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Indoor Radon Measurement in Dwellings of Khorramabad City, Iran

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ABSTRACT

Introduction: Exposure to indoor radon increases the risk of lung cancer. This study examined the level of indoor radon in dwellings of Khorramabad city, by using passive alpha-track detector (CR-39) during winter of 2016.
Materials and Methods: In the present study, we detected the concentration of indoor radon in 56 dwellings. A passive sampling instrument (alpha-track detector with CR-39 polycarbonate films) was utilized to measure indoor radon gas concentration. The distribution map of indoor radon concentration was prepared using Arc GIS software.
Results: Radon concentration in the dwellings varied from 1.08 to 196.78 Bq/m^3, with a mean value of 43.43±40.37 Bq/m^3. The average annual effective dose received by the residents of the studied area was estimated to be 1.09 mSv. Our results showed a significant difference between the average radon concentrations in houses and apartments, with a higher level in houses.
Conclusion: Indoor radon concentration in 10.1% of the dwellings was determined to be higher than the limit (100 Bq/m^3) recommended by the World Health Organization.

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Introduction

Everyone is exposed to a range of natural and man-made radiation sources [1]. The natural radiation sources are responsible for most of the radiation exposure, and radon typically constitutes up to 50% of the background radiation [2]. The average annual effective dose from all the natural radiation sources was estimated to be about 2.4 mSv, of which approximately 1 mSv is due to the inhalation of radon in indoor environments [3]. Radon is a short-lived, naturally occurring, radioactive gas formed during the normal decay of uranium and thorium to stable lead [4]. Radon has 27 known isotopes among which are three naturally occurring isotopes [5]: actinon (^{219}Rn) is in the ^{235}U series with a half-life of 4 s; thoron (^{220}Rn) is in the ^{232}Th chain with a half-life of 55.6 s, while radon (^{222}Rn) originates in the ^{238}U decay series with a half-life of 3.82 days [6]. The most stable radon isotope is ^{222}Rn [7].

Radon occurs widely in the environment, especially in rocks, soil, building materials, and water [8, 9]. It is also released from some artificial sources such as radioactive waste landfills [9]. Radon enters the residential environment via cracks and holes in concrete floors and walls, drainage pipes, connecting parts of buildings, hollow block walls, and heating, ventilating, and air conditioning (HVAC) ducts [10, 11]. In outdoor environments, radon is usually released in the air, while in indoor spaces like buildings, mines, and caves, it can accumulate to cause the risk of lung cancer [12]. The most important factors controlling the migration and accumulation of radon gas in buildings include: 1- the characteristics of the bedrock and soils that affect fluid transport (permeability and porosity), 2- the structure and construction of the building and the type, design, operation, and maintenance of the HVAC system, and 3- environmental factors like temperature (high heating during the colder months causes a chimney

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effect, which draws soil gases like radon into the home), wind speed, and wind direction, which can further the chimney effect [13, 14]. Radon and its progeny, dispersed in the aerosols from indoor and outdoor air, pose significant radioactive hazards to human lungs. During respiration, radon progeny is deposited in the lungs and irradiates the tissue, thereby damaging cells and causing lung cancer [15]. The World Health Organization (WHO) and the US Environmental Protection Agency (EPA) state that radon is the second leading cause of lung cancer after smoking [16]. Studies showed that in Europe, 8-15% of all lung cancer cases might be attributable to radon in dwellings [17]. Based on a case-control study in the US and North America, exposure to radon is associated with 15,400 to 21,800 cases or approximately 10% of lung cancer cases annually [18].

It should be noted that any radon exposure poses some risk and no level of radon is safe. Even radon concentrations below 4 pCi/L (equivalent to 148 Bq/m^3 based on the directive of the United States Environmental Protection Agency) pose some risk [11]. The WHO and International Committee of Radiation Protection (ICRP) set 100 Bq/m^3 as the reference value to minimize the health risks caused by exposure to radon; they also pin pointed that radon concentration should not exceed 300 Bq/m^3, which is equivalent to 10 mSv/y [13].

