



Original Article



Indoor Radon in Larijan Buildings Affected by Geological Characteristics

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Abstract

Background: The decay of uranium and thorium is the primary source of radon emissions, a radioactive gas. The transfer and accumulation of this gas indoors pose serious health risks.

Methods: This study investigated indoor radon concentrations in buildings located in areas with different geological characteristics. Thirty-six buildings were examined across three locations in Larijan, Iran, with samples collected from living rooms and bedrooms over a three-month period.

Results: The average radon concentrations in bedrooms and living rooms were 114.40 Bq/m³ and 128.35 Bq/m³, respectively. Indoor radon levels in buildings near hot springs were 24.66% higher than those in buildings close to, and 45.31% higher than those in buildings far from, hot springs. Seasonal variation was also observed: the average concentration in winter was 112.05 Bq/m³, compared with 130.89 Bq/m³ in summer. These findings indicate that both climatic and geological conditions significantly influence indoor radon levels.

Conclusion: Since radon concentrations in most buildings exceeded the World Health Organization (WHO) guideline of 100 Bq/m³, implementing exposure control programs in residential buildings is essential.

Keywords: Indoor air pollution, Radon, Hot spring

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Introduction

Environmental pollution is a major threat to human health and, in some cases, can cause irreversible diseases or even death.¹ Among its forms, air pollution is one of the most serious, contributing to numerous diseases and thousands of premature deaths worldwide.² While air pollution is often perceived as an outdoor issue, indoor air pollution also has a substantial impact on public health.³ Indoor gas pollutants represent one of the main threats to human health. Their effects depend on factors such as building quality, ventilation type, seasonal variations, and individual sensitivity, and they can lead to a range of health complications.⁴ Radon is recognized as one of the most important indoor air pollutants and a major public health concern.⁵

Radon, a radioactive gas, is primarily released through the decay of uranium and thorium in the earth's crust.⁶ Because of its natural origin, exposure is very common; in fact, more than half of global exposure to natural radioactive materials is related to radon.⁷ The World Health Organization (WHO) has classified radon as an

important carcinogen and a leading cause of lung cancer after smoking.⁸ Indoor radon levels depend on multiple factors, including ventilation, seasonal variations, geology, and land use.⁹ For instance, poorly ventilated buildings can trap radon, leading to higher concentrations.^{10, 11} Globally, the average annual exposure to natural radiation sources in areas with background radiation is about 2.4 millisieverts, with nearly 52% (1.2 mSv) attributed to radon inhalation.^{11,12} Moreover, since more than 95% of natural radiation exposure occurs indoors,¹² radon represents a critical health concern.

As indoor radon concentrations increase, so does the risk of lung cancer.¹³ Radon is colorless and odorless, produced in the soil and capable of entering buildings through cracks and openings.¹¹ Its health impact stems from the emission of alpha particles that penetrate the lungs and damage tissue.^{8,13} Geological conditions that enhance radon release, combined with building characteristics that influence radon entry, play key roles in determining indoor exposure levels.

Given these risks, measuring radon concentrations



in residential areas is essential for identifying high-risk locations and implementing control measures. The Larijan region of Iran, characterized by its numerous hot springs, presents a high potential for radon exposure. Therefore, obtaining accurate information on indoor radon levels in this area is an important first step toward risk management. This study aimed to assess indoor radon concentrations in Larijan, Iran, particularly in areas near hot springs, and to evaluate residents' exposure.

Materials and Methods

Study Area

This study was conducted in the Larijan region of Iran. As shown in Figure 1, the study area consisted of three residential zones, and twelve residential buildings were selected from each zone for sampling. The region is located on the northern slopes of the Alborz mountain range, south of the Caspian Sea, in a mountainous setting. A key characteristic of the area that could influence indoor radon concentrations is the presence of hot springs, located in the western part of the study area (marked with the letter A in Figure 1). The geographical and natural conditions of Larijan have supported the growth of tourism as the main economic activity. Notably, there are no industrial operations or major external sources of air pollution in the region.

Sampling

Sampling was conducted at 36 residential buildings in Larijan. In each building, two points were selected for measurement: one bedroom and the living room. Sampling was performed in two phases, during winter and summer. Permeation chambers were placed at a height of 1.5 meters from the floor and left in place for one month. To minimize the influence of heat on radon levels, the devices were positioned as far as possible from heaters and other thermal sources.

Analysis

Each permeation chamber consisted of a 250-cc cylindrical plastic container with a mesh door to allow airflow and a filter to remove dust. The detector inside the chamber was a polycarbonate film (Figure 2). After exposure, the detectors were transported to the laboratory and chemically etched in a solution containing 15% potassium hydroxide, 40% ethanol, and 45% water. This process revealed alpha particle tracks on the detector surface, which were then examined and counted under an optical microscope.

