Journal of Information Systems Engineering and Management
2025, 10(34s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Investigation of Radon Gas Concentration and its Implications on Human Health, in Hawassa Town, Ethiopia

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ARTICLE INFO

Received: 29 Dec 2024

Revised: 12 Feb 2025

Accepted: 27 Feb 2025

ABSTRACT

This study is to investigate the radon concentration and associated health impact in randomly selected dwellings and offices, in Hawassa town, Ethiopia. The measurement is conducted in twenty five homes and fifteen offices for seven days in each room, from May to December 2024. Using a Digital portable radon detector the short-term average radon concentration data is collected and analysed.

The measured indoor radon concentration varies from 76.9 $Bqm^{-3}$to 304.2 Bqm^{-3}, and the mean of these data is 173.78 Bqm^{-3}. The minimum, maximum, and mean annual effective dose rates are 1.94 $mSvy^{-1}$, 7.67 $mSvy^{-1}$, and 4.38 $mSvy^{-1}$ respectively. Excess Lifetime Cancer Risk ranges from a minimum value of 0.007 to a maximum value of 0.026, with an average value of 0.015. The collected data is compared with national and international studies and recommendations by different organizations. Most of the values are above the recent recommendation by the World Health Organization (100 Bqm^{-3}). The findings indicate the need for awareness creation, radon-level mitigation, and further study.

Keywords: Radon Concentration, Annual Effective Dose Rate, Excess Lifetime Cancer Risk, Digital Radon Detector, Health Impact, Radon Mitigation

INTRODUCTION

Radon is a radioactive gas that is created from the decay of Radium. It is the component of the radioactive Uranium decay chain that ends with stable lead. It is heavier than air and should remain in the basements. However, the difference in temperature of the air molecules inside and outside the buildings allows radon gas to enter houses through cracks in the floors, leaks around sewage pipes, and structural gaps in the buildings. Radon is a major component of natural background radiation to which human beings are exposed and it exists everywhere in our environment. When Radon gas (Rn-222) is inhaled, its decay products Polonium (^{218}Po), Bismuth (^{214}Bi), and Lead (^{214}Pb) will be attached to the respiratory organs and cause decay. This decay process emits ionizing Alpha radiation, which can damage respiratory organ tissues. In a long time, this damage results in an increase in the risk of lung cancer. For this reason, Radon is known as the leading cause of lung cancer after smoking.

Radiation is energy in a wave or particle form, which travels through a vacuum or a material media. Electromagnetic waves such as Radio waves, Microwaves, Light, and X-rays are good examples of radiation as a wave. Alpha emission, Beta emission, and Neutron emission are radiations in particle form. We all are exposed to radiation daily throughout our lives from natural sources (such as cosmic radiation from space, terrestrial radiation from the ground, inhalation of air, ingestion of food and water) as well as artificial sources (from industry, medical equipment, electronic device)(ICRP, 2018). Radiation can be utilized in medicine, industry, and research in various ways when used correctly. However, a high dose of radiation can damage cells and tissues. These radiations are categorized into two: ionizing and non-ionizing radiations. As its name indicates, the former radiation carries high energy that can release electrons and ionize atoms at the molecular level.

In contrast, radiations that do not ionize atoms are unable to do so because they lack enough energy. Some of the common sources of ionizing radiation are cosmic rays, radioactive elements, medical equipment, and nuclear tests. Radioactive elements are the primary sources of natural background radiation to which humans are exposed. Radon gas covers the major portion of this radiation(Nations et al., 2001).

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This paper emphasizes measuring the amount of Radon gas, in some randomly selected residential houses and Hawassa College of Teacher Education offices in Hawassa town, Ethiopia, and compares the results with other studies.