Worldwide studies were conducted to measure indoor radon concentration [19-23]. Radon monitoring has been carried out in many Iranian cities such as Yazd, Lahijan, Ardabil, Sar-Ein, Namin, Hamadan, Taft, Ashkezar, Mehriz, Harat, Bafgh, Tabas, Meybod, Ardakan, Abarkooh, Qom, Mashhad, Tabriz, Shiraz, and Sari [24-32]. There are two major approaches to prepare the maps of radon: 1) area-based, 2 km, 5 km, and 10 km grid square resolution [33] and 2) population-based, nearly one sample per 5,800 populations [34].

Due to the lack of radon concentration measurement in Khorramabad city, radon monitoring was found valuable. Thus, we aimed to measure radon in dwellings in the city of Khorramabad to calculate the effective dose caused by the inhalation of radon.

Materials and Methods

Study Area

Lorestan Province is located in the western part of Iran, and it is neighbouring Hamadan and Markazi provinces from north, Isfahan from east, Khuzestan from south, and from west it neighbours with Kermanshah and Ilam provinces (Figure 1). The major cities in this province are Khorramabad, Borujerd, Aligoodarz, Dorood, Koohdasht, Azna, Alashtar, Noor Abad, and Pol-e-Dokhtar.

Khorramabad city, the capital of Lorestan Province, is located 490 kilometres from Tehran, the capital of Iran. Its longitude and latitude are 48°22′ and 33°29′, respectively, with the elevation of 1171 metres above sea level. The average daily temperature in the city of Khorramabad is 16.5°C. The population census in 2012 revealed this area to have a population of 355,000 people in 6233 km^2 [35].

Data Collection

This cross-sectional study was carried out during winter of 2016. In this study, we used estimation of indoor radon measurement points based on area. To achieve high-precision results, the scale of 1×1 km^2 was chosen. Accordingly, 65 dwelligs were randomly recruited using Google Earth software (Figure 1). The sampling distribution was almost homogenous. To determine the parameters affecting the concentration of radon in indoor air, a form was used to collect information, such as the type of building (house or apartment), the age of the building, the type of materials, the type of floor, cracking and splitting on the wall and roof, and the heating and ventilation systems. The geographical coordinates of points were recorded using a GPS (Garmin, Germany) for radon mapping of Khorramabad city. The distribution map of radon in the dwellings of Khorramabad city was prepared using the ArcGIS software (ESRI, USA, version 10).

A passive sampling instrument (alpha-track detector with CR-39 polycarbonate films) was used to measure indoor radon gas concentration. The detector (Track Analysis System, United Kingdom) consists of a 2.5×2.5 cm CR-39 polycarbonate film placed inside a plastic holder (Figure 2). For quality assurance and quality control, eight detectors as the duplicate sample (5-10%) and seven detectors as the blank sample (5-10%) of all the testing locations were used. Thus, in this study, 80 detectors were left in 65 dwellings. Determination of radon was carried out based on the US Environmental Protection Agency protocol [36].

