially viable uranium deposits have been discovered in recent years and; the second one is the ongoing rapid expansion of human settlements in Dodoma which warrants radiological safety assessment in the proposed and existing residential areas. Therefore, the aim of this research is to investigate radon concentrations in soils of Dodoma, Central Tanzania for the purpose of categorizing areas and highlighting the potential for elevated indoor radon concentrations. To the best of the author's knowledge, no study has determined radon levels in soils of Tanzania, and Dodoma in particular.

^{238}U (4.5 x 10^{9}y) → ^{234}Th (24.1 d) → ^{234}Pa (1.17m) → ^{234}U (2.47x 10^{5}y) → ^{230}Th (8 x 10^{4} y)
↓
^{214}Po (180µs) ← ^{214}Bi (19.7m) ← ^{214}Pb (26.6m) ← ^{218}Po ← **^{222}Rn (3.8d)** ← ^{226}Ra (1622y)
↓
^{210}Pb (22.3y) → ^{210}Bi (5.01d) → ^{210}Po (138.4d) → ^{206}Pb (stable).

Figure 1: Uranium – 238 decay series

MATERIALS AND METHODS

Description of the study area

Dodoma City shown in Figure 2 is located at latitude 6° 9' 40.2624'' S (-6.161184) and longitude 35° 44' 43.5336'' E (35.745426). The elevation of Dodoma is 1,120 meters above sea level and is characterized by two distinct seasons; wet and dry. The area receives an average of 610 mm of rainfall per annum mostly during its wet season between December and April. Generally, the

City experiences a dry season during the remainder of the year. It is the capital of the Dodoma Region and the capital of Tanzania. It is located in the centre of the country, approximately 480 kilometres inland from the Indian Ocean coast and about 441 km south of Arusha. It is approximately 259 kilometres north of Iringa via Mtera Hydropower Station. For easy access and convenience, the study was conducted along main roads leading to Singida, Arusha and Iringa (Figure 2).

