Determination of Rn- 222 concentration and annual effective dose of inhalation in the vicinity of hot springs in Kerman province, southeastern Iran

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ABSTRACT

Background: Human exposure to Radon-222 gas is one of the most important natural radiation sources of radioactive gases, and inhalation of this gas and its decay products can cause lung cancer. Therefore, this study was conducted to measure Rn-222 concentration and determine annual effective dose of radon inhalation in the vicinity of hot springs in Kerman province, southeastern Iran. ***Materials and Methods:*** This study was carried out on 16 hot springs of Kerman province. Concentration of Rn-222 was measured using RAD-7 electronic system. Also, annual effective dose amounts of inhalation were estimated according to the formula provided by UNSCEAR (2000). ***Results:*** Minimum and maximum amounts of Rn-222 concentration in the samples were equal to 0.158±0.129 and 56.100±5.680 Bql-1, respectively. Annual effective dose amounts of inhalation were determined between 0.000±0.000 to 0.177±0.017 mSvy-1. Concentration of radon was more than 11 Bql-1 (the safe limit set by the EPA) in 5 samples collected from hot springs. Annual effective dose of inhalation of radon was more than 0.1 mSvy-1 (the safe limit set by the WHO) in Jooshan hot spring. ***Conclusion:*** By comparing concentration amounts of the samples with the EPA safe limit, it was concluded that, 11 hot springs were safe. Also, annual effective dose amounts of inhalation of all hot springs, except one of them were lower than the safe limit set by WHO.

INTRODUCTION

Radiation rays are present around us and in all over the earth. Some radiations are essential for life, such as heat and light received from the sun and some of them are used in medicine to diagnose and treat diseases. But other Radiation rays such as radioisotopes of radon and products developed from decay of uranium and thorium can be completely harmful to the humans (1). In recent years, natural radioactivity has received a great deal of attention and has been investigated due to public concern arising from radiation risks and the possibility of damage to health of the societies (2). This type of natural radiation depends to various factors such as geological region and geographical conditions of that region and its amount can vary from place to another place (1). Human exposure to Radon gas is one of the most important natural radiation sources of radioactive gases caused by decay of radium-226 in uranium-238 chain (3, 4). This radioactive element is odorless and colorless and has a half-life of 3.83 days (5). Radon exists naturally in soil and rocks, and is found almost everywhere in the earth. This gas is an important source of emitting alpha particles, which is easily soluble in water under the pressure (1). Hence, groundwater passing through uranium-rich soils has a high concentration of radon (2). Also, Radon-222 concentration in groundwater resources is 2 -3 times higher than other radioactive substances (5). Therefore, high concentration of radon may cause concern about its effects on human's health (1). So that, by inhalation or ingestion of drinking water containing radon, this gas enters the lungs and starting to decay and generating alpha-ray emitting radioactive decay products causing damage to the lung cells and ultimately causing cancer cells (5). Also, hot springs are important in terms of therapeutic characteristics and tourist attractions. So given closed space around the pools, presence of visitors in these areas, depending on the time spent on the site and amount of radioactive material into and around these pools, causes exposure of them and increases risk of contamination with radioactive substances for these people (6). So, appropriate measures should be taken against risks of exposure due to radionuclides in water for people spending a lot of time in mineral hot springs with high activity (7). Therefore,

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measurement of concentration of radioactive substances inside these waters in the vicinity of hot springs seems to be necessary in order to provide protective instructions for the visitors of these hot springs. Beitollahi, *et al.,* performed dosimeter studies in Mahallat hot springs, in central province, Iran. They reported that average concentration of radon-222 was in the range of 145 - 2731 Bql^{-1} (8). Hashemi, *et al.,* in a study on Jooshan hot spring obtained an amount of 0.063±0.003 $mSvy^{-1}$ for annual effective dose of inhalation (9). Kozłowska, *et al.,* in a study conducted in Poland, reported that amounts of annual effective dose of absorbed were between 0.003 - 1.1 in $mSvy^{-1}$ for spring and well water (10). Hot springs are natural features of Kerman province, and therapeutic properties of these hot springs encourage the officials of the province's tourism industry to identify and enhance tourism facilities for hot springs (11). Therefore, this study was conducted to measure radon-222 concentration and to determine annual effective dose of inhalation in the vicinity of hot springs of Kerman province. It is noteworthy that, this research is the first study measuring radon concentration in hot springs with different physical characteristics in Kerman province, as well as investigating harmful effects of high radon concentrations on the humans' health.