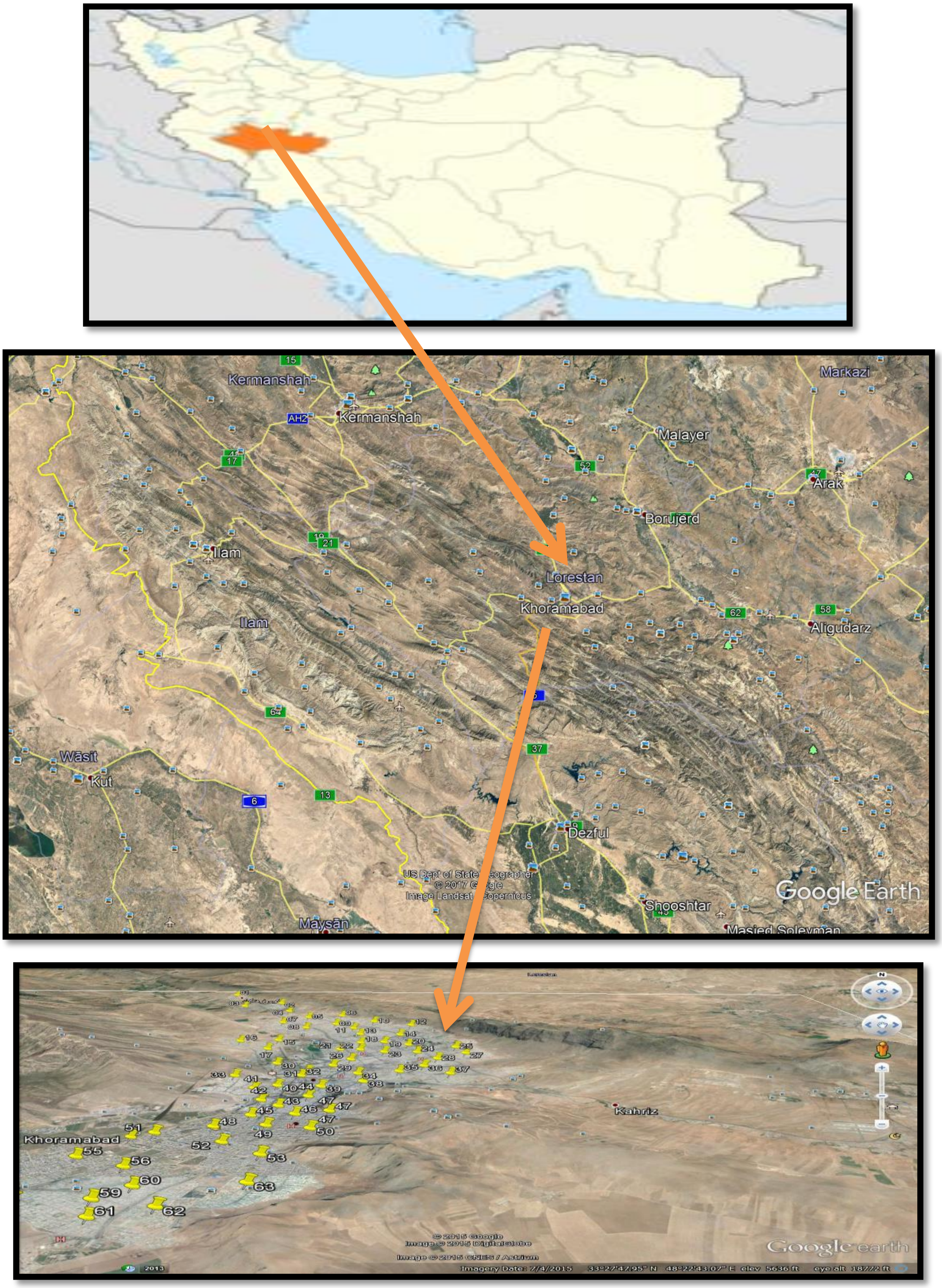

Figure 1. Location of Lorestan Province in Iran and radon sampling locations in Khorramabad dwellings

Figure 2. Detectors to measure radon

In this study, six samples were lost by the householders during the sampling period. The samples were thus collected from 59 points of the city. After exposure, all the detectors (74 detectors) were wrapped in their protective aluminium foils and Zip Kips and then delivered to the Reference Radon Lab, Central Research Laboratory, Mazandaran University of Medical Sciences. In the laboratory, detectors were chemically etched with 6.25 N NaOH at 85°C for 3 h and then washed with distilled water and dried. Finally, the detectors were read by an automated counting system equipped with a mechanical and electronic system and controlled entirely using a computer. The counting system took 30 microscope images from each CR-39 film and the number of alpha particles (tracks) of these images was calculated. The track density was then changed to radon concentration in Bq/m^3 using calibration and conversion factors (the calibration factors of the detectors were previously determined by the Atomic Energy Organization of Iran [37]).