Results and Discussion

The findings of radon concentration measurement in the areas studied have been shown in Table 1. It was found that the concentration of radon had a spatial variation; the difference of the concentrations in the three areas was 45.31%. The mean indoor radon concentrations in the room of the buildings studied in three areas included A, B, and C were 131.69, 115.12, and 96.4 Bq/m³, respectively, while the mean indoor radon concentrations in the living room were 160.45, 119.66, and 104.95 Bq/m³, respectively. The mean indoor radon concentrations in the room of the studied buildings were 114.40 Bq/m³, which was 12.19% lower than the mean indoor radon in the living room of the buildings studied.

The comparison of radon concentration in the studied locations with the standard provided by the WHO has been given in Figure 3. The average concentration of radon in the room and living room was higher than the standard by 14.40 and 28.33 Bq/m³, respectively. Also, the average concentration in both sampling points in the buildings studied in winter and summer was higher than the standard by 12.05 and 30.89 Bq/m³, respectively. Also, the density of hot springs in the three studied areas and the mean indoor radon concentration in the buildings of each area have been indicated in Figure 3. This comparison

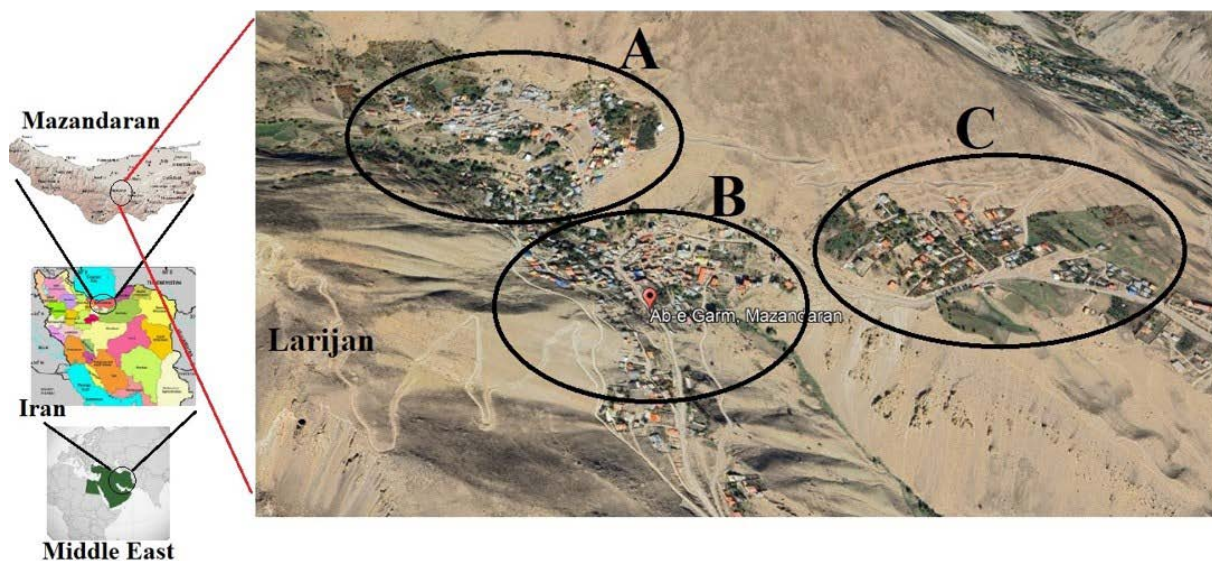


Figure 1. Location of the area studied

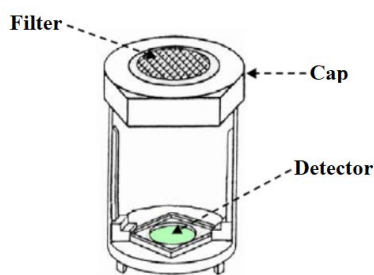


Figure 2. Schematic of indoor radon sampler

Table 1. Average concentration of radon in the locations studied

		Radon concentration (Bq/m ³)	
		Summer	Winter
A	Room	117.83	145.55
	Living room	182.73	138.17
B	Room	148.04	82.2
	Living room	131.07	108.25
C	Room	103.32	89.6
	Living room	101.35	108.55

illustrated that there was a direct relationship between the increase in the number of hot springs and the increase in radon concentration in the studied buildings.

Natural exposure to radioactive elements significantly affects human health, with more than half of this exposure attributed to indoor radon.^{14, 15} Radon is a hazardous gas and one of the leading causes of lung cancer. In fact, exposure to indoor radon is the second most important risk factor for lung cancer after cigarette smoke.¹⁶ Therefore, analyzing radon concentrations in indoor environments is a critical first step in designing control programs to reduce associated health risks. For instance, the average radon concentrations in bedrooms and living rooms of residential buildings in Germany were reported as 49 Bq/m³, which is much lower than those measured in Larijan.¹⁷ An increase in indoor radon directly raises the risk of lung cancer: every 100 Bq/m³ increase elevates lung cancer risk by 8–16%.¹⁸ Thus, identifying the key factors influencing indoor radon concentrations is essential to reduce exposure and related health risks.