MATERIALS AND METHODS

The study area

This study was performed in Kerman province, located in southeast of Iran, which is the first-largest province of Iran with an area of 183,285 km^2. Kerman is situated at latitude of N 30˚ 28' 45" and longitude of E 57˚ 07' 26". Hot springs are natural attractions of province and are located in different cities of Kerman province. This study was performed on 16 hot springs of Kerman province and concentration of radon was measured in all of them. Hot springs were selected according to high public reception and accessibility of visitors to them. Figure 1 shows locations of 16 selected hot springs.

Sampling

This study was performed in 16 selected hot springs from July 2018 to September 2018. In each sampling location, geographical coordinates (Longitude and Latitude) and height from free sea level related to each hot spring were determined using GPS device, and temperature was measured by a digital thermometer. In near the vicinity of hot springs, water samples were collected in plastic bottles with 250 ml capacity, and they were closed tightly in order to avoid losses of radon gas, and then were labeled according to their sampling time and locations. All these samples were taken from corresponding locations with great care and under standard conditions, and were transferred to the laboratory, and ultimately radon concentration was measured in the samples.

Figure 1. Map of the study area provided with numbers associated with 16 locations of hot springs according to classification in terms of number of each hot spring as shown in table 1 (Modified from Google Maps).

Measurement technique

To measure radon concentration in water samples, RAD-7 detector was used (manufactured by Durridge Company, Inc.) connected to a RAD H_2O accessory (radon in water), which determines radon concentration in water with high accuracy (12).This device is a solid state detector which can measure energy of alpha particles electronically and its measurement range is from 4 to 400,000 Bqm^{-3}. RAD-7 detector works based on detection of alpha particles and measurement of their energy due to decay of radon and ionization created by these particles in semiconductor.

There are two different protocols for detector including Wat-40 and Wat-250 connected to 2 glass bottles of device with volumes of 40 and 250 ml, herein, glass bottle with capacity of 250 ml was used. To measure radon concentration dissolved in water sample, sample bottle was connected to RAD-7. To extract the radon from water sample, air pump of RAD-7 was turned on ,and then device extracted the radon continuously using closed loop aeration process within 5 min (in which the air recirculates through water sample) until RAD H_2O system reached to equilibrium state and no radon removed from the water sample. In this process, almost 94% of radon was extracted from the water sample and was transferred into detector chamber. After that, the pump was stopped automatically, and then the system waited for 5 min, in order to reach to equilibrium between water, air and radon products attached to the detector. After reaching to equilibrium state, the device started counting alpha particles inside the chamber every 5 minutes, involving 4 cycles of 5 minutes. During these cycles, radon decayed to polonium isotopes (Po-218, Po-214, and Po-210) and these isotopes emitted alpha particles. Electrical field in the chamber guided positively charged ions toward active surface of the detector, and then the device produced electrical signals proportional to the energy level of alpha particles. Alpha particles generated various levels of energy related to different isotopes of polonium and generated signals with different intensities in the detector, but the device only used Po-218 isotope to measure radon concentration. Finally, the detector recorded each alpha particle with respect to its energy and measured concentration of radon from number of recorded particles [13, 14]. In total, the process lasted for 30 min, and the device presented a report related to radon concentration in each cycle as well as average radon concentration (average radon concentration counted from the 4 cycles).

Determination of annual effective dose of inhalation of radon gas

Radon released from water of hot springs can be inhaled by the visitors consequently influencing on their health. To evaluate decay risks of radon on people who are in contact with the hot springs, annual effective dose of inhalation of radon was determined according to the report published by the UNSCEAR organization [15], calculated by Equation 1 as follows:

$$E_{eff}(mSvy^{-1})=C_{RnW}(Bql^{-1})\times F\times R_{aw}\times DCF\times t\times 10^{-3} \quad (1)$$

E_{eff}: annual effective dose of inhalation

C_{RnW}: Radon concentration in water

F: Equilibrium factor between radon and its progenies (0.4)

R_{aw}: the ratio of radon in air to the radon in water (10^{-4})

DCF: the dose conversion factor for radon exposure [9 nSv (Bq h m^{-3})$^{-1}$]

t: exposure time (8760 hour)

Correlation between radon gas concentration and hot spring temperature, as well as correlation between radon concentration and hot spring height from the free sea level were analyzed by SPSS software version 23 using general linear model. A p-value of <0.05 was considered as statistically significant.

