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A Quantitative Assessment of Indoor Radon Level and Its Annual Effective Dose in Buildings of Gachin Rural District in Hormozgan Province, Iran

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ABSTRACT

Introduction: Measurement of indoor radon concentration and its determining factors is crucial for improving public health and developing proper methods that can reduce indoor radon concentrations. This study aimed to measure the indoor radon concentration and to examine its variations in relation to variables, such as the construction materials, ventilation, and age of buildings.

Material and Methods: Indoor radon concentrations were measured using solid-state nuclear track detectors (SSNTDs) during winter. Each detector was mounted 50-90 cm above the surface flooring of bedrooms and living rooms. After three months of exposure, the detectors were collected and transferred to a laboratory. They were then etched in 6.25 N NaOH solution in a bath at a constant temperature of 90°C for 240 minutes. Next, the detectors were washed with distilled water and dried. The alpha particle tracks were counted using an automatic alpha track counting system.

Results: The mean radon concentration was 53.20 Bq/m^3, and 94% of the samples had a radon concentration <100 Bq/m^3, which is the action level proposed by the World Health Organization (WHO). The annual effective dose varied from 0.25 mSvy^{-1} to 3.05 mSvy^{-1}, with a mean dose of 0.91 mSvy^{-1}. The results showed that the type of constructed materials and ventilation influence the indoor radon concentration in winter.

Conclusion: The annual effective dose in the study area was below the global average of 1.15 mSvy^{-1}. Therefore, local residents must be informed about the health risks of high radon concentrations and understand the role of improved ventilation in reducing the indoor radon levels.

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Introduction

Radon (Rn-222) is a natural, radioactive, noble gas, which occurs naturally in soils and rocks and accumulates in mines and houses. Exposure to this element accounts for more than 50% of the annual effective dose of natural radioactivity [1]. It has been shown that radon gas and its decay products cause many complications in humans. In many studies, a liner relationship has been suggested between exposure to radon gas and development of lung cancer [2-4]. Besides, exposure to radon gas is the first cause of lung cancer among non-smokers and the second cause of lung cancer among smokers [5-8]. Available radon in soils and rocks continuously diffuses in water; therefore, radon concentration in groundwater is higher than surface water. In other words, the presence of high concentrations of radon in groundwater indicates that use of groundwater as drinking water causes a potential health risk and increases the risk of stomach cancer [9].

Since radon gas is available in soils, rocks, and mineral products, it can be also found in building materials. The small gaps in the rigid bedding of houses are responsible for the spread of radon, which is found in soils and construction sites, as well as underground passages, holes in walls, expansion joints, and tiny holes in hollow walls [10]. There are various factors that influence the flow of radon in buildings, such as weather, floor level [11], season [12], permeability of soil, and lifestyle [13]. Each factor has different effects on the indoor radon concentration.

There are published reports indicating the higher concentration of indoor radon in the first floor as compared to higher floors [11, 14-17]. Besides, it has

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been shown that the indoor concentration of radon is higher in some seasons, mainly due to better ventilation. For instance, a case study conducted in four northern cities of Iran revealed the higher levels of radon during winter and fall compared to spring and summer [11]. Overall, understanding the effects of various factors on the indoor concentration of radon can provide us with accurate information for implementing effective programs to reduce the indoor radon concentrations and improve public health.

In this study, after measuring the indoor radon concentration and inhalation dose, the effects of various factors on the indoor radon concentration were examined. This study aimed to examine the effects of construction materials, flooring type, age of building, ventilation (number of windows), and type of room (e.g., bedroom and living room) on the indoor radon concentration. To the best of our knowledge, this study is the first work conducted in Hormozgan Province, Iran; therefore, it can help us fill the knowledge gap in this area. Moreover, the results of this study can be used for mapping the national radon levels.