Previous studies confirm these effects. Trevisi et al reported that radon levels are influenced by geological and structural characteristics of buildings.¹⁹ Baltrėnas et al showed seasonal variation, with higher levels in colder seasons—similar to the results of this study.²⁰ Ivanova et al found that geographic features can also lead to elevated concentrations.²¹ Likewise, Santos et al observed in Brazil that indoor radon varied significantly with humidity across wet and dry seasons.²² Radon levels are shaped by geological conditions, building quality, climate, and human activities.²³ The main mechanism of radon entry indoors is pressure differences between the building and the soil, which drive radon-laden air inside.¹¹ Mining and excavation are known to increase emissions.²⁴ However, since there are no major mining or industrial activities in

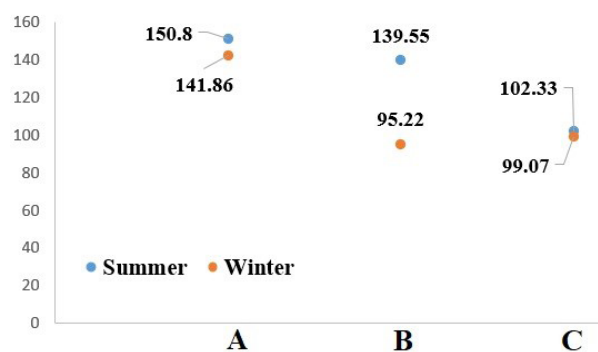


Figure 3. Indoor radon concentration in locations studied (Bq/m³)

Larijan, the elevated concentrations observed here were mainly influenced by geological factors, particularly hot springs. Area C, which had fewer hot springs compared to Areas A and B, showed lower radon concentrations. This indicates that proximity to hot springs is a major factor, increasing risks for nearby residents. In this situation, the risk associated with indoor radon is higher in buildings that were near hot springs. The influence of geological characteristics, the quality of the floor, and the quality of ventilation are known as three important factors in indoor radon concentration.¹¹ Because the content of radium, which is affected by the geological characteristics, and the transfer of radon to the indoor environment, which is affected by the permeability of the surface and bottom, are the main criteria for indoor radon concentration.²⁵ For example, a study in Norway found that areas with higher soil radium content produced higher indoor radon levels, and a strong association was observed with floor materials and ventilation.²⁶

Although Area C recorded somewhat lower levels than Areas A and B, radon concentrations in most Larijan buildings still exceeded recommended standards, posing health risks to residents. Radioactive contamination—whether natural or anthropogenic—remains a serious global health concern.⁸ Among all radionuclides, radon has the highest ratio in natural exposure, which is more difficult to control.¹⁰ Mining can further exacerbate exposure, as reported in eastern Kazakhstan where long-term, large-scale mining increased radon levels.²⁷ In Larijan, geological conditions linked to hot springs require close monitoring by local health authorities. Radon-induced lung cancer is a major health burden, responsible for approximately 21,000 new cases annually in the United States and 1,400 deaths in the United Kingdom.²⁸ In Ireland, studies show that 280 out of 2,300 annual lung cancer cases are attributable to radon exposure.²⁹ One practical solution for Larijan is to improve building quality, particularly floor construction, since radon entry from the ground is a major source of indoor contamination.¹⁰ Updating construction and building operation standards could help. For example, large-scale studies in Canada (25,000 buildings) and Sweden (36,000 buildings) highlighted the need for new building code interventions to reduce radon exposure.³⁰

Conclusion

Indoor radon concentration was studied in the buildings of Larijan region. The studied buildings were classified into three groups based on the geological features caused by the hot springs, and samples were taken from the rooms and living rooms of each building in summer and winter. The results showed that overall average indoor radon concentration was 121.47 Bq/m³. On average, radon levels in living rooms were 12.19% lower than those in bedroom. Although radon concentrations in all buildings exceeded the WHO guideline of 100 Bq/m³, none of the values were higher than the national standard of 300 Bq/m³. Radon levels were significantly higher in buildings located near hot springs. These concentrations represent a potential health risk for residents, particularly an increased risk of lung cancer. Therefore, implementing mitigation strategies, such as improving building quality, especially floor construction, is essential to reduce exposure and associated health impacts.

Authors' Contribution

Conceptualization: Somayeh Dadashpoor, Parvin Nassiri, Alireza Mirzahosseini, Nabiollah Mansouri, Zahra Azizi.

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Methodology: Somayeh Dadashpoor, Alireza Mirzahosseini, Nabiollah Mansouri.

Project administration: Alireza Mirzahosseini.

Resources: Somayeh Dadashpoor.

Software: Somayeh Dadashpoor, Zahra Azizi.

Supervision: Alireza Mirzahosseini.

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Visualization: Somayeh Dadashpoor, Alireza Mirzahosseini.

Writing—original draft: Somayeh Dadashpoor, Parvin Nassiri, Zahra Azizi.

Writing—review & editing: Somayeh Dadashpoor, Alireza Mirzahosseini, Nabiollah Mansouri.

Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval

Not applicable.

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