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Radon concentration and effective doses in farm soil of Rustenburg, South Africa

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► ***Short Report***

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ABSTRACT

Background: Radon, a naturally occurring radioactive gas, and the most significant contributor to human exposure from naturally ionizing radiation sources, accounting for over half of the total dose. ***Material and Methods:*** In the present work, radon concentrations in soil were measured using an AlphaGUARD portable detector, and the corresponding effective doses to humans were estimated in accordance with ICRP recommendations. ***Results:*** The measured concentrations ranged between 129.53±31.75 and 659.60±68.24 Bq/m³, with an average of 363.61±54.64 Bq/m³, while the estimated annual effective doses range from 8.82 to 44.93 mSv/yr, with a mean of 24.77 mSv/yr. Observed radiological indices are significantly above the recommended value of 10 mSv/yr by the World Health Organization and the International Commission on Radiological Protection, indicating a significant radiological risk. ***Conclusion:*** The study highlights the significance of continuous radon monitoring and recommends implementing radon mitigation measures to minimize potential radiological hazards. In addition, the findings provide valuable data to support policymaking aimed at reducing radon exposure to as low as reasonably achievable (ALARA) and to guide future monitoring efforts in the study region.

INTRODUCTION

Radon gas and other naturally occurring radioactive materials have emerged as a key area of interest for the International Atomic Energy Agency (IAEA), and they are frequently included in IAEA publications and studies, as well as in European Council directives. Uranium and radium in the Earth's crust decay to produce radon, a naturally occurring radioactive gas known as the heaviest of noble gases [1]. It contained three well-known isotopes (^{222}Rn, ^{220}Rn and ^{219}Rn, with half-lives of 3.82 days, 55.8 seconds, and 3.98 seconds, respectively) from the uranium decay series [2]. Radon and its progenies are the main source of human exposure to natural radiation, contributing about 50% of human exposure to radiation [1, 3]. ^{222}Rn is the major cause of human health risks; it is associated with lung cancer when inhaled as a result of alpha decay, which leaves radon progenies in the lungs [2]. The United States Environmental Protection Agency has associated about 21,000 annual deaths with radon and classifies it as a lung carcinogen in nonsmokers.

Several epidemiology studies have reported radon as the leading cause of cancer, and agricultural sites have been associated with higher exposure risk from exposed soil, irrigation water and other environmental media with accumulated radon [4]. However, its colourless, odourless, tasteless and radioactive nature makes early detection impossible, except with specialized equipment [5]. Radon variation globally depends on the geological, anthropogenic, and mineralogical formations, along with soil composition, compaction, porosity, permeability, emanation capacity of the ground and anthropogenic activities in each region [6, 7]. Soil serves as a medium for radon migration to biological systems, and a major and continuous source to humans, as well as an indicator for future radiation impact assessment and radiation protection [8].

In addition to other environmental factors, such as mining and industrial activities, climatic conditions and soil type, the uranium content of the underlying rock and soil is the primary determinant of environmental radon level [9]. Thus, radon concentration in soil is a direct reflection of the presence of uranium or other radioactive materials in soil. Radon-222 is released from surface soil into the atmosphere, where it further decays to short-lived radionuclides, such as ^{218}Po, ^{210}Pb and ^{214}Bi, that contribute significantly to inhalation dose [10]. This is because radon consists of small solid particles that can be easily inhaled and is capable of emitting high-ionized alpha, beta or gamma radiation, which can interact with biological tissues to induce cancer or other health effects in humans [6].

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Human internal radiation exposure to alpha particles is primarily from radon inhalation and ingestion of alpha-emitting radionuclides such as polonium, thorium, plutonium, and uranium isotopes [11]. Radon and its progeny are renowned carcinogens, with several epidemiological studies and animal data providing information on the health risks associated with inhalation and ingestion of radon (radon-222) [3, 12]. European, North American and Chinese residential case-control studies associate the risk of lung cancer with radon-222 exposure, while the International Commission on Radiological Protection (ICRP) links about 10% of total lung cancers to radon [13, 14]. However, very little information is available on radon concentration and associated health risks in farm soil, especially in mining vicinities, in Africa. Thus, this study aims to assess radon concentration in farm soil sampled from the mining vicinity of Rustenburg, South Africa. This is to provide baseline data for radiological protection against radon exposure in the farming and mining areas of Rustenburg, South Africa.

The discharge and dispersion of mining and industrial waste, including radon gas, radioactive dust, and other radioactive materials, into the environment, such as farmlands and water bodies pose a significant global challenge due to the substantial health risks, they present to both human and animal health. Therefore, this study seeks to estimate the associated health risk due to radon exposure in farm soil, collected in the mining area of Rustenburg, one of the mining cities in South Africa. This is to assess the contribution of radon to the total radiation dose, provide data on radon levels in farm soil, following the reported activity concentration of natural radionuclides in the study area, by Olagbaju, Wojuola [15].