This study was carried out in three villages of Hormozgan Province in south of Iran. Gachin district, where these three villages were selected from, is one of the most promising uranium mining and milling areas in Iran, with a production capacity of 21 tons per year [18]. This area is widely known as a naturally radioactive area. Also, many local residents obtain some of their construction materials, such as plaster, from areas close to the mines and use them in construction. However, there is a lack of convincing evidence on how these materials affect the indoor radon concentrations. Therefore, we conducted this study to bridge the current knowledge gap.

As mentioned above, Gachin district is a naturally radioactive region, because it is home to uranium mines. Moreover, people in this area use local construction materials, such as plaster, in their constructions, along with materials made by local manufacturers. Therefore, it is assumed that the indoor radon concentration in local buildings is higher than the standard level. The current study aimed to test this assumption using quantitative methods. Our findings will be presented in the Results Section, and their implications will be discussed in detail in the Discussion Section.

Materials and Methods

Study area

Gachin rural district is situated in west of Hormozgan Province in south of Iran (Figure 1). This rural district is mostly known for its uranium mines. Gachin-e Paeen, Gachin-e Bala, and Bostanu are the major areas in Gachin rural district. Gachin-e Paeen and Gachin-e Bala are located 10 km away from the sea, while Bostanu is located near the sea. Local people use local construction materials that are made of sand and soil, harvested from local mines. Considering the high level of radioactivity in this area, it is important to understand the role of construction materials in indoor radon concentrations. In this study, 150 houses (10% of total houses) were selected as the sample size and distributed proportionally in each village (Table 1).

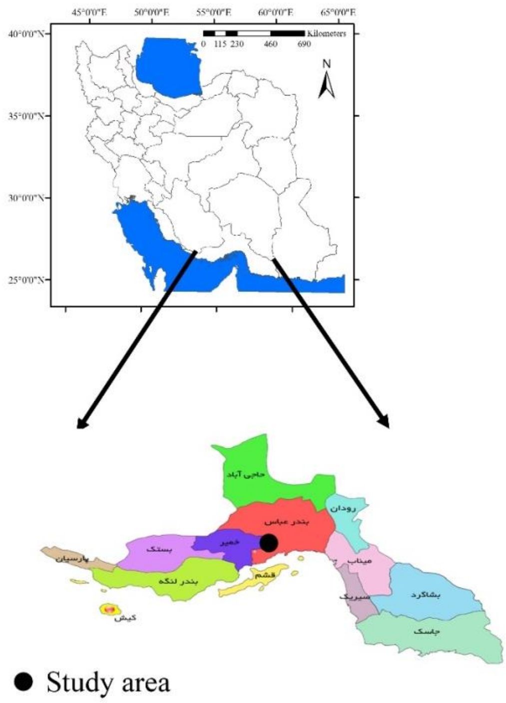

Figure 1. The locations of the studied villages

Table 1. The studied villages and the number of samples in each village

Village	Number of households	Sample size
Bostanu	150	38
Gachin-e Bala	280	69
Gachin-e Pain	200	43
Total number	630	150

Experimental studies

Solid-state nuclear track detectors (SSNTDs)

The SSNTDs were applied to measure the indoor radon concentration (using an alpha-track detector with CR-39 polycarbonate films). These detectors have some important advantages, such as light weight, simple etching process, low cost, and small size of the chamber, which convinced us to use them for indoor radon measurements. Considering the wide range of radon/thoron concentrations in which they can be used, these detectors are suitable options for large-scale measurements. They consist of a 2.5×2.5 cm CR-39 polycarbonate film, placed inside a plastic holder (Figure 2). The plastic holder protects the CR-39 film against nuclear particles, ensuring the robustness of the findings. These detectors enable measurements over long periods of time, as one of their main advantages. The Atomic Energy Organization of Iran (AEOI) has been producing samples, while previous works from

Ramsar [19], Ardabil [20], and Shiraz [21] have specified the track density quantization, detection, and chemical etching.

Figure 2. The Cr-39 detectors to measure the indoor radon levels in this study.