SPSS version 22 and Excel version 2010 were employed for statistical analysis of the data. Kolmogorov-Smirnov test, Mann-Whitney U test, and Kruskal-Wallis test were run to analyze the data. P-value less than 0.05 was considered statistically significant.

Results

In this study, the concentration of radon at three points was below the detection limit (1 Bq/m^3). A detailed description of the methods for determining the detection limit can be found elsewhere [38]. As a result, the analyses were conducted on the basis of 56 points.

Table 1. Descriptive statistics of indoor radon concentrations in 56 dwellings

Radon concentration(Bq m^{-3})					
No. of dwellings	Mean± SD†	Minimum*	Maximum*	Median	G.M‡
56	43.43±40.37	1.08	196.78	31.95	27.35

†SD= Standard deviation, ‡G.M= Geometrical mean
*The associated uncertainty (95%) is ±0.90 Bq m^{-3}.

The Concentration of Radon in Khorramabad

Table 1 presents descriptive statistics obtained from the measurement of the indoor radon concentrations in 56 dwellings of Khorramabad. The results of indoor radon measurements in the studied area range between 1.08 to 196.78 Bq/m^3 with the mean of 43.43±40.37 Bq/m^3. Figure 3 exhibits the histogram of radon concentration in 56 dwellings of Khorramabad.

Factors Affecting Radon Concentration

Comparing the conditions of buildings in Khorramabad city, it was found that the type of building is the main factor affecting radon concentration. Other factors such as age of the building, location of gas measurement, materials used in floor and walls, the presence or absence of cracks, type of windows, and kitchen ventilation and heating system did not show any significant differences. However, the results of some of the most important factors are mentioned below.

The Effect of the Type of Building on Radon Concentration

The dwellings were classified into apartments and houses. The results of radon concentration in apartments and houses are presented in Table 2. As shown in Table 2, the concentration of radon gas in apartments of Khorramabad was within the range of 1.08 to 196.78 Bq/m^3 (with an average of 34.76 Bq/m^3), while the concentration of radon gas in houses of Khorramabad was within the range of 1.46 to 148 Bq/m^3 (with an average of 46.89 Bq/m^3).

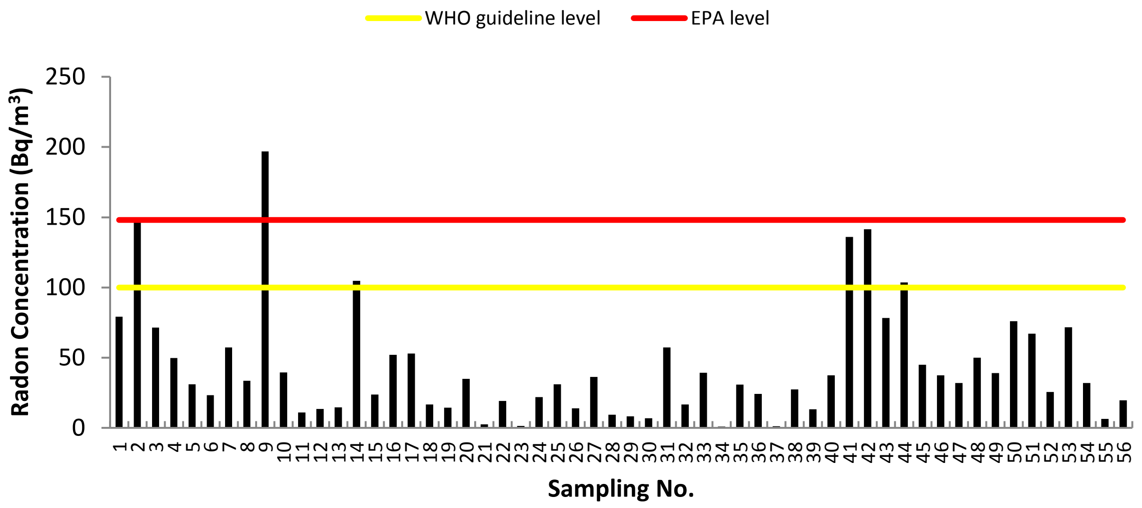

Figure 3. The histogram of radon concentration in 56 dwellings of Khorramabad

Table 2. The concentration of radon in apartments and houses

Radon concentration(Bq m-3)						
Building type	N	Mean± SD	Min	Max	Median	G.M
Apartment	16	34.76±53.74	1.08	196.78	16.86	14.56
Houses	40	46.89±33.83	1.46	148	37.64	35.18