Radon is naturally produced radioactive inert gas that is not distinguished by human sense organs due to its colourless, odourless, and non-smelling properties (Demewoz, 2017). Radon (Rn) is the heaviest gaseous element with atomic number 86 and atomic mass 222. It is located in group 18 and period 6 in the modern periodic table with noble gases. Radon (^{222}Rn) is the direct result of natural radioactive Radium (^{226}Ra) decay, that leads to Alpha radiation emission. Radium (^{226}Ra) is a member of the Uranium (^{238}U) decay chain that exists in the soil, building materials, underground water, and rocks. From many isotopes of Radon, the three naturally available isotopes are Radon, Thoron, and Actinon with symbols (^{222}Rn), (^{220}Rn), and (^{219}Rn) correspondingly, which are the natural decay chain of the natural radio nuclides Uranium (^{238}U), Thorium (^{232}Th), and Uranium (^{235}U) respectively. Of the three isotopes of Radon, ^{222}Rn is the highest stable isotope with a half-life of 3.82 days (Tamiru Beshah & Dagne Muhe, 2020). The remaining Radon isotopes are short -lived and live for limited periods. Therefore, Radon is not a stable element and it undergoes radioactive decay that results in other short-lived radioactive decay products called radon progeny. Alpha, Beta, and Gamma radiations are emitted during the radioactive decay and this transformation continues until stable ^{206}Pb (Lead) is obtained. From radon progeny, Alpha emitters, Polonium (^{218}Po) and Lead (^{214}Pb) cover 90% of radiations from radon exposure. These radiations, which are ionizing, affect the health of humans. In general, radon covers 55% of the background ionizing radiations of the environment and it is identified as a health hazard to humankind(WHO, 2009).

Radon can enter homes and offices through fractures in surfaces and walls, construction gaps, openings around service water pipes, hollows within walls, and water during showering and washing. When Radon gas is inhaled with air, it undergoes radioactive decay inside respiratory organs and produces solid radioactive elements called radon progeny or decay products. These decay output include isotopes such as polonium -218, polonium-214, and lead-214. These solid particles can lodge in the lungs and emit ionizing alpha particles that can damage lung tissues. This damage increases the probability of facing lung cancer over time, especially with long exposure to high levels of radon concentration. Hence Radon is known as the most common origin of lung cancer in people who are smoking and the primary cause of cancer disease from non-smokers with an estimated 3% to 14% of all cancer cases (WHO, 2009). The percentage of cancer cases depends upon the amount of radon concentration and the duration of exposure. Therefore, the impact varies from country to country and even from place to place depending upon the geology of the environment, the living style of the people, and the climate condition.

This study was conducted in Hawassa, a town in Sidama regional state in the southern part of Ethiopia. The primary data sources were some randomly selected residential houses and Hawassa Teacher Education College offices. Most of the residents of Hawassa spend their time in indoors, therefore, measuring and evaluating the level of radon in dwellings and offices is an appropriate methodology to find the direct health impact as a result of radon gas. Radon concentration is determined using the Alpha spectroscopy method with a portable digital radon detector, and the physical quantities associated with it are derived from the data collected.

1. Annual Effective Dose

The accumulation of radon gas and total exposure are the two factors that determine the annual effective dose rate inhaled by the population, as provided by (Aswood et al., 2022)

$$D_{Rn} = C_{Rn} \times F \times O \times T \times DCF$$

Where,

C_{Rn} is the total Radon concentration (Bqm^{-3})
D_{Rn} is the annual effective inhalation dose(mSv/y)
F is called the equilibrium factor, which is the ratio of Radon progeny to Radon and is equal to 0.4
O stands for indoor occupancy factor, which is the proportion of time spent in the area = 0.8
T exemplifies the indoor occupancy time in a year that is 24h × 365d = 8760h per year
DCF is Dose Conversion Factor / 9×10^{-6} $mSvh^{-1}$ per Bqm^{-3} (Al-Khalifa & Aood, 2014)

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2. Excess Lifetime Cancer Risk /ELCR

It is a measure applied to predict the increased probability of people developing cancer over their age due to exposure to radon and is given by (Aswood et al., 2022)

$$ELCR = D_{Rn} \times LE \times RF$$

The symbols represent:

D_{Rn} stands for the annual effective inhalation dose rate
LE is an abbreviation for the life expectance of an individual (according to a WHO report in 2024 for both sexes the average value is 67.3 years for Ethiopia)
RF is a risk factor (5×10^{-4}/WLM) (ICRP, 2018)

MATERIALS AND METHODS

A. Study area

Hawassa Town

Hawassa is a town that serves as the administration centre of Sidama regional state, which is located on the eastern side of Lake Hawassa. The town got its name from the Lake Hawassa, which is found in the Great Rift Valley. The distance from the capital city of Ethiopia, Addis Ababa, to Hawassa town, is 273km, to the south. The town has a latitude of 7°3'N and a longitude of 38°28'E with an elevation of 1708 meters above sea level. The total population is estimated to be 577075 with a density of 5200 per square kilometer (Ethiopian Statistics Agency, 2003). Throughout the year temperature varies from 54 °F to 87 °F and is rarely below 49 °F or above 92 °F.

