JHAD
Health and Development Journal

https://jhad.kmu.ac.ir
10.34172/jhad.92332
Vol. 11, No. 2, 2022, 98-104

Original Article

The Annual Amount of Radon Radiation from Drinking Water Sources in Children and Adults in Roudan county, Iran

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Abstract

Background: Radon is a major source of natural radiation in water, soil, and air. Natural sources of radiation are major contributors to the radiation humans and other living beings receive.

Methods: This cross-sectional study was conducted on drinking water sources of three cities and 18 villages of Roudan county in 2021. The measurement of radon concentration in the collected samples was performed using the RAD7 device.

Results: In the studied water sources, the highest and lowest radon concentrations were 11.00 ± 2.09 and 0.95 ± 0.23 kBq/m^3, respectively. The average radon concentration was 4.98 ± 0.76 Bq/L which was lower than 11 Bq/L (the EPA level recommended for drinking water). The mean annual effective dose of radon, due to direct and continuous water intake for adults and children was 48.01 ± 11.56 and 65.86 ± 15.86 µSv/y, respectively.

Conclusion: The results of this study showed that radon concentrations in two regions of Roudan county were higher than the allowed World Health Organization (WHO) concentration and people who normally use these resources for drinking during the year are exposed to abnormal radiation levels.

Keywords: Radiation, Radon concentration, Effective dose, Water pollution, Hormozgan, Roudan county

Citation: Dehghani Ghanatghestani M. The annual amount of radon radiation from drinking water sources in children and adults in Roudan county, Iran. Health Dev J. 2022;11(2):98–104. doi:10.34172/jhad.92332

Received: January 31, 2023, **Accepted**: August 19, 2023, **ePublished**: August 26, 2023

Introduction

Humans are exposed to a variety of radiation sources throughout their lives, and rays from radioactive materials are a potential health hazard for humans (1,2). According to the latest data provided by the World Health Organization (WHO), the mean radiation each person receives from normal radiation sources is estimated to be 2.4 mSv.y^{-1} while the rate of radiation received from artificial sources is 0.8 mSv.y^{-1}(3). Therefore, natural sources of radiation account for a major proportion of the radiation that humans and living beings receive (4). Natural radiation from internal origins in the human body (energy of about 5.5 MeV) can cause DNA destruction in sensitive internal tissues, including the lungs (5).

Radon is a natural radioactive element that results from the decay of ^{238}U, ^{235}U, and ^{222}Th on Earth (3). The most stable isotope of this element is ^{222}Rn, which is used in radiotherapy. Radon accounts for approximately 55% of the natural radiation that people are exposed to (4). Due to the high ionization power of radon, the alpha radiation caused by the decay of radon is a risk compared to other rays (β and γ) from internal radiation origins, leading to damage to the gastrointestinal and respiratory tract of humans and the possibility of lung and stomach cancer (6-8).

Radon gas is continuously generated within the rock strata, migrating through the Earth's crust to the atmosphere. The radiological health hazards associated with radon due to the consumption of ground water have become a global environmental issue (9). According to the WHO, radon is the second cause of lung cancer after smoking and one of the most important health problems in developed countries (1). In the United States, too, ^{222}Rn is the second most important risk factor for lung cancer after smoking (4,7).

When a person consumes water containing ^{222}Rn, the α rays released by its decay cause damage to the DNA of the stomach's cells. Radon can also enter the bloodstream by infiltration into the stomach wall and then spread throughout the body (10). The concentration of radioactive material in groundwater is higher than in surface water due to contact with igneous rocks and the sedimentary bedrock (11,12). According to the WHO, the maximum allowed value of ^{222}Rn concentration in drinking water is 100 kBq/m^3 (13). The USEPA has declared the allowed maximum contamination level of radon concentration in water to be 11 Bq/L (14).

In studies conducted in India by Rani et al, the water resources of 65 villages were measured and the minimum and maximum annual absorption doses of Radon were reported to be 8.82 and 49.98 mSv/y, respectively (15). Fonollosa et al reported radon concentrations of 15 water springs in southern Catalonia, Spain, as ranging from 1.4

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to 105 Bq/L (16). Wu et al, in China, reported the mean radon concentration in 73 samples of groundwater to be 11.8 Bq/L (17). In Iran, Rahimi et al reported that the concentration of radon in drinking water resources of the Rafsanjan and Anar regions were 0.32 ± 0.12 Bq/L and 13.9 ± 2.45 Bq/L, respectively (18). In two separate studies, Malakootian et al measured the concentration of radon in drinking water resources around the Lalehzar and Rafsanjan faults as 0.74 and 26.88 Bq/L, respectively (19,20). The concentration ranges of radon dissolved in groundwater were 0.87–6.73 Bq/L in Himachal Pradesh (21) and 0.14–35 Bq/L in Punjab (22). The average and range of ^{222}Rn concentration in the bottled water of Bandar Abbas city were reported to be 641 ± 9 Bq/m3 and 0–901 Bq/m3, respectively (23).