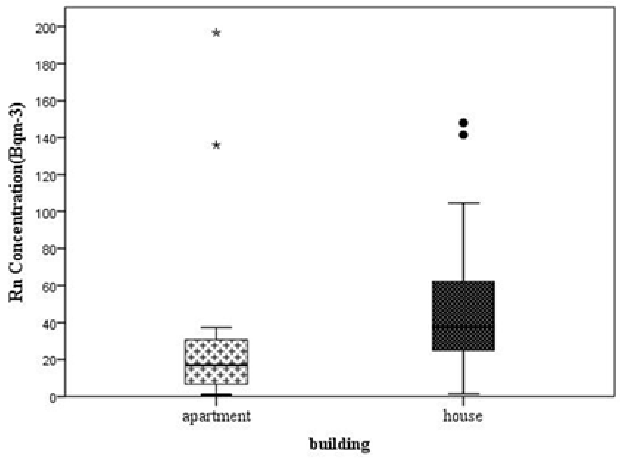

Figure 4. Radon concentration variations with the type of building

Table 3. Radon concentrations in various floors

			Radon concentration(Bq m^{-3})			
Floor type	N	Mean± SD	Min	Max	Median	G.M
Basement	12	63.97±63.82	1.08	196.78	50.94	29.30
Ground floor	31	42.99±31.83	2.72	135.98	34.99	31.88
1st floor	9	27.48±23.43	6.39	79.28	19.17	20.72
2nd floor	4	21.04±14.86	1.33	37.40	22.71	12.65

The comparison of the type of building using the Mann-Whitney U test represented a significant difference (P=0.007) in radon concentration between apartments and houses. These results confirmed that radon concentration was higher in houses relative to apartments (Figure 4).

The Effect of Floor Type on Radon Concentration

The results of radon concentration in different floors are presented in Table 3. There is a decrease in mean radon concentration from the basement to higher floors (63.97-21.04 Bq/m^3). Based on the Kruskal-Wallis test, the differences between the basement and other floors were not statistically significant (P=0.255).

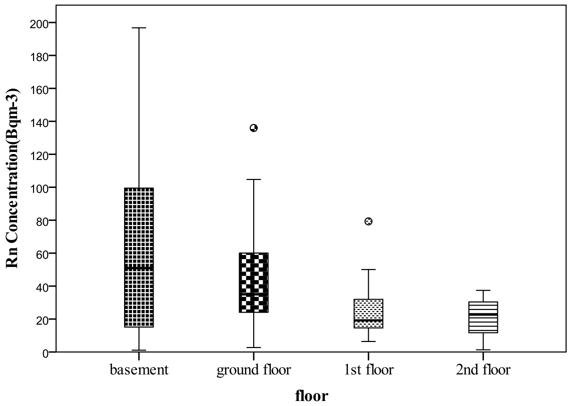

Figure 5. Variations in radon concentration in different floors of dwellings

Figure 5 shows that the basement floors compared with other floors had higher concentrations of radon. In other words, the radon concentration decreases with increasing height from the ground level.

The effect of measurement location on radon concentration

The results of radon gas measurement in different places of dwellings in Khorramabad are presented in Table 4. According to the present study, the mean radon concentrations in the bedrooms, living rooms, basements, and storerooms were 43.20, 19.01, 51.90, and 57 Bq/m^3, respectively. Thus, the living rooms had the lowest radon concentrations compared with other places (Figure 6), although based on the Kruskal-Wallis nonparametric test, the difference was not statistically significant (P=0.158).