RESULTS

Table 1 presents characteristics of 16 hot springs studied in Kerman province in terms of geographical coordinates (Longitude and Latitude), height of the hot spring from free sea level, temperature of the hot spring, as well as results obtained from measurement of mean radon concentration in the samples related to these hot springs in terms of Bql^{-1} and calculated values regarding annual effective dose of inhalation of radon in the hot springs in terms of $mSvy^{-1}$. As shown in table 1, mean hot spring height from free sea level and mean temperature of 16 hot springs were equal to 2128.75 m and 30.56 °C, respectively.

Table 1. Physical characteristics, mean radon concentration, and annual effective dose of inhalation related to 16 hot springs in Kerman province.

Name of the hot springs	Longitude (E)	Latitude (N)	Height (m)	Temp (˚C)	The mean radon Concentration (Bql^{-1})	Annual effective dose of inhalation ($mSvy^{-1}$)
1. Jooshan	57˚."21 .'38	30˚."12 .'09	1632	45	56.100±5.680	0.177±0.017
2. Amireh Keykhosravi	56˚."46 .'36	29˚."50 .'37	2471	26	15.700±2.170	0.049±0.006
3. Chamanrang	56˚."17 .'39	29˚."47 .'35	2450	36.5	7.460±1.270	0.023±0.004
4. Dehraees	56˚."17 .'28	30˚."37 .'27	2044	23	19.700±3.670	0.062±0.011
5. Shirinak	57˚."26 .'00	29˚."23 .'31	2742	26	4.740±0.648	0.014±0.002
6. Arjas	56˚."07 .'32	30˚."31 .'25	2196	25	6.520±0.763	0.020±0.002
7. Khajeh	56˚."29 .'56	30˚."35 .'34	1840	25	13.100±2.740	0.041±0.008
8. Hormak	57˚."40 .'54	29˚."22 .'38	1364	30	31.500±3.530	0.099±0.011
9. Maskoun	57˚."21 .'52	29˚."42 .'00	1970	39.5	1.860±0.717	0.005±0.002
10. Ghevar	57˚."36 .'39	29˚."49 .'12	2559	57	4.200±0.683	0.013±0.002
11. Ghezak	57˚."07 .'24	29˚."18 .'39	2139	34	2.880±0.360	0.009±0.001
12. Babatorsh	57˚."05 .'24	29˚."27 .'18	2433	29	0.749±0.395	0.002±0.001
13. Siyahgol	56˚."30 .'31	30˚."38 .'25	2146	20	0.158±0.129	0.000±0.000
14. Khodadadi	56˚."42 .'36	29˚."54 .'37	2471	27	8.960±1.200	0.028±0.003
15. Ab Bad Sang	56˚."06 .'04	30˚."56 .'49	1699	26	2.040±1.900	0.006±0.005
16. Ghelosalar	56˚."32 .'27	30˚."55 .'25	1904	20	0.555±0.374	0.001±0.001
Mean	-	-	2128.75	30.56	11.015	0.034

Also, mean concentration of radon measured for all samples was equal to 11.015 Bql^{-1}.

Minimum and maximum radon concentrations of samples were equal to 0.158±0.129 and 56.100±5.680 in Bql^{-1}, respectively. These amounts were related to Siyahgol and Jooshan hot springs, respectively.

Figure 2 shows the histogram related to changes in radon concentration in samples taken from the hot springs presented in table 1.

Concentration amounts in measured samples were compared with concentration amount proposed by the United States Environmental Protection Agency (EPA), (11 Bql^{-1}) [16], and results of the study

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showed that, (table 1 and figure 1) 5 samples had a concentration higher than the amount set by the EPA, corresponding to Jooshan, Amiriye Keykhosravi, Dehraees, Khajeh ,and Hormak hot springs.

Mean annual effective dose of inhalation of radon was equal to 0.034 $mSvy^{-1}$ for all hot springs. Minimum annual effective dose of inhalation of radon was obtained as 0.000±0.000 $mSvy^{-1}$, corresponding to Siyahgol hot spring, and maximum amount was obtained as 0.177±0.017 $mSvy^{-1}$, corresponding to Jooshan hot spring. Figure 3 shows the histogram related to changes in annual effective dose of inhalation of radon associated with 16 hot springs.