In addition to agricultural uses, the groundwater resources in Roudan county provide the drinking water needed by the cities and villages of this county. In 2019, the volume of underground water in Roudan county was estimated at 320,206 million cubic meters, of which 93.9% is used in the agricultural sector, 4.5% for drinking and in the domestic sector, and the rest in other sectors. This County has 4402 deep and semi-deep wells, which includes 22.6% of all wells in Hormozgan Province. Therefore, the presence of radon in the groundwater of this county is a concern for the health of the residents of villages and cities in this area.

Methods

In the present research, based on the initial geological studies of the region, the type of fractures and position of faults in Roudan county, as well as the distribution of cities and villages and their population density, three cities and 18 villages were selected for the sampling of groundwater resources located in the geographical coordinates ranging from 56°50′ E to 57°29′ E and from 27°5′ N to 27°59′ N. The total population of the studied villages was 84405 people, of which 42962 were males and 41443 were females, and the population of children (less than 10 years) was 18662.

The total number of water wells in the 21 settlements studied was 241 wells, and according to the Cochran's sample size formula, 87 water wells were randomly selected for sampling. Sampling of well water was performed twice per season in the two seasons of spring and summer in 2021 by the standard method (ASTM Standards D5903 and D6089).

Measurement of radon concentration in the collected samples was performed using the RAD7 device. RAD7 (manufactured by Durridge) with a Rad H20 accessory was used to measure radon in water within the concentration range of less than 10 pCi/L to greater than 400 000 pCi/L.

The RAD7 device works based on the alpha particle energy emitted by radon and thoron. The RAD method employs a closed loop aeration design in which the air volume and water volume are constant and independent of flow rate. The air recirculates through the water and continuously extracts the radon until a state of equilibrium develops. The RAD system reaches this state of equilibrium within about 5 min, after which no more radon can be extracted from the water. The schematic diagram of RAD7 is presented in Figure 1.

This device has two glass bottles of 40 and 250 cc and two protocols (Wat 40 and Wat 250) are defined based on this. In this study, the Wat 250 protocol was used. According to this protocol, the first 5 minutes of bubbling was carried out automatically. During the bubbling phase, 94% of the radon gas dissolved in water was removed, and the pump stopped automatically after 5 minutes. The system waited for 5 minutes for the gas to reach equilibrium. The alpha particles were then counted after 5 minutes. Radon concentration was measured during the four stages. The nuclei of Rn-222 decays in the chamber of RAD7 and produces Po-218 positive-charged ions. The electrical field in the chamber causes drifting of the ions toward the detector. The nucleus of Po-218 has a short half-life and decays on the active surface of the detector, emitting alpha particles. These particles enter the detector, and the machine generates signals proportionate to the intensity of alpha particles. Then the device records the alpha particles according to the recorded energy and determines radon concentration according to the number of recorded particles.

The device was in purge phase for 10 minutes after each sample reading in order to remove residual radon. The time required for each sample, including the time needed to purge was 40 minutes. Radon concentration was measured five times for each sample and the minimum, maximum, and average radon activity (average of five measurements) and tolerance (measurement error) were recorded. The minimum detectable concentration of RAD7 was 0.2 Bq/L.

During the measurement period, ^{222}Rn decayed inside the chamber and α particles were produced. The detector recorded α particles according to their energy and determined the concentration of radon based on the number of recorded particles.

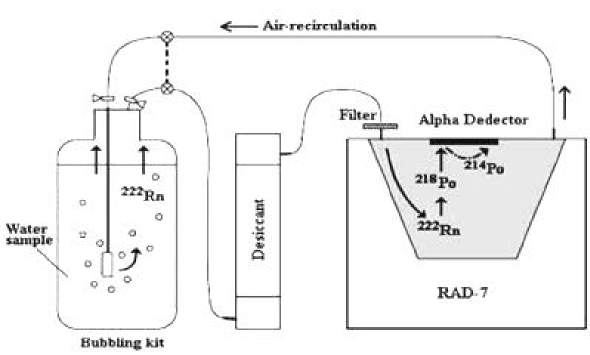

Figure 1. Schematic representation of RAD7 and its measuring instruments

After measuring radon concentration, the annual effective dose of ingestion (AED_{ing}) was calculated using equation 1 (2):

$$AED_{ing}\ (\mu Sv.y^{-1}) = C_{RnW} \times D_W \times DCF \times EF \qquad (1)$$

In this equation, C_{RnW} is the radon concentration in Bq/L, D_W is the daily water intake, 2 L/day for adults and 1.5 L/day for children (24), *DCF* is the ingesting dose conversion factor of ^{222}Rn 10^{-8} Sv/Bq (25), and *EF* is the exposure frequency in 365 days per year (24).