MATERIALS AND METHODS

Study area

The study area is located in Rustenburg, South Africa, where its climate ranges from subtropical to Mediterranean, offering various agricultural opportunities, including crop and animal farming. It is among the countries with the most diverse and comprehensive crop farming systems in Africa. South Africa is also widely associated with mining and industrial activities, resulting in radioactive wastes littered in farmlands and communities [15]. This study was conducted in the farming area of Rustenburg, which is also one of the country's major mining areas. It is also known as the platinum cities, because about 9o% of the country's platinum comes from there. It is also reported to produce more platinum than any other single area in the world.

Measurement method

To estimate radon concentration in the farm soil, soil samples were randomly collected from the farming area of Rustenburg. This is due to the limited internal battery operating time of 8 to 10 hours and the limited access to power for recharging the detector on the farm, as well as concerns about detector security from drought, theft, and danger in the study area. A homogenous composite sample was created by mixing the four samples collected at each sampling location on the farm. A metallic probe attached to the detector was inserted to measure the radon concentration after the sampled soil was air-dried, pulverised and packaged in an airtight tube. An AlphaGUARD 2000 PRQ radon gas analyzer, produced by Genitron Instruments (Germany), was used to determine the concentration of radon in sampled soil. The AlphaGuard is a portable radon detector with an efficiency of 1 cpm at 20 Bq/m^3 and a detection range of 2 to 2,000,000 Bq/m^3. It can be powered directly from an AC power source for instant operation, and it also has an inbuilt battery that can be charged for later and independent use.

In this study, the AlphaGuard was set to continuous flow mode at 10-minute intervals for radon estimation, after the metallic probe had been inserted into the tube containing the soil samples. Radon gas was continuously pumped through the capillary tube to the detector, along with soil gas, using the Alpha pump. In the ionization chamber, a pulse was generated by the alpha particles of radon and its progeny ionizing the air volume through interactions in the electric field. The concentration of radon is precisely proportional to the electric pulse produced by creating equilibrium between radon and its progeny.

Dose estimation

Radiation doses are used to estimate the health risk associated with radiation exposure. Humans are exposed to radon through inhalation of very small, ionized particles from soil and dust. The absorbed dose rate equivalent resulting from exposure to radon in the investigated farm soil is estimated using equation (1):

$$D_{Rn}=C_{Rn}\times D\times H\times F\times T \quad (10)$$

where, C_{Rn} (Bq/m^3) is the mean radon concentration in soil, F (0.6) is the outdoor equilibrium factor, T is the time (8760 hr), H is the outdoor occupancy factor (0.6) and D is the dose conversion factor (9 ×10^{-6} mSvhr^{-1}/ Bqm^{-3}) [16].

The effective dose due to radon exposure from farm soil in (mSv/yr) is the activity that enters the respiratory or gastrointestinal tract from the environment and is calculated using equation (2):

$$H_{Rn}=D_{Rn}\times W_R\times W_T \quad (2)$$

where D_{Rn} is the absorbed dose, W_T is 0.12, which is the tissue weighting factor for the lung and W_R is

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20, which is the radiation weighting factor for alpha particles [3].

The working level (WL) is calculated using equation (3):

$$WL = \frac{C_{Rn} \times F}{3700}, \quad (3)$$

where D_{Rn} is radon concentration in Bqm^{-3}, and F is the equilibrium factor for radon, which has been taken as 0.4, as suggested by [7].

Statistical analysis

Comparative analyses were conducted to determine if radiological indices fall within World Health Organization (WHO) and International Commission on Radiological Protection (ICRP) recommendations.

RESULT

In this study, the annual effective dose and cancer risk associated with radon inhalation in soil, as well as radon concentration, were estimated from measured radon concentrations in farm soils and are presented in table 1. The mean radon concentration of the sampled soil, measured over 24 hours using AlphaGuard, ranges from 659.60±68.24 Bq/m^3 in maize vegetation (MAS) to 129.53±31.75 Bq/m^3 along the mine and road (AMR), with a mean concentration of 363.61±54.64 Bq/m^3. The mean radon concentration was observed to be above 200 Bq/m^3, given by the International Commission on Radiation Protection and below the World Health Organization limits of 100 Bq/m^3 [1, 17]. The variation in radon concentrations across the sites suggests a heterogeneous distribution of uranium and radium in the underlying soils, which is influenced by lithology, soil porosity, and anthropogenic activities such as mining and farming.