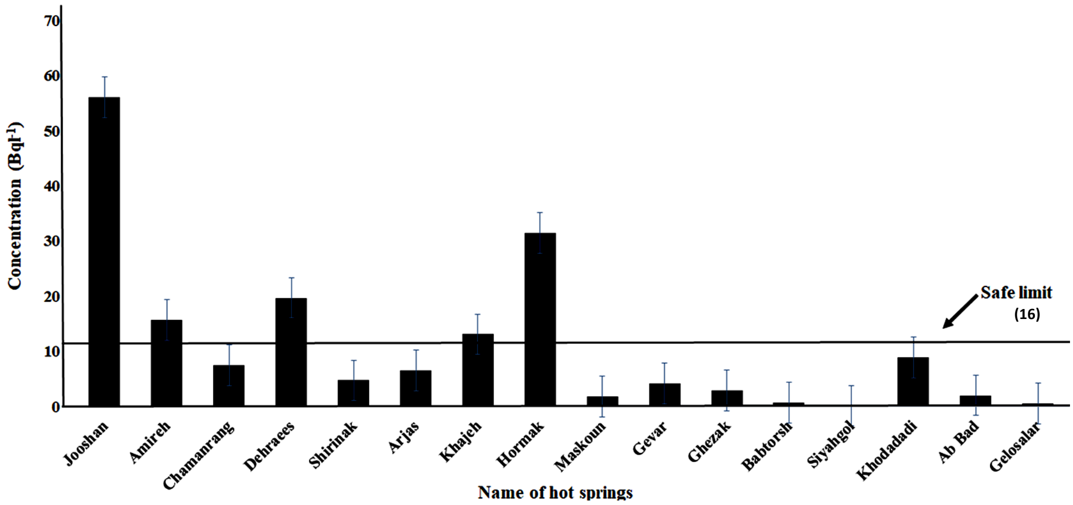

Figure 2. Histogram related to changes of radon concentration for 16 investigated hot springs in Kerman province and comparison of them with safe limit (11 Bql^{-1}) proposed by EPA organization.

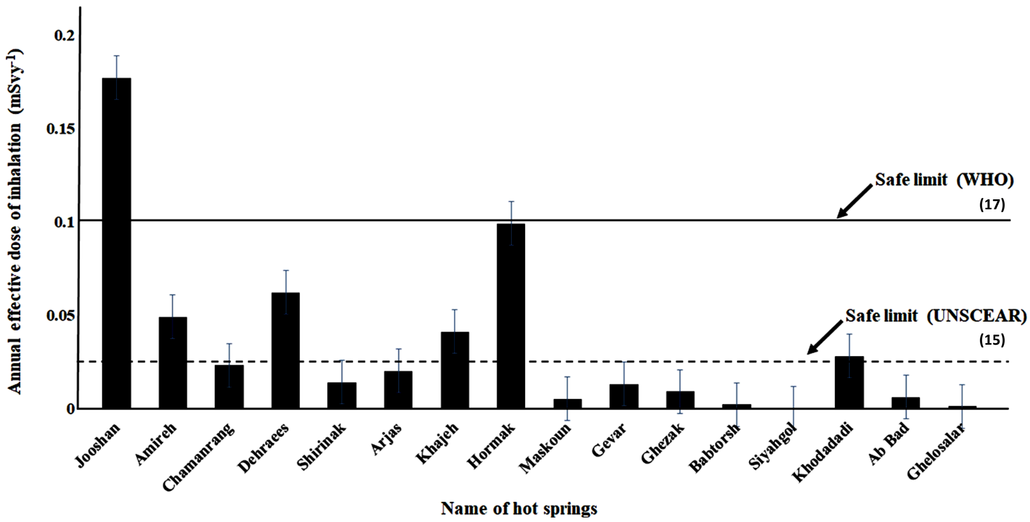

Figure 3. Histogram related to changes of annual effective dose of inhalation of radon for 16 hot springs in Kerman province and comparison of them with two safe limits proposed by WHO (0.1 $mSvy^{-1}$) and UNSCEAR (0.025 $mSvy^{-1}$) organizations.

Comparison of annual effective dose of inhalation of hot springs with the safe limit proposed by the World Health Organization (WHO), which is 0.1 $mSvy^{-1}$ [17] showed that, for Jooshan hot spring, this amount was more than the amount set by the WHO.

Also, annual effective dose amounts of inhalation were compared with the safe limit approved by the UNSCEAR (2000) organization [15], and results of study showed that, 6 hot springs had amounts more than 0.025 $mSvy^{-1}$ (the safe limit set by mentioned organization), corresponding to Jooshan, Amiriye Keykhosravi, Dehraees, Khajeh, Hormak ,and Khodadadi hot springs.

DISCUSSION

High concentration of radon gas in hot springs can increase lung cancer risk for people through inhalation of radon released from the water [5]. In this study, concentration of radon-222 was measured in 16 different hot springs in Kerman province, and then annual effective dose of inhalation was determined for each hot spring.