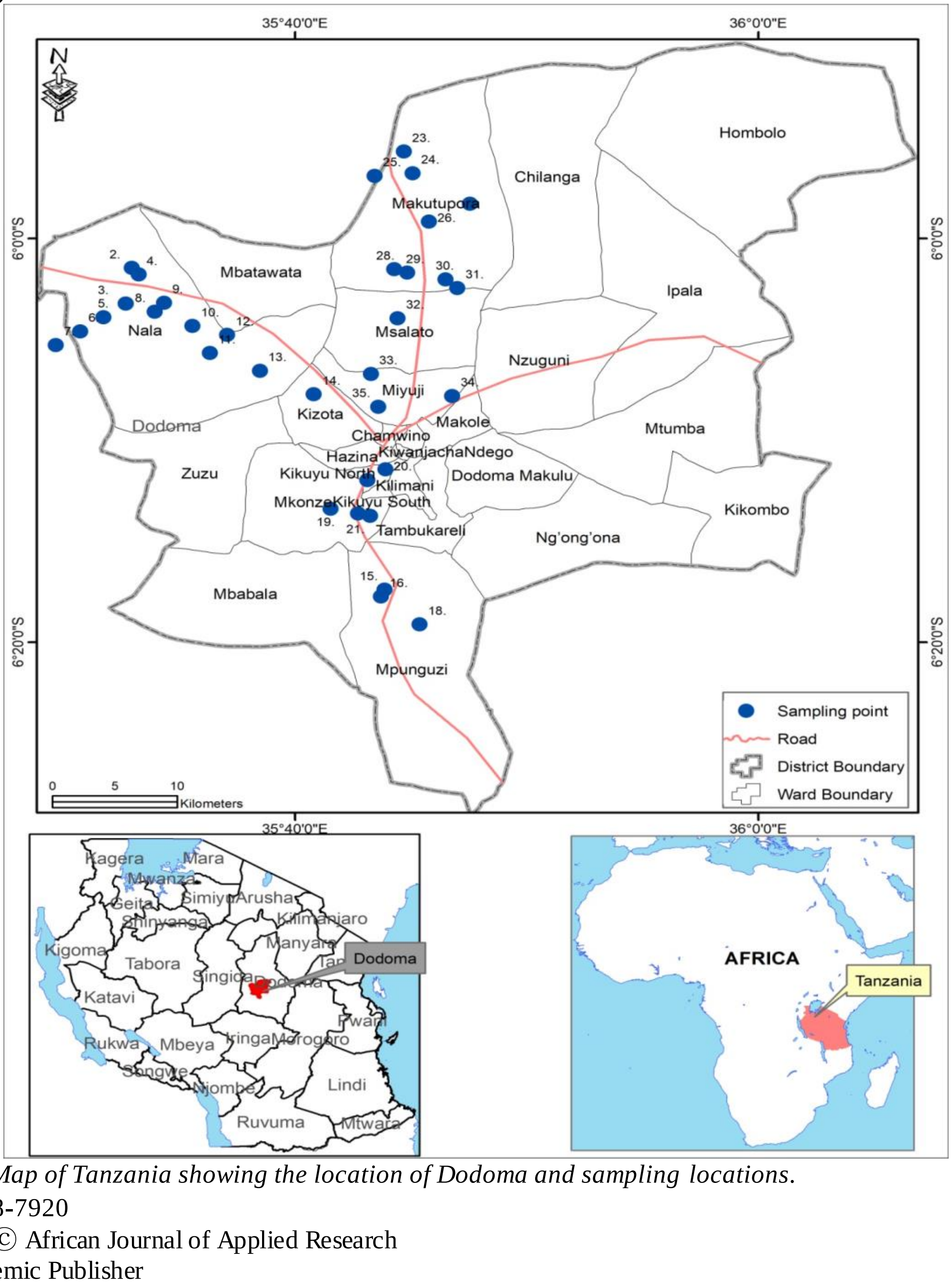

Figure 2: Map of Tanzania showing the location of Dodoma and sampling locations.

Experimental set up and radon measurement

Radon emanation from soils was investigated using a professional radon gas monitor (Alpha GUARD) coupled with an alpha-pump and soil-gas probe (Figures 3 – 4). AlphaGUARD is a portable equipment, either battery or main-operated radon monitor with high sensitivity and fast linear response at 2 to 2000000 Bq.m^{-3}, outstanding accuracy and high storage capacity (Saphymo, 2014). The accessories for soil gas measurements consist of a soil gas probe with an exchangeable drilling tip with an air-lock which is closed by a rivet and capillary probe. The procedure described in Kunovska et al. (2013) and Koray et al. (2014) was used during this work. Briefly, the soil gas probe was inserted into soil to a depth of approximately one meter (1m) with the aid of a heavy hammer. Removal of a rivet was achieved by inserting the capillary probe into the drilling rod and pushing it forward to hit the rivet letting the opening for sucking the soil gas free. Air sucking from the ground was done for ten minutes using the alpha pump connected to the AlphaGUARD through a capillary tube containing progeny filter stops. While sucking, the air was simultaneously forced into the chamber of the alpha GUARD where detection and quantification of radon were triggered. Shown in Figure 3 are the alpha pump, AlphaGUARD, soil gas probe, rivet, capillary probe, and heavy hammer used in the experimental set-up. The measuring mode of AlphaGUARD was selected at “1 min FLOW”. Pumping was done for approximately 10 min whereby both radon-222 (half-life = 3.8 days) and thoron-220 (half-life = 55 seconds) were collected. In order to determine only ^{222}Rn concentration, AlphaGUARD and probe were separated and the chamber was kept tightly closed from all sides for approximately 10 min, the time needed for thoron-220 to decay. After initial growth, the concentration became stabilized and therefore, the average of the last five stabilized values were taken as radon concentration in soil gas. One measurement was taken from each sampling location. Also, the environmental conditions (pressure, temperature and humidity) were recorded in each measurement cycle but their effect on radon emanation was not investigated during this study.