The annual effective dose of inhalation (AED_{inh}) was also calculated using Equation 2 (2):

$$AED_{inh}\ (\mu Sv.y^{-1}) = C_{RnW} \times R \times F \times O \times DCF \qquad (2)$$

In this equation, C_{RnW} is the radon concentration in Bq/L, *R* is the ratio of radon in air to radon in water (10^{-4}), *F* is the equilibrium factor between radon and its progenies (0.4), *O* is the average indoor occupancy time per individual (7000 hours to year) and *DCF* is the dose conversion factor for radon exposure (9 $nSv.Bq^{-1}h^{-1}m^3$) (26). The total effective annual dose (AED_T) is also obtained from the total effective annual dose of ingestion and inhalation.

Results

As shown in Table 1, of the 87 sampling stations, the radon concentration in the water wells of the Abnama region, with 11.00 ± 2 .09 Bq/L, was higher than other stations. The lowest radon concentration was related to the water of the wells of Komiz village with 0.95 ± 0.23 Bq/L. The mean radon concentration in the 21 studied regions of Roudan county was 4.89 ± 1.18 Bq/L. Figure 2 shows the spatial distribution of the measured radon concentration in the sampling stations. The results of one-way analysis of variance showed that there was a significant difference between the mean concentration of radon in the measured wells ($P < 0.001$, $r = 0.81$). Also, the mean radon concentration in all studied samples was significantly ($P < 0.001$) lower than the 11.1 Bq/L level recommended by USEPA (14).

According to the measured values of radon concentration, the minimum and maximum values of annual effective dose of radon due to direct and continuous water intake (ingestion and inhalation) for adults were 9.28 ± 2.26 and 108.02 ± 20.52 $\mu Sv.y^{-1}$, respectively. Also, the minimum and maximum values of effective annual dose (ingestion and inhalation) for children were 12.73 ± 3.10 and 148.17 ± 28.15 $\mu Sv.y^{-1}$, respectively (Table 1).

Figures 3 and 4 show the annual absorbed dose of radon for ingestion and inhalation for each of the studied regions. It is noteworthy that different effective doses are obtained

Table 1. Radon concentrations in well water samples and annual effective doses (ingestion and inhalation) due to the use of water from the studied sources

Sample location	Population	No. of sampling wells	Radon concentration (Bq/L)	Annual mean effective dose for ingestion and inhalation ($\mu Sv.y^{-1}$)	
				Adults	Children
Roudan	36121	9	6.10 ± 1.21	82.17 ± 16.30	59.90 ± 11.88
Zyaratali	2679	4	5.99 ± 1.26	80.64 ± 16.97	58.79 ± 12.37
Bikah	8732	8	3.71 ± 0.98	49.97 ± 13.20	36.43 ± 9.62
Sekol	2187	4	1.75 ± 0.75	23.57 ± 10.10	17.19 ± 7.37
Rahdar	346	2	9.87 ± 2.24	132.95 ± 30.17	96.92 ± 22.00
Komiz	3831	2	0.95 ± 0.23	12.73 ± 3.10	9.28 ± 2.26
Khirabad	2569	4	1.67 ± 0.45	22.49 ± 6.06	16.40 ± 4.42
Nazak	446	3	3.43 ± 1.04	46.20 ± 14.01	33.68 ± 10.21
Eslamabad	5618	5	6.19 ± 1.25	83.38 ± 16.84	60.79 ± 12.28
Faryab	1146	7	6.98 ± 1.42	94.02 ± 19.13	68.54 ± 13.94
Dehgelkan	917	3	2.48 ± 0.98	33.41 ± 13.20	24.35 ± 9.62
Jaghin	1277	2	8.90 ± 2.24	119.88 ± 30.17	87.40 ± 22.00
Berentin	5799	8	4.59 ± 0.90	61.79 ± 12.12	45.04 ± 8.84
Kharaji	4712	5	2.31 ± 0.58	31.17 ± 7.81	22.72 ± 5.70
Abnama	1341	3	11.00 ± 2.09	148.17 ± 28.15	108.02 ± 20.52
Sarzeh	374	2	2.37 ± 0.91	31.86 ± 12.26	23.22 ± 8.94
Naserabad	1052	3	2.93 ± 0.78	39.47 ± 10.51	28.77 ± 7.66
Sarjoeih	3938	5	3.60 ± 1.12	48.47 ± 15.09	35.33 ± 11.00
Mosaferabad	293	2	6.74 ± 1.25	90.79 ± 12.28	66.19 ± 16.84
Vaziri	547	3	5.35 ± 1.97	72.06 ± 26.54	52.54 ± 19.35
Chiramabad	480	9	5.78 ± 1.08	77.86 ± 14.55	56.76 ± 10.61