Figure 1 below shows the Geographical map of Hawassa Town

Fig1. Geographical location of the study area

B. Methodology

The Radon gas accumulations in some randomly chosen resident houses and offices of Hawassa Town are measured with the Alpha spectrometry method. For this purpose, a passive radon diffusion chamber with an accuracy of 5% ± 0.14 pCi/L is implemented.

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Fig 2 Portable digital Radon concentration measuring device

The portable digital Radon detector is placed at a half meter above the ground, and one and a half meters away from the doors, windows, or air ventilation. The detector is kept in one place in the room for 7days and the short-term average value is obtained from the screen display. The same procedure is followed to measure Radon(^{222}Rn) concentrations in all the sample rooms that are randomly selected.

The measurement were carried out in summer (rainy season in Ethiopia), which typically spans from June to November. During this time, most parts of the country experience heavy rainfall, particularly in the southern part of the country.

RESULTS AND DISCUSSIONS

The measured amount of the gas in randomly picked living rooms in resident houses and offices in Hawassa town and the corresponding calculated values of annual effective dose rate and Excess lifetime cancer risk percentage are summarized in Table 1. The concentration of the radon values varies from 76.9 Bq m^{-3} to 304.2 Bq m^{-3} with a mean value of 173.78 Bq m^{-3}, which is within the recommended values of ICRP(Harrison & Marsh, 2020) but the mean value of 173.78 Bq $m^{-3}$is more than the recommended level 100 Bq $m^{-3}$by World Health Organization (WHO, 2009). From the data collected more than 80% of the level of radon is above and less than 15% is below the action level of WHO. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000), the data depicted in Table 1 shows that in all the dwellings and offices the measured radon concentration is more than the world mean level of 40 **Bqm^{-3}.** The average concentration of Radon calculated (173.78 Bq m^{-3}) disagrees with the United States of America Environmental Protection Agency action level (148 Bq m^{-3})(EPA, 2003). About 38% of the measured Radon concentration is above and around 62% of the data collected is below EPA recommendations.

Table1. The radon level, annual effective dose rate, and excess lifetime cancer risk values in randomly selected dwellings and offices of Hawassa town, Ethiopia.

Sample Number	Sample house	Level	Short-term average of C_{Rn} (Bq/m^3)	Annual effective dose(mSv/y)	Excess Lifetime Cancer Risk/ELCR (%)
1	Living room	G + 0	267	6.74	0.023
2	Living room	G + 0	98.4	2.48	0.008
3	Living room	G + 0	174.8	4.41	0.015
4	Living room	G + 0	241	6.08	0.020
5	Living room	G + 0	175.3	4.42	0.015
6	Living room	G + 0	83.5	2.11	0.007
7	Living room	G + 0	302.6	7.63	0.026
8	Living room	G + 0	164.9	4.16	0.014
9	Living room	G + 0	204	5.15	0.017

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10	Living room	G + 0	128.4	3.24	0.011
11	Living room	G + 0	149.2	3.76	0.013
12	Living room	G + 0	267.3	6.74	0.023
13	Living room	G + 0	109.5	2.76	0.009
14	Living room	G + 0	93.7	2.36	0.008
15	Living room	G + 0	138.2	3.49	0.012
16	Living room	G + 0	188	4.74	0.016
17	Living room	G + 0	153.8	3.88	0.013
18	Living room	G + 0	76.9	1.94	0.007
19	Living room	G + 1	183.2	4.62	0.016
20	Living room	G + 1	217	5.47	0.018
21	Living room	G + 1	231.7	5.85	0.020
22	Living room	G + 1	164.9	4.16	0.014
23	Living room	G + 1	148.2	3.74	0.013
24	Living room	G + 1	204.7	5.16	0.017
25	Living room	G + 1	104.8	2.64	0.009
26	Office	G + 1	127	3.20	0.011
27	Office	G + 1	96.2	2.43	0.008
28	Office	G + 0	304.2	7.67	0.026
29	Office	G + 2	139.5	3.52	0.012
30	Office	G + 1	156	3.94	0.013
31	Office	G + 0	194	4.89	0.016
32	Office	G + 0	273	6.89	0.023
33	Office	G + 1	152.8	3.85	0.013
34	Office	G + 2	197.5	4.98	0.017
35	Office	G + 2	136.4	3.44	0.012
36	Office	G + 1	218.8	5.52	0.019
37	Office	G + 0	247.4	6.24	0.021
38	Office	G + 0	187	4.72	0.016
38	Office	G + 1	142.8	3.60	0.012
40	Office	G + 1	107.4	2.71	0.009
	Minimum Value		76.9	1.94	0.007
	Maximum value		304.2	7.67	0.026
	Mean Value		173.78	4.38	0.015