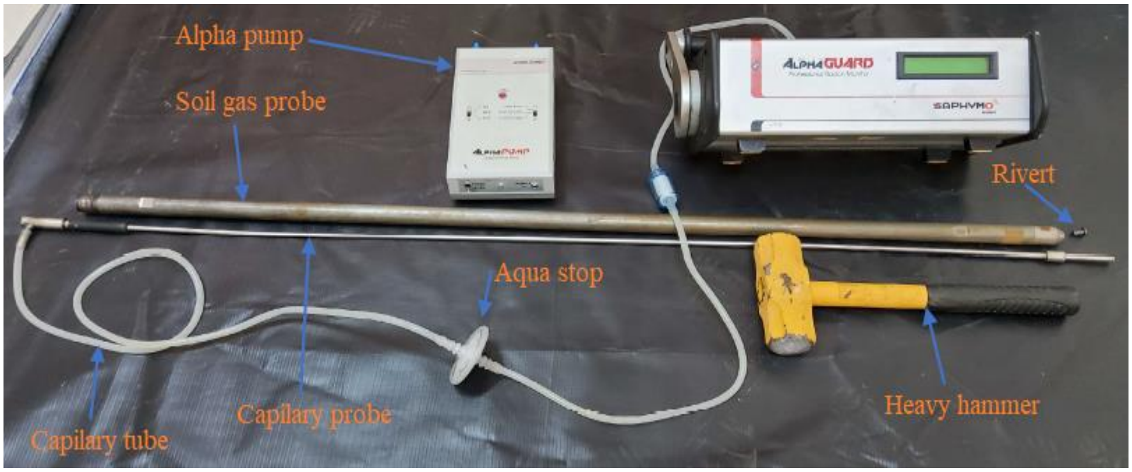

Figure 3: Rivet, capillary probe, heavy hammer and the tube used in the experimental set up.

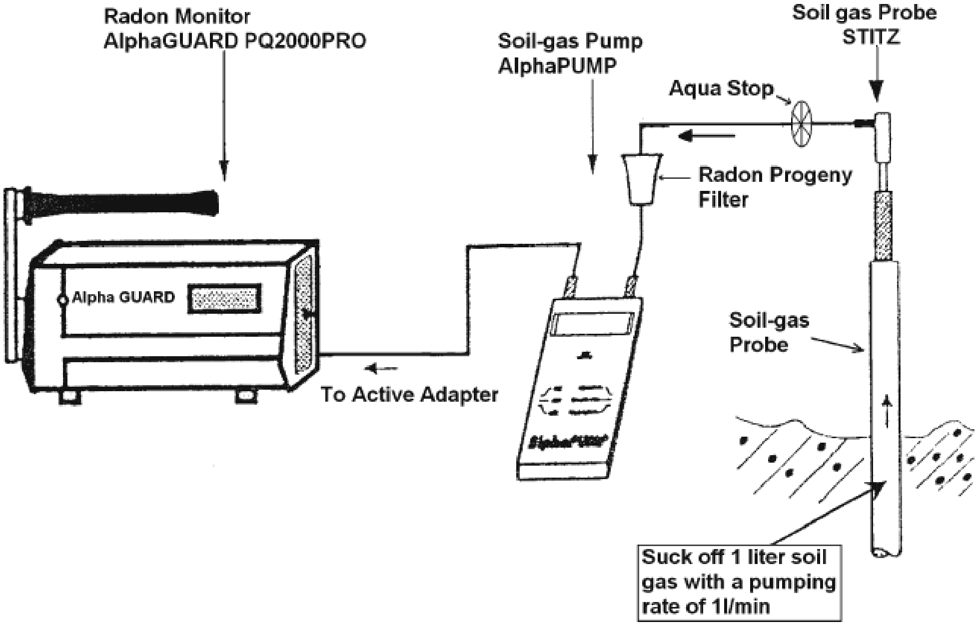

Figure 4: Equipment set up for measuring radon in soil gas (Saphymo, 2014)

RESULTS

Results of radon concentrations in soils from the environs of Dodoma City, Central Tanzania are presented in Table 1. These results were interpreted and compared with published works related to the radon risk criterion as detailed in the discussion section. Results were also compared with

Swedish and the Czech Republic risk criteria for area classification purposes as shown in Table 2.