according to different dosimetry factors for a given concentration. Therefore, it is important to pay attention to the standard used to calculate the effective dose and express its results. As can be seen, the highest and lowest effective annual doses of radon due to ingestion were 80.30 ± 15.26 and 6.90 ± 1.68 μSv.y^{-1}, respectively. Also, the highest annual effective dose of radon due to inhalation was 27.72 ± 5.27 μSv.y^{-1} and the lowest absorbed value of radon due to inhalation was 2.38 ± 0.58 μSv.y^{-1}.

Figure 5 shows the total effective annual dose of ingestion and inhalation. The highest and lowest annual effective doses were 108.02 ± 20.52 and 9.28 ± 2.26 μSv y^{-1} for the Abnama and Komiz stations, respectively. Comparison of these doses with the allowed WHO value from the 21 studied regions showed that in a single station the total effective annual dose was higher than the standard value (12,23). Also, the total annual effective dose of radon in all studied wells was significantly lower than 100 Bq/m^3, which is the action level proposed by the World Health Organization (13).

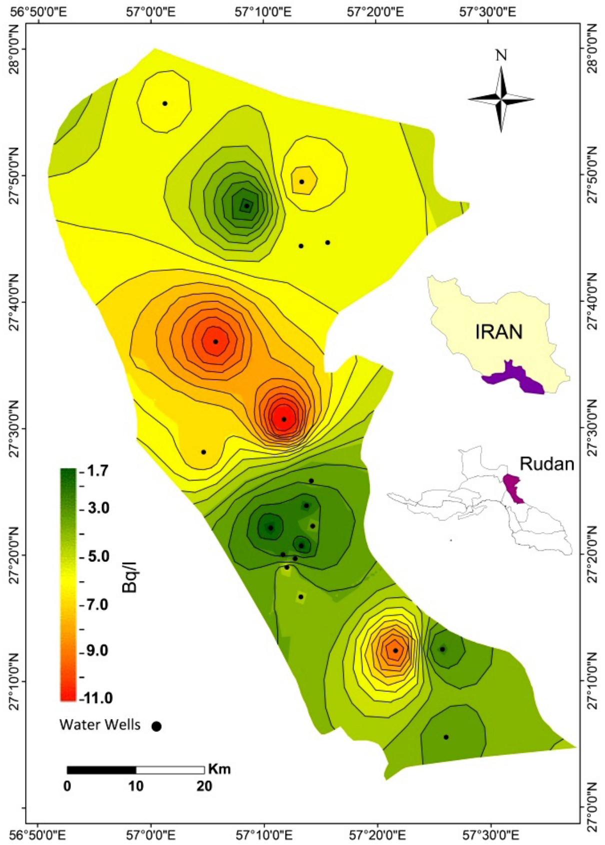

Figure 2. Map of the radon concentration with location of springs and lineaments in Roudan county

Of the population living in the study areas, 21.5% were children under 10 years old, for whom the effective absorbed dose is higher. In this study, the effective annual dose absorbed by children was about 18.75 μSv.y^{-1} higher than that of adults (Figure 6). However, the results of the independent sample *t*-test showed that there was no significant difference between the annual values of radon absorption in the two groups of adults and children ($P < 0.001$).

Discussion

Among the studied regions, the highest radon concentration measured was 11.00 Bq/L, which is less than the values reported by Akar Tarim et al, which were on average 19.9 Bq/L in groundwater in Bursa, Turkey (27), Rani et al, with a mean of 19.9 Bq/L in northern Rajasthan, India (15), and Marques et al with a mean of 21.8 Bq/L in Brazil (28).

As shown in Table 2, this study found a mean annual effective dose of radon in drinking water samples equal to 56.94 (±23.46) μSv.y-1, which was less than the values reported by Wu et al in China as 72.6 μSv.y-1 (17), Rahimi et al in Iran, which was 45.7–309.2 μSv.y-1 (18), and Srinivasa et al in Chikmagalur city, Karnataka state, India, as 1.39–414.9 μSv.y-1 (30), but higher than the results reported by Duggal et al in the Bathinda district of Punjab State as 21.34 μSv.y-1 (29), Akar Tarim et al in Turkey as mean 11.1 μSv.y-1(27), Marques et al in Brazil as mean 21.8 μSv.y-1 (28), Manzoor et al. in Pakistan which was