In this study, each detector was mounted 50-90 cm from the floor surface of the bedroom or living room away from the doors and windows, based on the guidelines by the Environmental Protection Agency (EPA) [22]. Accordingly, the detectors were placed 10 cm away from other objects (not within 10 cm from the doors and windows). Besides, we avoided placing the detectors in locations near the heat (e.g., on appliances, near fireplaces, under direct sunlight, and areas of high humidity). Figure 3 presents a schematic layout of a typical living room/bedroom, with a detector located 50 cm away from the floor surface of the room.

After three months of exposure during winter, the detectors were collected, wrapped in protective aluminum foil, and transferred to the Comprehensive Research Laboratory of Mazandaran University of Medical Sciences for analysis. The alpha particle tracks on the polymers of dosimeters were determined using electrochemical etching, and the concentration of radon was measured by the number of detected alpha tracks. Next, for unfolding the alpha tracks, the detector films used in the laboratories were extracted from the dosimeters and applied in chemical etching. The films were etched with 6.25 N NaOH solution and then bathed in this solution at a steady temperature of 90ºC for 240 minutes.

After washing the detectors with distilled water and drying them, the number of alpha tracks was determined using an automatic alpha track counting system. This electrical-mechanical system was entirely operated by a computer. The numeration system selected a sample of 30 microscopic images from each CR-39 film and then calculated the alpha tracks of these images. The track density was then converted to radon concentration in Bq/m^3, using conversion factors and calibration approaches suggested by the AEOI. The alpha tracks of a detector, with seemingly different densities, are shown in Figure 4.

(a) (b)

Figure 3. A simple representation of detectors placed in a building (a: in a living room, b: in a bedroom).

Figure 4. Image samples obtained by an electronic microscope (images show the alpha particle tracks on the CR-39 film)

Radon effective dose assessments

Since indoor radon can cause various human health risks, it seems necessary to calculate the radiation dose from radon concentration. In this study, the following formula, which has been used in the literature [23, 24], was used to compute the annual effective dose from the integrated radon concentration:

$$D = \frac{C_{Rn} \times 0.4 \times 3.88 \times 7000}{170 \times 3700} \quad (1)$$

where D is the annual effective dose (mSvy^{-1}); the equilibrium factor and the ICRP conversion factor are 0.4 and 3.88 mSv.WLM, respectively; C_{Rn} is the radon concentration in Bq/m^3; and 7000 and 170 are the number of hours per year and the number of hours per working month, respectively.

Results

Indoor radon concentrations

The indoor radon levels shown in Figure 5 indicate that about 94% of the samples had radon concentrations lower than the WHO action level, which is 100 Bq/m^3 [25]; also, in approximately 6% of the samples, the indoor radon concentration was above 100 Bq/m^3. However, if these results are compared with the action level of EPA (148 Bq/m^3), it will be revealed that only 1.3% of the samples had radon concentrations above the EPA action level. The analysis of 150 samples showed that the indoor radon level in the studied areas ranged from a minimum of 177 Bq/m^3 to a maximum of 15 Bq/m^3, with a mean level of 53.20 Bq/m^3.

Determinants of indoor radon concentration

Effect of construction materials on radon concentration

Houses in the studied areas were mainly constructed by three main materials, which include concrete, brick walls, and adobe. The measured indoor levels of radon in houses with the mentioned construction materials are presented in Table 2. It is clear that adobe houses had the highest indoor concentration of radon (83.84 Bq/m^3), while the level of indoor radon was the lowest in concrete houses (36.84 Bq/m^3). Besides, constructions with brick walls as the main construction material showed a moderate indoor radon concentration (65.55 Bq/m^3).