The effect of the materials used in floors on radon concentration

To study the effect of construction materials used in the floor on radon level, dwellings with two types of materials (mosaic or cement: 45 dwellings and ceramic: 11 dwellings) were surveyed. Table 5 illustrates the results of this survey. As can be observed in this table and Figure 7, dwellings with mosaic or cement floors had the highest radon concentration, although the Mann-Whitney U test showed no significant differences between the concentrations of radon in dwellings with mosaic or cement floors and those with ceramic floors (P=0.628).

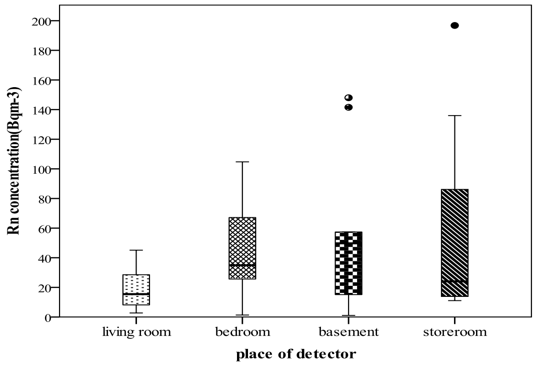

Figure 6. Radon concentration variations in different places of dwellings

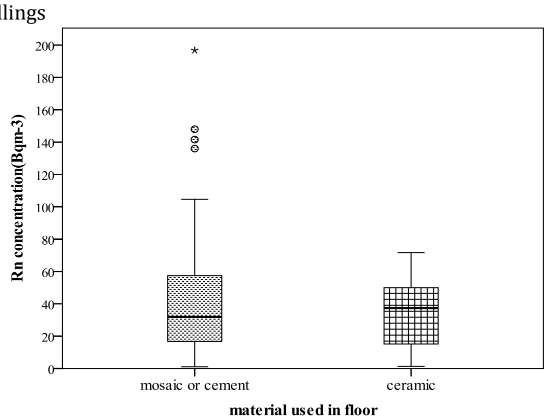

Figure 7. Variations in radon concentration in accordance with the type of material used in the floors

Table 4. The concentration of radon in different places of dwellings

Radon concentration(Bq m^{-3})						
Place of measurement	N	Mean± SD	Min	Max	Median	G.M
Bedroom	29	43.20±27.56	1.33	104.72	34.99	32.74
Living room	8	19.01±14.89	2.72	45.12	15.44	13.89
Basement	11	51.90±50.56	1.08	148	49.8	24.64
Storeroom	8	57±69.90	11.07	196.78	24.07	32.34

Table 5. The concentration of radon in dwellings with different floor materials

Radon concentration(Bq m-3)						
material used in floor	N	Mean± SD	Min	Max	Median	G.M
Mosaic or cement*	45	45.79±43.25	1.08	196.78	31.95	29.44
ceramic	11	33.76±24.56	1.33	71.56	37.4	20.23

* Since the number of homes with cement floor were 2 (less than 5), which individually the comparison is not possible, cement merged with mosaic.