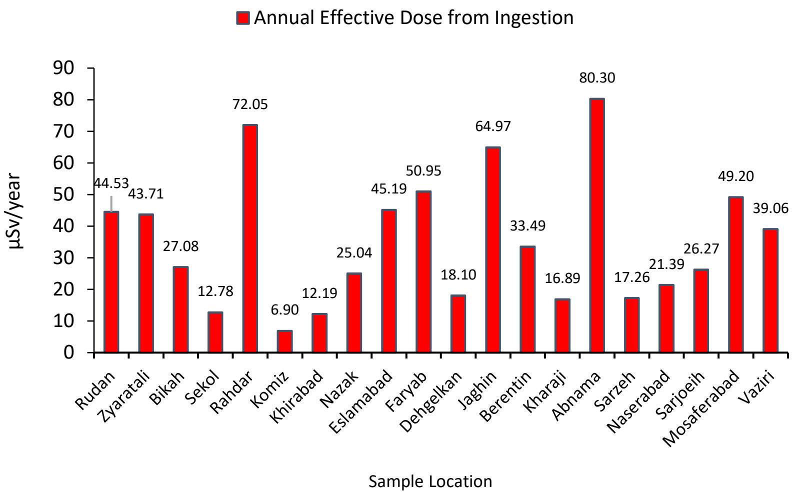

Figure 3. The effective annual dose due to the ingestion of radon in the water of the studied wells

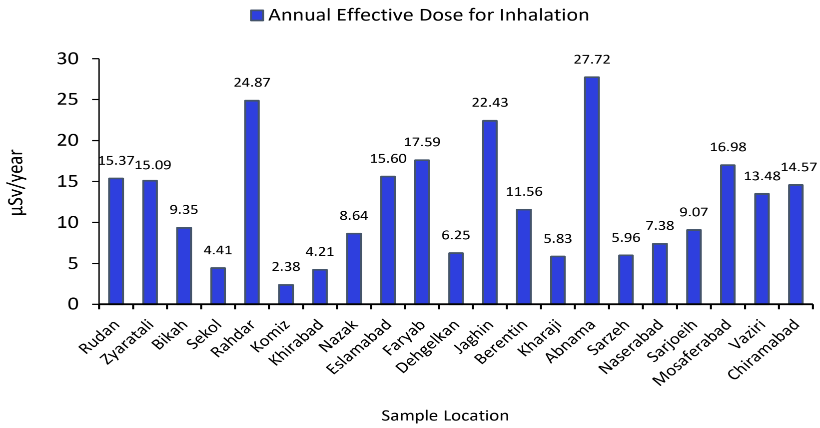

Figure 4. The effective annual dose due to the inhalation of radon in the water of the studied wells

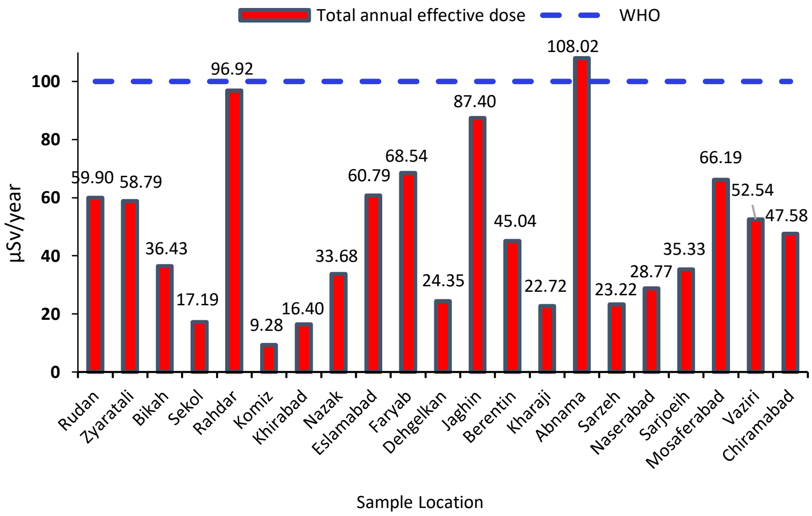

Figure 5. The total annual effective dose of radon in the water (The dashed line the WHO total annual recommended limit)