The calculated yearly effective dose rate ranges from 1.94 **mSvy**$^{-1}$ to 7.67**mSvy**$^{-1}$ with a mean value of 4.38 **mSvy**$^{-1}$ that is also within the recommended value (3 **mSvy**$^{-1}$ –10 **mSvy**$^{-1}$) by the International Commission on Radiological Protection (ICRP, 1993). Calculated percentages of Excess Life Time Cancer Risk also vary between the lowest 0.007 to the highest 0.026 with an average of 0.015. Even though the average value of ELCR is within the recommendation of ICRP, some measurements are above and below the action level.

The data summarized in Table 1 shows a direct relationship between Radon concentration and annual effective dose rate. Moreover, there is a positive correlation between Radon gas accumulation and excess lifetime cancer risk. That means, when Radon concentration increases, the possibility of having lung cancer also increases. Therefore, it is crucial to control the level of Radon concentration by taking different actions.

Some studies have been done in different towns in the country, Ethiopia, and the findings are summarized in Table 2. The minimum concentration of Radon (12.24 Bq/m^3) is measured in Debresina whereas the maximum value (708.12 Bq/m^3) is registered in Wolayita Sodo. The average concentration in all seven studies agrees with the International Commission on Radiological Protection recommendations (below 300 Bqm^{-3}). Calculated mean value of all seven studies, which could be taken as the average value in the country, is also within the upper limit by ICRP.

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Table 2: The comparison of minimum, maximum, and mean values of Radon concentrations in some towns in Ethiopia.

Study area	Minimum level (Bq/m3)	Maximum level (Bq/m3)	Mean value (Bq/m3)	Author
Axum	39.00	116.00	76.30	(Assefa & Bhardwaj, 2020)
Lalibela	52.45	353.95	140.64	(Demewoz, 2017)
Debresina	12.24	251.94	102.87	(Tamiru Beshah & Dagne Muhe, 2020)
Debremarkos	98.70	392.75	217.01	(Megbar & Bhardwaj, 2014)
Fiche salale	44.40	240.50	135.88	(Demewoz, 2017)
Wolayita Sodo	30.78	708.12	236.72	(Maregu et al., 2019)
Hawassa	88.80	192.40	139.89	This study
Mean	52.34	322.24	149.90	

From the findings in Table 2, only the Mean concentration obtained in Axum (76.30 Bq/m3) is within the recommended value (100 Bq/m3) by the World Health Organization (WHO, 2009). The rest six studies and the average of the seven studies are above the action level by a WHO. This shows the need for action to be taken to mitigate the Radon concentration in the country. Moreover, there is no Threshold lower limit for Radon concentration, which is safe for human beings.

There are so many reasons behind the difference in Radon gas accumulation obtained in different towns in the country. Some of the possible factors are, the type of device used to measure the Radon concentration, the total time given, the geographical location of the study area, the season in which data is collected, the type of materials used to build the dwellings, the living style of the people, the ventilation type and access, etc.