The estimated values of working level (WL), annual absorbed dose rate and effective dose rate were also presented in Table 1, and they vary from 14.00 to 71.31, 3.68 mSv/yr to 18.72 mSv/yr, 8.82 mSv/yr to 44.93 mSv/yr with corresponding mean values of 39.31, 10.32 mSv/yr and 24.77, respectively. The mean annual effective dose is observed to be significantly above 10 mSv/yr, given by the International Commission on Radiation Protection in most of the study area [1]. This suggests that populations living and working in the study area are at a high risk of radiological health effects, particularly lung cancer associated with long-term radon inhalation.

DISCUSSION

The results demonstrate that radon concentration varies considerably across the different vegetation plots, reflecting the heterogeneous distribution of uranium content in the soil. This variation can be attributed to differences in land use, soil composition, and proximity to anthropogenic activities. Notably, the elevated radon concentrations observed in farming areas compared to samples along the road may be explained by the farms' proximity to mining zones and industrial waste deposits, which are known sources of uranium and radium. The low concentrations of radon observed in samples along the road could be due to surface erosion, leaching, and other human activities that promote radon dispersion or dilution in roadside soils [18].

Radon concentration in the investigated areas is found to be above the 100 Bq/m^3 and 200 Bq/m^3 given by the World Health Organization and the International Commission on Radiation Protection, respectively [1]. Additionally, radon concentrations in the study area were compared with reported values from other countries worldwide and are presented in table 2. The mean radon concentration in the study area was found to be higher than the values obtained in Pakistan, Libya, Malaysia, Brazil and India. This can be attributed to the variation in the local geology, mineralogy, soil uranium content, climatic conditions and anthropogenic activities in each country [9]. These findings highlight the influence of both natural and human-induced factors on radon levels in soils.

The estimated annual effective dose in the study area is found to be above the recommended safety thresholds of 10 mSv/yr, given by the International Commission on Radiation Protection and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) for exposure due to natural radiation sources [17]. This indicates a potential radiological health concern, particularly for populations with long-term occupational or residential exposure in the affected areas. Thus, the study recommends the need for regular monitoring of radon concentrations in agricultural soils, especially in regions impacted by mining and industrial activity. Mitigation measures such as improved soil aeration, land use planning, and public awareness campaigns are recommended to reduce exposure risks as low as reasonably achievable (ALARA). Also, these results contribute to the global radon database and highlight the impact of various land use and anthropogenic activities on environmental radiation levels.

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Table 1. Radon concentration, effective dose due to radon inhalation.

c	Sample Id	C_{Rn} (Bq/m^3)	m WL	D_{Rn} (mSv/yr)	H_{Rn} (mSv/yr)
Soil from Beetroot plot	BRS	645.74±73.68	69.81	18.33	43.99
Soil from Maize Plot	MAS	659.60±68.24	71.31	18.72	44.93
Soil from Mint plot	MTS	370.39±57.23	40.04	10.51	25.23
Soil from Parsley plot	PSS	264.39±79.73	28.58	7.50	18.01
Soil from Wheat Plot	WTS	275.86±45.46	29.82	7.83	18.79
Soil from Onion Plot	ONS	200.10±37.93	21.63	5.68	13.63
Soil from Leeks Plot	LKS	306.14±43.38	33.10	8.69	20.85
Soil close to mine and road	CMR	420.71±54.33	45.48	11.94	28.66
Soil along mine and road	AMR	129.53±31.75	14.00	3.68	8.82
Minimum		129.53±31.75	14.00	3.68	8.82
Average		363.61±54.64	39.31	10.32	24.77
Maximum		659.60±68.24	71.31	18.72	44.93

Table 2. Average radon concentration in soil from other parts of the World.

Location	Radon Concentration (Bq/m^3)			References
	Minimum	Maximum	Mean	
India	177.5	583.40	330.50	(7)
Brazil	4.00	404.00	69.00	(19)
Malaysia	67.219	295.068	198.44	(16)
Libya	59.30	515.80	325.50	(20)
Pakistan	--	--	261.67	(21)
Study Area	129.53	659.60	338.69	Present study

CONCLUSION

This study investigated soil radon concentrations in the farming areas of Rustenburg, South Africa, using AlphaGuard. The results obtained show radon concentration vary slightly across sampling points due to different land use, soil composition, and proximity to anthropogenic activities. Also, estimated radiological risks are above the recommended values by the World Health Organization and International Commission on Radiological Protection (ICRP), making the study area of radiological concern. The study highlights the significance of continuous radiation monitoring and recommends implementing radon mitigation strategies in the study area. It also provides valuable baseline data that can inform future research, regulatory policies, and long-term monitoring programs aimed at limiting radon exposure, As Low As Reasonably Achievable (ALARA).

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Data availability: The authors confirm that the data supporting the findings of this study are available within the article

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