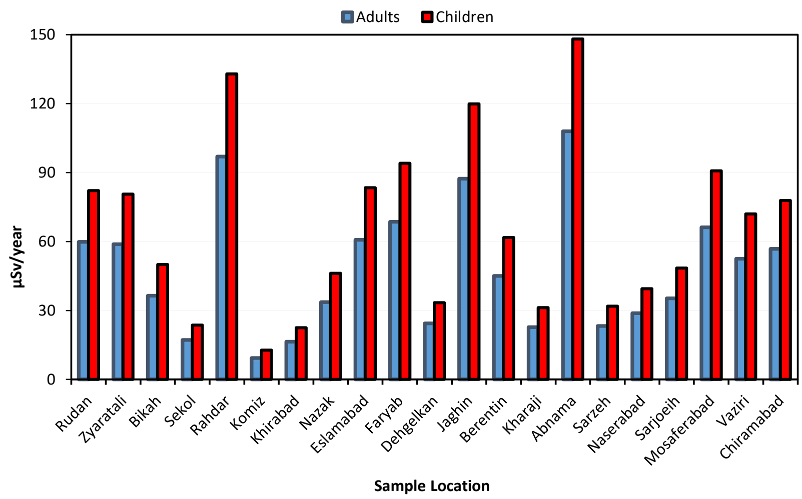

Figure 6. Comparison of the total dose of radon between adults and children

16.5 ± 12.8 µSv.y-1 (31), Nasser et al in Oman which was 0.38 ± 0.99 µSv.y-1 (32), Cosma et al 15.4 µSv.y-1 and Nikolopoulos and Louizi in Cyprus and Greece as mean 5.9 and 5.4 µSv.y-1, respectively (33, 34). Also, the annual mean effective dose for ingestion and inhalation measured in this study are in the range of the values measured by Forte et al and Cho et al (35,36).

This research aimed to determine the mean annual effective dose of radon in the drinking water resources of the residents of the villages of Roudan county, and showed that due to the active fractures and faults in the region, which are the probable source of radioactive radiation, the concentration of radon dissolved in groundwater is on average 4899 Bq/m^3, which is more than the

Table 2. Comparison of radon concentration in groundwater reported by different investigators

Sample location	Annual mean effective dose for ingestion and inhalation (µSv.y⁻¹)		References
	Range	Mean	
China	28.7–393.8	72.6	Wu et al, 2018 (17)
Iran	45.7–309.2	76.1	Rahimi, et al, 2018 (18)
Turkey	1.46–53.64	11.1	Akar Tarim et al, 2012(27)
Brazil	0.95–36.0	21.8	Marques et al, 2004 (28)
India	8.82–49.98	21.34	Duggal et al, 2013 (29)
India	1.39–414.9	62.04	Srinivasa et al, 2019 (30)
Pakistan	7.3–28.8	16.5	Manzoor et al, 2008 (31)
Oman	0.38–0.99	0.57	Nasser et al, 2019 (32)
Romania	0.5–129.3	15.4	Cosma et al, 2008 (33)
Cyprus	0.3–20.0	5.9	Nikolopoulos and Louizi, 2008 (34)
Greece	0.8–24.0	5.4	Nikolopoulos and Louizi, 2008 (34)
Italian	3.6–371.7	104.1	Forte et al, 2007 (35)
South Korea	2.9–300.0	86.9	Cho et al, 2004 (36)
Iran	9.28–148.17	56.94	Present investigation

recommended level of 11.0 Bq/L reported by USEPA (14).

In this study, the mean values obtained for ground waters in the area were 4.98 ± 0.76 Bq/L. The minimum and maximum values of the annual effective dose of radon due to direct and continuous water intake (ingestion and inhalation) for adults were 9.28 ± 2.26 and 108.02 ± 20.52 $\mu Sv.y^{-1}$, respectively. The mean value of the total annual effective dose due to inhalation of waterborne radon and ingestion was about 11.8% higher than the WHO's recommended reference dose level (RDL) of 0.1 mSv for annual intake of drinking water. The RDL of 0.1 mSv is equal to 10% of the dose limit for the intervention level recommended by the International Commission on Radiological Protection (ICRP) and the International Basic Safety Standards (3). However, this value is only 1% of the intervention exemption level (1 mSv) recommended by the ICRP (37,38). A study conducted by Abdallah et al on well and spring water in Lebanon showed that the radon concentrations of samples were more than 11 Bq/L (39). A similar study conducted in Mashhad revealed that the radon concentration in 70% of drinking water samples from various places and supplies of public water were higher than the EPA's permitted standard (40). The difference between the results of the present research and other studies depends on several factors, including temperature, geological features, the condition of the waterways, and the distance of water resources from faults and fractures (7,38).

Conclusion

The results of this study showed that radon concentration in two regions of Roudan county was higher than the allowed concentration by the WHO and people who normally use these resources for drinking during the year are more exposed to radiation. These results can also change under environmental, spatial, and temporal changes. The obtained results will be useful for the Environmental Protection Organization and the Water and Wastewater Company of Hormozgan province for better management of the groundwater resources of the region and sustainability for use. Expanding the search areas throughout Hormozgan province will be necessary and mandatory to create a radon zoning map.

Acknowledgements

The author would like to thank the chemistry laboratory research assistant of Bandar Abbas Islamic Azad University, who helped in this research project.

Competing Interests

The author declares no conflict of interest.