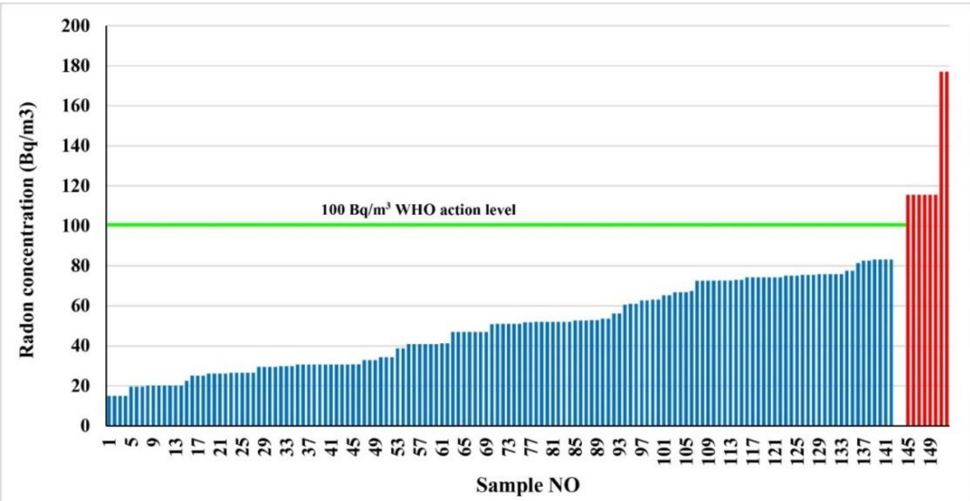

Figure 5. The histogram of indoor radon concentrations in the study area

Table 2. Indoor radon concentrations in houses made of different materials

Variables	CRn (Bq/m3)	Max (Bq/m3)	Min (Bq/m3)	Range (Bq/m3)	F (Sig.)
Construction materials					
Concrete	36.84	75.05	15	60.05	67.05***
Brick walls	65.55	177.00	46.95	130.05	
Adobe	83.84	115.50	63.19	52.31	
Flooring type					
Mosaic	76.66	177.00	46.95	130.05	113.28***
Ceramic	27.38	53.65	15.00	38.65	
Cement	51.41	77.50	38.75	38.75	

***Difference is significant at 0.01 (two-tailed).

Effect of materials used in floors on radon concentration

The present findings showed a significant difference between the type of used flooring material and the level of indoor radon concentration (Table 2). In this regard, houses in which mosaic was used to cover the surface of the ground floor accounted for a higher amount of radon accumulation (76.66 Bq/m^3). Interestingly, constructions using ceramic showed the lowest concentration (27.38 Bq/m^3); this finding seems to be related to the fact that granite (mosaic) is expected to have a higher radon exhalation rate than other construction materials [26, 27]; therefore, the floors of houses that are entirely covered by mosaic have higher indoor radon concentrations [28]. Also, a moderate radon concentration was reported in houses with floors made of cement (51.41 Bq/m^3).

Effects of ventilation and age of building on radon concentration

The results showed that higher ventilation was both negatively and significantly correlated with the indoor radon concentration. In other words, buildings with better ventilation had lower indoor radon concentrations. For instance, if buildings had more windows, they would have lower radon concentrations, as the windows facilitated the free flow of air in the buildings. Moreover, the present results revealed that radon concentration was not the same in different rooms of a building. The radon concentration in living rooms was relatively lower than the bedrooms. The average radon levels in bedrooms and living rooms were 55.73 Bq/m^3 and 50.66 Bq/m^3, respectively, and the difference was statistically significant (T=22.96, Df=149, P>0.000); this finding can be explained by the level of ventilation in different rooms of a building.

Arguably, living rooms have better ventilation than bedrooms (since the doors are opened and closed more frequently). Additionally, they are designed to capture sunlight as much as possible, resulting in the lager number of windows and better ventilation. In terms of the building's age, the results revealed no significant relationship between the building's age and the level of indoor radon concentration. However, some case studies found a positive correlation between the age of building and indoor radon concentrations [11].