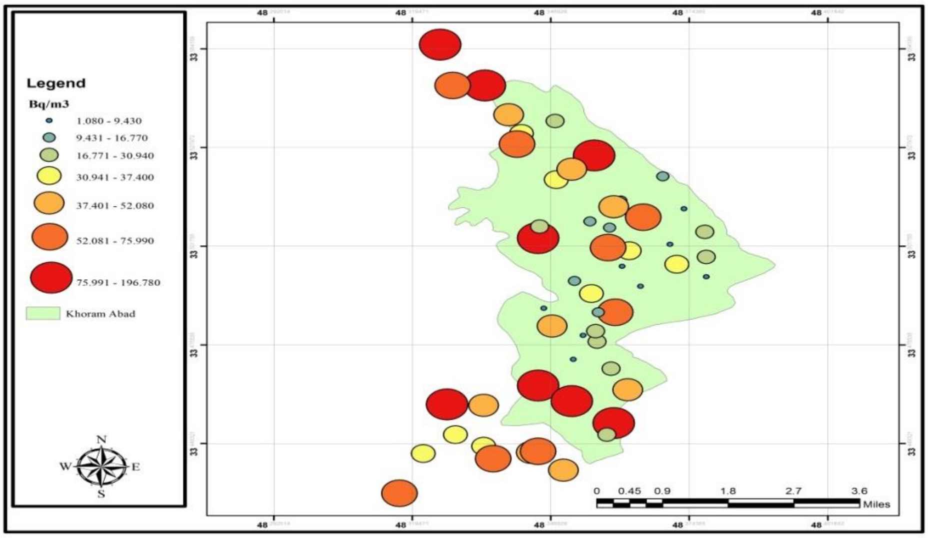

Figure 8. Distribution map of indoor radon in Khorramabad

Radon Distribution in Khorramabad

Figure 8 illustrates the distribution map of indoor radon concentrations in Khorramabad city.

Discussion

The results showed a high mean radon concentration in the city of Khorramabad (Table 1). As shown in Figure 3, 10.1% (six cases) of the dwellings had radon levels higher than the action level (100 Bq/m^3) recommended by the WHO and only in 1.6% (1 case) of the samples radon concentration was more than 148 Bq/m^3 (the US EPA standard).

The average annual effective dose (mSv/y) received by the inhabitants of the area under study due to indoor radon was estimated using the following formula suggested by UNSCEAR-2000 [3]:

$$D = C \times F \times H \times T \times F' \quad (1)$$

where C is the indoor radon concentration (in Bq/m^3), F denotes the equilibrium factor of radon (assumed to be 0.4 for indoor measurement), H indicates the occupancy factor (0.8 for indoor measurement), T signifies the hours for a year (365.25×24=8766 hy^{-1}), and F' is the dose conversion factor for whole body dose calculation (9 nSv/h per Bq/m^3). Since the mean radon concentration in Khorramabad is 43.43 Bq/m^3, the approximate average annual effective dose from radon inhalation is 1.09 mSv/y (range: 0.027 and 4.96 mSv/y). On the basis of ICRP-69 [39], 7.1% of the samples (four cases) were found to have more than 3 mSv/y annual effective dose. However, the average annual effective dose of the dwellings was lower than the action level.

The cause of high radon concentration in houses could be that houses are in contact with the soil, hence radon in the soil can easily enter the indoor spaces. In the majority of apartments, the basements or ground floors are used as parking lots, which can act as a reservoir for radon. On the other hand, apartment buildings are newer constructions, with better tightening of the bottom slab, which prevents radon entry. The results of this study are consistent with those of several studies [19, 20].

Decreasing radon concentration with increasing distance from the earth has been shown in several studies [21, 22]. Owing to the higher levels of radon in basements, it can be stated that the main source of radon in buildings is the release of radon from the soil and rocks in the earth. Also, due to the higher density of radon gas than the air, it accumulates at lower levels.

In previous studies, it was shown that living rooms have a lower radon concentration than bedrooms [10]. Low concentration of radon in living room is due to sufficient ventilation.

As previously mentioned, the building materials and other products of rock and soil contain natural radionuclides that eventually produce uranium and radon. The amount of radionuclides in building materials depends on the characteristics of rock or soil used in them. High levels of radon were observed in buildings with mosaic rather than buildings with ceramic floors. This may be because mosaic is a mixture of cement, sand, and stone, but ceramic is made of clay; the natural activity in clay is lower than in cement and sand [23, 40].

As displayed in Figure 8, the concentration of this risk factor in the central parts of the city is lower than in the other areas, which is probably because the central parts of the city are newer and most of the buildings in these parts are of the apartment type.

Conclusion

Indoor radon concentrations were detected in 56 dwellings of Khorramabad city, Iran. To conclude, indoor radon concentration in Khorramabad city is a health risk for about 10% of dwellings. The results of this study could be used for providing radon map of Iran.

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