References

1. National Research Council (US) Committee on Risk Assessment of Exposure to Radon in Drinking Water. Risk Assessment of Radon in Drinking Water. Washington, DC: National Academies Press; 1999.
2. United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR). The General Assembly with Scientific Annex. New York: United Nations; 2000.
3. World Health Organization (WHO). Guidelines for Drinking-Water Quality, The Third Edition Incorporating the First and Second Addenda, Vol. 1 Recommendations, 3rd ed. Geneva: WHO; 2008.
4. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Sources, Effects and Risks of Ionizing Radiation. New York: United Nations; 2009.
5. Auvinen A, Salonen L, Pekkanen J, Pukkala E, Ilus T, Kurttio P. Radon and other natural radionuclides in drinking water and risk of stomach cancer: a case-cohort study in Finland. Int J Cancer. 2005;114(1):109-13. doi: 10.1002/ijc.20680.
6. Kendall GM, Smith TJ. Doses to organs and tissues from radon and its decay products. J Radiol Prot. 2002;22(4):389-406. doi: 10.1088/0952-4746/22/4/304.
7. Tirmarche M, Harrison JD, Laurier D, Paquet F, Blanchardon E, Marsh JW. ICRP Publication 115. Lung cancer risk from radon and progeny and statement on radon. Ann ICRP. 2010;40(1):1-64. doi: 10.1016/j.icrp.2011.08.011.
8. Grande S, Risica S. Radionuclides in drinking water: the recent legislative requirements of the European Union. J Radiol Prot. 2015;35(1):1-19. doi: 10.1088/0952-4746/35/1/1.
9. Seid AM, Turhan Ş, Kurnaz A, Bakır TK, Hançerlioğulları A. Radon concentration of different brands of bottled natural mineral water commercially sold in Turkey and radiological risk assessment. Int J Environ Anal Chem. 2022;102(19):7469-81. doi: 10.1080/03067319.2020.1830989.
10. Thompson RE, Nelson DF, Popkin JH, Popkin Z. Case-control study of lung cancer risk from residential radon exposure in Worcester county, Massachusetts. Health Phys. 2008;94(3):228-41. doi: 10.1097/01.HP.0000288561.53790.5f.
11. Hussein AS. Radon measurements in water samples from western desert of Egypt using nuclear track detectors and estimation of corresponding doses. Radiat Prot Environ. 2014;37(3):165-8. doi: 10.4103/0972-0464.154879.
12. Kam E, Bozkurt A. Environmental radioactivity measurements