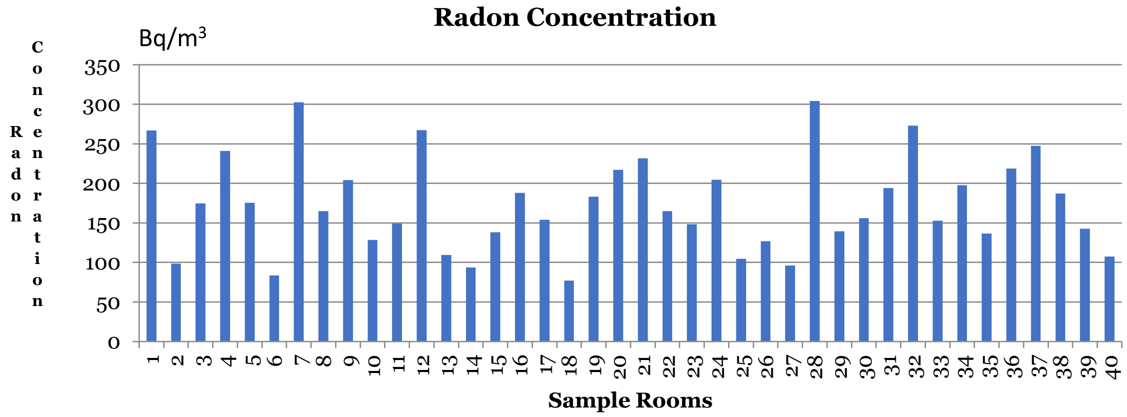

Fig 2 A bar graph of Sample rooms and their corresponding Radon Concentration in Hawassa Town, Ethiopia.

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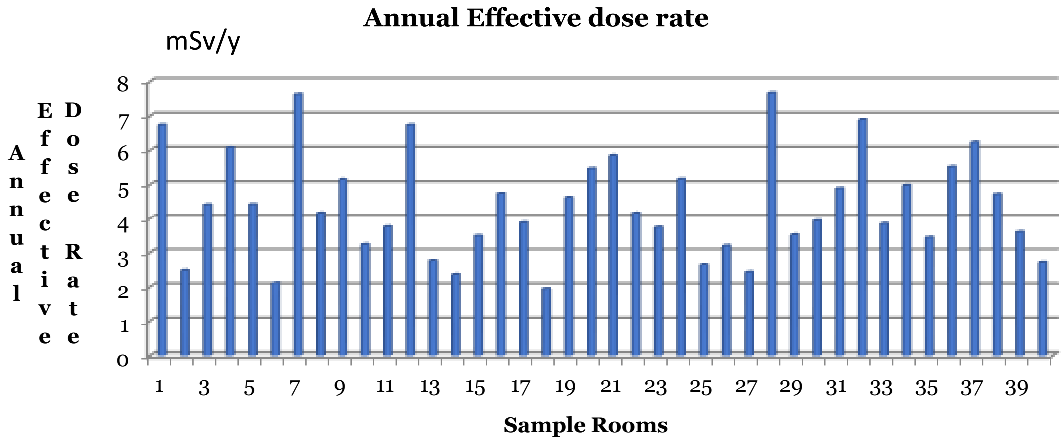

Fig 3 A bar chart of the Annual Effective Dose Rate in Sample Rooms in Hawassa Town, Ethiopia.

The Radon concentration action level set by different organizations and countries is listed in Table 3.

Table 3 Radon Action level set by different organizations and countries.

Organization or country	Radon Action level in Bq/m^3	Year set	remark
USA (USEPA)	148	1988	
WHO	100	2009	If 100Bq/m^3 is not achievable, it has to be less than 300 Bq/m^3
ICRP	100 - 300	2011	
UK	200		The target is 100 Bq/m^3
Ireland	200	2007	
Canada	200	2007	
India	200		residential
	400		workplace

CONCLUSION

The findings of the study prevail the accumulation of Radon gas beyond the action level set by WHO and its health implications in the dwellings and offices of Hawassa Town. The results show variations in the concentration of Radon, the corresponding annual effective dose, and Excess Lifetime Cancer Risk from house to house. This difference could be due to the quality of ventilation used, the type of materials used to build the house, the age and geographical location of the house, the lifestyle of the residents, etc. Even though, the average Radon concentration (173.78Bq/m^3), and mean annual effective dose rate (4.38mSv/y) of the findings are within the action level of some global organizations, like ICRP. There is no lower limit Radon concentration value, which is safe to live in. Therefore, the population has to be aware of the problem and take action to control the level of Radon concentration. In general, the findings reveal the need for awareness creation and further studies throughout the country.

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The author(s) hereby declare that no generative AI technologies, including but not limited to large language models (LLMs) and text-to-image generators, have been employed at any stage of the writingor editing process of this manuscript. This assertion applies to the entire development of the work, from the initial drafting through to its final revisions, ensuring that all content is the product of human effort, intellectual engagement, and manual input. The author(s) affirm that the ideas, language, and structure have been crafted without assistance from any artificial intelligence tools designed for content generation, modification, or enhancement.

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