Statistical analysis was performed on 16 hot springs to investigate the correlation between radon concentration and hot spring temperature, as well as the correlation between radon concentration and hot

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spring height from free sea level. Analysis results showed a significant correlation between radon concentration and hot spring height from free sea level (p=0.033), but there was no significant correlation between radon concentration and hot spring temperature (p=0.186).

Various studies have been conducted on radon concentration in different hot springs of different cities of Iran such as Bandar Abbas, Tehran, and Chaharmahal and Bakhtiari [5, 18, 19]. In the present study, investigation of radon concentration amounts in hot springs showed that, 31% of hot springs had a concentration higher than the safe limit determined by EPA. Also, annual effective dose amounts of inhalation were compared with the safe limits set by WHO and UNSCEAR (2000), which amount of annual effective dose of inhalation in Jooshan hot spring (0.177 $mSvy^{-1}$) was more than the safe limit set by WHO, and also 37% of hot springs had amounts higher than the safe limit set by UNSCEAR (2000) organization.

In addition, regarding comparison of amounts of radon concentration in different hot springs, several studies have been investigated in Jordan, Brazil, Turkey, and Macedonia (Northern Greece) [20-23]. Table 2 shows amounts of the radon concentration in other cities of Iran and in other countries of the world.

Table 2. Comparison of average radon concentration of 16 hot springs obtained in this study.

Country/City	Jordan	Brazil	Turkey	Macedonia (Northern Greece)	Tehran	Chaharmahal and Bakhtiari	Bandar Abbas	Present study
Mean Radon Concentration(Bql^{-1})	3.9	120	10.84	50	3.7	2.3	0.684	11.015
Reference number	20	21	22	23	18	19	5	-

Mean radon concentration of 16 hot springs in the present study was lower than mean concentration measured in countries such as Brazil and Macedonia (Northern Greece). Also, mean radon concentration of 16 hot springs in this study was higher than mean concentration of radon obtained in Jordan, Turkey [20], and cities of Tehran [5], Chaharmahal and Bakhtiari [19], and Bandar Abbas [19].

In this study, range of changes in radon concentration was between 158 - 56.100 in Bql^{-1}.

Kandari, *et al.,* in a study on 15 samples, determined radon concentration between 1.7 - 57.7 in Bql^{-1} [24]. Also, Fonollosa, *et al.*, in a study conducted in Spain, measured range of radon changes in 15 springs in southern Catalonia from 1.4 to 105 in Bql^{-1} [25]. These minimum and maximum reported amounts are comparable to results of the present study.

Different concentrations of radon in various hot springs expose the people to different doses of this radioactive substance. So that, annual effective dose amount of inhalation is function of radon concentration in hot spring, and in the present study, these amounts were determined between 0.000 - 0.177 in $mSvy^{-1}$, that were comparable to results of other studies.

Hashemi, *et al.,* determined annual effective dose of inhalation of radon as 0.06 $mSvy^{-1}$ in the Jooshan hot spring [9]. While, in the present study, this amount was determined to be 0.177 $mSvy^{-1}$ in the Jooshan hot spring.

Rani, et al., in a study on water of 65 villages in India, determined annual effective dose of absorption between 8.82 - 49.98 μSvy^{-1} [26].

Differences in results of these studies can be due to different geological and geographical structure of the regions, distance of hot springs existing in the vicinity from faults and fractures, time and sampling, and environmental conditions [13, 25, 27].

In cases where radioactivity exceeds permitted amounts, appropriate instructions and arrangements should be made by relevant organizations to reduce the risks due to radiation higher than permitted amounts in hot springs. Installing boards at hot spring to inform and alert visitors is necessary to avoid hazards of hot springs.

Also, in this study, one of advantages of measuring the radon concentration in the vicinity of hot springs of Kerman province is providing a national background map of radon associated with hot springs, according which one can determine exact geographical location of hot springs and calculate annual effective dose of inhalation received by visitors from hot springs. Also, it is recommended to perform this study in other provinces where there are hot springs, to develop a national map related to background radiation of radon gas.

CONCLUSION

By comparing results obtained from measurement of radon concentration in water samples with the safe limit set by EPA, it was observed that, 5 samples related to hot springs had amounts more than this safe limit. Also, annual effective dose of inhalation in 6 hot springs was higher than safe limit set by the UNSCEAR (2000)[15]. Accordingly, it is recommended to install a board showing radon concentration amount in the vicinity of hot springs for public information.

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