in Kastamonu region of northern Turkey. Appl Radiat Isot. 2007;65(4):440-4. doi: 10.1016/j.apradiso.2006.11.005.
13. World Health Organization (WHO). Guidelines for drinking-water quality. In: Incorporating the First and Second Addenda. 3rd ed. Geneva: WHO; 2008.
14. United States Environmental Protection Agency (USEPA). Radon in drinking water health risk reduction and cost analysis. Fed Regist. 1999;64(38):9560-99.
15. Rani A, Mehra R, Duggal V. Radon monitoring in groundwater samples from some areas of northern Rajasthan, India, using a RAD7 detector. Radiat Prot Dosimetry. 2013;153(4):496-501. doi: 10.1093/rpd/ncs130.
16. Fonollosa E, Peñalver A, Borrull F, Aguilar C. Radon in spring waters in the south of Catalonia. J Environ Radioact. 2016;151 Pt 1:275-81. doi: 10.1016/j.jenvrad.2015.10.019.
17. Wu Y, Cui H, Liu J, Shang B, Su X. Radon concentrations in underground drinking water in parts of cities, China. Radiat Prot Dosimetry. 2018;178(4):354-8. doi: 10.1093/rpd/ncx121.
18. Rahimi M, Asadi Mohammad Abadi A, Jabbari Koopaei L. The measurement of radon gas dissolved in groundwater and determination of annual effective absorbed dose of radon gas in Zarand city in 2016. J Rafsanjan Univ Med Sci. 2018;16(12):1126-37. [Persian].
19. Malakootian M, Soltani Nejhad Y. Determination of radon concentration in drinking water of Bam villages and evaluation of the annual effective dose. Int J Radiat Res. 2017;15(1):81-9. doi: 10.18869/acadpub.ijrr.15.1.81.
20. Malakootian M, Khashi Z, Iranmanesh F, Rahimi M. Radon concentration in drinking water in villages nearby Rafsanjan fault and evaluation the annual effective dose. J Radioanal Nucl Chem. 2014;302(3):1167-76. doi: 10.1007/s10967-014-3345-1.
21. Singh P, Singh P, Sahoo BK, Bajwa BS. A study on uranium and radon levels in drinking water sources of a mineralized zone of Himachal Pradesh, India. J Radioanal Nucl Chem. 2016;309(2):541-9. doi: 10.1007/s10967-015-4629-9.
22. Pant D, Keesari T, Rishi M, Sharma DA, Thakur N, Singh G, et al. Spatiotemporal distribution of dissolved radon in uranium impacted aquifers of southwest Punjab. J Radioanal Nucl Chem. 2020;323(3):1237-49. doi: 10.1007/s10967-019-06656-w.
23. Fakhri Y, Mahvi AH, Langarizadeh G, Zandsalimi Y, Rasouli Amirhajeloo L, Kargosha M, et al. Effective dose of radon 222 bottled water in different age groups humans: Bandar Abbas city, Iran. Glob J Health Sci. 2015;8(2):64-71. doi: 10.5539/gjhs.v8n2p64.
24. Institute of Standards and Industrial Research of Iran (ISIRI). Drinking Water Sampling Instructions. No. 2348. ISIRI; 2013.
25. World Health Organization (WHO). Guidelines for Drinking-Water Quality. Vol 1. Recommendations, 3rd ed. Geneva: WHO; 2004.
26. United Nations Scientific Committee on the Effects of Atomic Radiations (UNSCEAR). Sources and Effects of Ionizing Radiation. Annex A: Exposure From Natural Sources of Radiation. New York: United Nations; 1993.
27. Akar Tarim U, Gurler O, Akkaya G, Kilic N, Yalcin S, Kaynak G, et al. Evaluation of radon concentration in well and tap waters in Bursa, Turkey. Radiat Prot Dosimetry. 2012;150(2):207-12. doi: 10.1093/rpd/ncr394.
28. Marques AL, Dos Santos W, Geraldo LP. Direct measurements of radon activity in water from various natural sources using nuclear track detectors. Appl Radiat Isot. 2004;60(6):801-4. doi: 10.1016/j.apradiso.2004.01.015.
29. Srinivasa E, Rangaswamy DR, Sannappa J. Measurement of radon concentration and evaluation of total dose in drinking water of Chikmagalur city, Karnataka. J Geol Soc India. 2019;94(1):100-4. doi: 10.1007/s12594-019-1273-y.
30. Duggal V, Mehra R, Rani A. Determination of 222RN level in groundwater using a Rad7 detector in the Bathinda district of Punjab, India. Radiat Prot Dosimetry. 2013;156(2):239-45. doi: 10.1093/rpd/nct054.
31. Manzoor F, Alaamer AS, Tahir SN. Exposures to 222Rn from consumption of underground municipal water supplies in Pakistan. Radiat Prot Dosimetry. 2008;130(3):392-6. doi: 10.1093/rpd/ncn156.
32. Nasser SM, Khandaker MU, Bradley DA, Isinkaye MO. Evaluation of radon concentration in irrigation and drinking waters from the eastern part of Oman and estimation of effective doses to Omanis. Radiat Prot Dosimetry. 2019;184(3-4):422-5. doi: 10.1093/rpd/ncz088.
33. Cosma C, Moldovan M, Dicu T, Kovacs T. Radon in water from Transylvania (Romania). Radiat Meas. 2008;43(8):1423-8. doi: 10.1016/j.radmeas.2008.05.001.
34. Nikolopoulos D, Louizi A. Study of indoor radon and radon in drinking water in Greece and Cyprus: implications to exposure and dose. Radiat Meas. 2008;43(7):1305-14. doi: 10.1016/j.radmeas.2008.03.043.
35. Forte M, Rusconi R, Cazzaniga MT, Sgorbati G. The measurement of radioactivity in Italian drinking waters. Microchem J. 2007;85(1):98-102. doi: 10.1016/j.microc.2006.03.004.
36. Cho JS, Ahn JK, Kim HC, Lee DW. Radon concentrations in groundwater in Busan measured with a liquid scintillation counter method. J Environ Radioact. 2004;75(1):105-12. doi: 10.1016/j.jenvrad.2003.06.002.
37. Paquet F, Bailey MR, Leggett RW, Lipsztein J, Marsh J, Fell TP, et al. ICRP Publication 137. Occupational intakes of radionuclides: part 3. Ann ICRP. 2017;46(3-4):1-486. doi: 10.1177/0146645317734963.
38. Protection against radon-222 at home and at work. A report of a task group of the International Commission on Radiological Protection. Ann ICRP. 1993;23(2):1-45.
39. Abdallah SM, Habib RR, Nuwayhid RY, Chatila M, Katul G. Radon measurements in well and spring water in Lebanon. Radiat Meas. 2007;42(2):298-303. doi: 10.1016/j.radmeas.2006.11.004.
40. Binesh A, Mowlavi AA, Mohammadi S. Estimation of the effective dose from radon ingestion and inhalation in drinking water sources of Mashhad, Iran. Iran J Radiat Res. 2012;10(1):37-41.