Table 1: Sampling locations, radon concentrations (kBq.m^{-3}) and ambient conditions.

Sampling location	**Radon levels (kBq.m^{-3})**	**Temperature (^{o}C)**	**Pressure (mbar)**	**Relative Humidity (% rH)**
1.	27.3 ± 1.1	27	864	62
2.	233.5 ± 8	26	906	73
3.	80 ± 3.4	30	909	58
4.	47.4 ± 2.1	29	912	61
5.	109.4 ± 4.2	33	899	53
6.	127.2 ± 4.8	24	899	79
7.	69.6 ± 5.5	28	893	66
8.	72.4 ± 3.0	31	888	56
9.	67.3 ± 2.8	38	884	42
10.	40.7 ± 2.1	33	887	49
11.	46.9 ± 2.9	37	891	41
12.	132.5 ± 4.9	27	882	73
13.	122.9 ± 4.9	32	881	52
14.	32.9 ± 2.3	33	881	46
15.	78.2 ± 2.9	33	889	55
16.	46.7 ± 2.1	26	887	75
17.	21.1 ± 3.3	33	884	45
18.	25.5 ± 3.5	35	882	39
19.	33.6 ± 3.3	33	880	46
20.	76.8 ± 3.5	30	898	56
21.	139.1 ± 5.0	34	897	52
22.	61.7 ± 2.3	37	892	44
23.	36.7 ± 2.5	36	894	41
24.	61.6 ± 2.4	37	892	39
25.	82.6 ± 3.2	42	889	33
26.	119.3 ± 4.3	25	886	64
27.	51.2 ± 2.2	29	894	61
28.	56.2 ±2.2	31	894	56
29.	49.3 ± 2.1	33	891	45

Sampling location	**Radon levels (kBq.m^{-3})**	**Temperature (^{o}C)**	**Pressure (mbar)**	**Relative Humidity (% rH)**
30.	67.1 ± 3.5	31	880	58
31.	35.2 ± 5.1	36	896	47
32.	18.8 ± 3.2	35	888	32

Table 2: Comparisons of results with Swedish and the Czech Republic risk criterion

Country	^{222}Rn concentrations in the Soil Gas (kBq.m^{-3})	Risk class	Frequency	Percentage
Sweden	< 10	Low	0	0
	10 – 50	Normal	13	41
	> 50	High	19	59
Czech Republic	<10	Low	0	0
	10 – 35	Medium	4	12
	>35	High	28	88

DISCUSSION

From Table 1, it is evident that radon concentration in soils ranged from 18.8 kBq.m^{-3} (location 32) to 233.5 kBq.m^{-3} (location 2) with the mean value of 71 kBq.m^{-3} and a standard deviation of 45 kBq.m^{-3}. Results show wide variability of radon concentrations in soils which may indicate that there is high variability in the naturally occurring radioactive materials (NORMs) content in the soil. It may also indicate high variability in the characteristics of the parent soil material as reported by Cinelli et al. (2014). Various health and environmental protection agencies have established radon risk classification of soils. In Sweden for example, soil radon concentrations are grouped as <10 kBq.m^{-3}, between 10 kBq.m^{-3} and 50 kBq.m^{-3} and > 50 kBq.m^{-3} for low, medium and high risk, respectively. In this case, there is no special construction requirement for low-risk areas. However, “radon protective” construction and “radon safe” construction is required for areas classified as normal and high risk, respectively (Duval, 1993; Esan et al. 2020). In the Czech Republic, radon levels are classified as <10 kBq.m^{-3}, between 10 and 35 kBq.m^{-3} and > 35 kBq.m^{-3} for low, medium and high risk, respectively (Neznal et al. 2004, Neznal and Martin 2005, Alonso et al. 2019). Comparisons of results with the Swedish and the Czech Republic risk criterion are presented in Table 2.