Table 3. Indoor radon concentrations and their respective doses in different houses

Indoor radon range (Bq/m^3)	Village (percentage)	Annual effective dose (mSv)
10-50	46	0.25-1.26
50-100	48.7	1.26-2.52
100-177	5.3	2.52-3.05

Radiation dose

The annual effective dose from the integrated radon concentration is shown in Table 3. The annual effective dose calculated in this study varied from 0.25 mSvy^{-1} to 3.05 mSvy^{-1}, with a mean value of 0.91 mSvy^{-1}.

Discussion

The present results showed that the average indoor radon concentration was 53.20 Bq/m^3 in the studied areas. Moreover, 6% of the buildings had radon concentrations higher than the action level recommended by the WHO, and only 1.3% showed radon levels above 148 Bq/m^3 (USA EPA standard). Comparison of indoor radon concentrations at the national level showed that the average radon concentration in this part of Hormozgan Province was lower than the levels reported in Shiraz (94 Bq/m^3) [11], Yazd (137.36 Bq/m^3) [29], Hamedan (108 Bq/m^3) [30], and Qom (123.43 Bq/m^3) [31], while it was higher than radon levels reported in Khorramabad (40.37 Bq/m^3) [32] and Tabriz (39 Bq/m^3) [33].

In the present study, we assumed the high level of indoor radon concentration due to the presence of several uranium mines in the area, besides richness of the region in minerals. However, the results showed lower radon concentrations in comparison with the levels reported in different parts of the country. One possible explanation seems to be the adequate level of ventilation in buildings due to the hot and humid weather. This area has extreme weather conditions, forcing local residents to equip their buildings with a variety of cooling devices that result in better ventilation.

Regarding the radon concentration at international levels, the average indoor radon concentration in the present study was higher than that reported in Turkey (50 Bq/m^3) [34], while it was lower than the levels reported in some other countries, such as India [35] and Ireland (60 Bq/m^3) [36]. The cause of high radon concentrations in buildings seems to be the construction materials and ventilation. In the majority of cases, buildings with the highest radon concentrations were those with cement and mosaic largely used in their construction. Generally, different construction materials contain various amounts of natural radionuclides, depending on the characteristics of rocks or soils they are derived from. Mosaic-tiled buildings had a higher dose of radon as compared to those with ceramic floors; the reason might be the composition of different materials. Mosaic mostly consists of stone, cement, and tiny particles of sand, while ceramic is made of clay, which has a much lower natural activity than cement and sand [37, 38].

Moreover, this study revealed that buildings constructed by adobe had the highest radon accumulation levels. This finding is in line with the results of some previous studies [11], which established a close relationship between the highest indoor radon concentration and the use of adobe. One possible explanation for the higher radon concentrations in houses made of adobe, compared to those with brick walls and concrete, is the higher propensity of adobe for radon emissions compared to other materials. The results also showed that living rooms had lower radon concentrations than bedrooms, which is consistent with previous studies [28, 29, 39]. The low concentration of radon in living rooms seems to 176be related to sufficient ventilation [32]. Also, the mean annual effective dose calculated in this study was 0.91 $mSvy^{-1}$, which is lower than the global average (1.15 $mSvy^{-1}$) [40] and even some other cities of Iran, such as Ramsar [41].

Conclusion

High indoor concentrations of radon in buildings can cause serious health complications; therefore, they need to be regularly monitored. This study aimed to measure the indoor radon concentrations and annual effective doses in the buildings of Gachin rural district. Moreover, the influential factors in indoor radon concentration were investigated. The results showed that 94% of houses had radon concentrations lower than 100 Bq/m^3, which is the action level of the WHO. Besides, this study revealed that radon concentration is highly correlated with better ventilation during winter. Also, construction materials significantly influenced the indoor radon levels, as different materials have different radon emissions. Given the significant effect of construction materials and ventilation on the indoor radon concentration, radon considerations should be implemented in construction materials and even in construction methods in the study area. Finally, local people must be provided with further information about the health risks of radon exposure.

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