Results of radon concentrations measured in this study revealed that 41% of the assessed areas were within the normal risk areas (10 – 50kBq.m^{-3}). They also show that 59 % of sampling points fall within high radon risk areas (> 50kBq.m^{-3}) based on the Swedish risk criterion. Further analysis shows that 12% of the sampling points fall within medium risk (10 – 35 kBq.m^{-3}) and 88% fall within the high-risk category (> 35 kBq.m^{-3}) based on the criterion set by Zchec Republic. Despite of slight difference between the Swedish and Zchec criterion, both agree that no sampling point (0%) can be classified as a low-risk area. Similarly, the estimated mean radon concentration (71 kBq.m^{-3}) put the soils of the surveyed areas into a high-risk category based on >50 kBq.m^{-3} and > 35 kBq.m^{-3} for criterion set by Swedish and Zchec Republic, respectively (Table 2).

In a study by Dogjani and Reci (2014) in Albania, all radon values exceeded 10kBq.m^{-3} meaning that no surveyed areas were in the low-risk class which is also the case in this study. Dogjani and Reci (2014) showed that 20% of sampled places had radon concentrations between 10 and 30 kBq.m^{-3} which is higher than 12% obtained during this study. Similarly, results reported by Dogjani and Reci (2014) indicate that 55% of sampled areas can be classified as high-risk areas (> 50 kBq.m^{-3}) which is somewhat less than 59% obtained in this study based on the Swedish risk criterion. For further comparison, a study by Esan et al. 2020 in Nigeria indicated that 34% of the assessed areas were of high radon risk based on Swedish risk criteria, thus justifying radon protective actions. Also, a study by Lara, et al. (2011) in Brazil revealed that 11% of the radon in soil gas measurements points were above the level of 50 kBq.m^{-3} and as stated by Swedish criterion, the corresponding soils were classified as "High-Risk Range", where the constructions require protective measures against radon.

Nevertheless, it is possible for areas considered as low risk to have indoor radon concentrations above the reference level and vice versa as reported by Nuhu et al. (2021). This is because of variability in many soil's physical parameters such as permeability, grain size, porosity, emanation coefficient, the internal structure of the soil, and weather factors such as air temperature, air pressure, etc. as described in Hubbard and Hagberg (1996); Mazur et al. (1999); Aburnurad and Tamimi (2001); Neznal and Martin (2005); Sun et al. (2012)., Alonso et al.(2019) and Thu et al. (2020). Since data on soil gas radon in Tanzania are scarce or missing, comparison with other studies conducted in Tanzania was not possible.

CONCLUSION

In conclusion, it is well known that radon is the biggest contributor to human radiation exposure from natural sources and that radon is the second largest cause of lung cancer after smoking. Also, it is well documented that radon exposure is more pronounced in confined places such as underground mines and indoor and that there exists a strong relationship between high indoor radon levels and high radium concentration in the local rocks. Therefore, an assessment of radon levels in soil gas in Dodoma City, Central Tanzania was necessary in order to establish preliminary data on radon in soil gas.

The author acknowledges that there are some limitations associated with this study. A major limitation is the small number of measured points which creates the need for a follow up study covering a wider area. Despite this limitation, this study has provided preliminary radon concentrations in the soils of Dodoma City which can assist in lessening radon-related risks.

Also, the study has pointed out the potential of the source of radon and can serve as a necessary tool for radon mitigation planning. In addition, this study has demonstrated an approach for measuring radon in soil gas, which is beneficial to current and future researchers, environmentalists and regulators, among others.

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Disclosure Statement

The author has no conflict of interest connected with this work.

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