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Estimated Annual Effective Doses of Radon in Springs and Qanats Nearby Kouhbanan Active Fault System; Iran

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Abstract

The presence of radon in drinking water causes health risks associated with exposure from both inhalation and ingestion. Since the studies show that faults near the water resources have a critical effect on the concentration of radon, Kouhbanan active fault zone, to find water resources with high radon concentration was chosen for the following investigation. Water samples were taken from all of the 39 drinking water springs and Qanats in the Kouhbanan region, both in the summer and winter. Its length is 280Km and is aligned from Bahabad city in north-west to the Kerman city in south-east. Some evidence of the activity of this fault system are young morphotectonic structures and earthquake events along of this faults. To determine the content of sample's radon, radon detector (RAD7) was used. In six out of water samples, radon levels was more than proposed emission 11.1kbm-3(MCL) by Environmental Protection Agency (EPA). The average annual effective dose in 2 regions is more than reference level of the European Union Council and world health organization (0. 1mSva-1) according to the average effective dose for ingestion of radon in water (0.002mSva-1) and inhalation (0.025mSva-1) by United Nations Scientific Committee on the Effective of Atomic Radiations. This study has concluded that the mean effective dose for ingestion and inhalation of radon in Kouhbanan fault zone, is greater than the amount recommended for water samples in 6 region.

Keywords: Radon concentrations; Drinking water; the annual effective dose; Kouhbanan active fault zone; RAD 7.

Introduction

Ionizing radiations are one of the factors in uncontrolled situations which may pose a risk to human health [1] .In addition to synthetic man-made radiation sources, Natural resources such as Cosmic rays and natural radioactive materials can produce this radiation

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[2]. Considering about radiation hygiene, Radon and its decay products are most major sources of public exposure from natural radioactivity [1, 3].The amount of the absorbed radiation by human body from natural sources is estimated about 2.4 $mSVa^{-1}$ that considerable amount of this absorption, 3.1 $mSVa^{-1}$, is caused by ^{222}Rn [4] and is more than half of the average effective dose of the world [1, 5].

Radon is a radioactive noble gas that occurs naturally [6, 7]. This gas is colorless, odorless and neutral electrical charge, and because alpha radiation and radioactivity, is very dangerous [8, 9]. Among of three Natural occurrence isotopes of radon (^{219}Rn ‹^{220}Rn‹^{222}Rn), ^{222}Rn is the most important due to its relatively long half-life of ^{238}u and abundance in nature, has a major impact on human health [10, 11]. The most stable and abundant isotope of radon, (^{222}Rn) is formed in the earth crust based on the below equation:

^{238}U(half-life of 4.4 billion years) →^{226}Ra (half-life of 1620 years) →^{222}Rn (half-life of 3.82 days)

Radon is produced both inside and at the surface of the rock particles that contain uranium and uranium decay series products in secular equilibrium. Radon atoms which escape from the mentioned particles are mostly produced by alpha recoil from radium disintegration of atoms located a few nanometers from the grain surface. After Radon was released from the grains of a pours material such as soil, it propagates and moves through the underground water transportation [12,13]. Radon can solve in the water and various factors such as temperature and PH affect the degree of its solubility in the water. Radon by spreading to places very far away from its original location in a short period of time [14] is known as a naturally occurring radioactive element able to move in the earth's crust [14]. Radon exists in the nature, on the ground, in the air and in the water sources such as lakes, rivers, springs, underground water and even raindrops [16, 17].

A wide range of diverse density of ^{222}Rn can be found in the underground water [17].Several factors such as geology, hydrology, meteorology, abundance parent radionuclides and absorbed nuclides by rocks and soil can affect this density [14, 18]. One of the most important variable factor of soluble Radon in water is related to geological factors such as lithology [19-21] and structural parameter (Faults) [22-25]. The best location for the accumulating groundwater are Geodynamic active site, Faults and Fractures in hard rocks that can be the permeable zone to withdraw radon from deeper sources of underground water resources[7,24,25].

So the presence of faults near the water resources has been identified as a critical effect on radon concentration [14, 26, 27, 28, 29, and 30].

Due to the carcinogenic effects ,high concentrations of ^{222}Rn in the indoor environment and drinking water is a major health risk for human health in the form of different type of cancers[4,32]. Radon exposure to humans through inhalation and ingestion when it enters the water for human consumption [33]. As radon decays with a short half-life elements, the radon daughters (^{214}Po, ^{218}Po), emits alpha particles. Radon daughters electrostatically concentrate on dust, oxygen, water vapor, rare gases in indoor and other solid surfaces that this solid particles (Aerosol) easily inhaled and attached by bronchial epithelium and cause high dose of irradiation [34]. Alpha rays emitted by radon and it's daughters is highly ionizing and have a high transfer linear energy (LET) and potential damage to lung cells DNA [35,36]. Alpha particles can start a series of cellular and molecular events that led to the development of lung cancer and many other kinds of cancer [37, 38]. According to the National Research Council of America approximately 30% of the ^{222}Rn activity concentration is in the stomach, especially in the stomach walls [39], which will irritate and worsen the stomach cancer [39]. The alpha particles emitted by radon and it's daughters are absorbed into the bloodstream through the stomach and move throughout the body [39] causing other diseases such as Alzheimer, Parkinson [42] and also other types of cancer, including leukemia, kidney, bone marrow, skin cancer, brain and spinal [42-44] . However, the risk of lung cancer due to radon exposure is much higher than the risk of other cancer and illnesses, as the ICRP risk of cancer in other organs in about 2% of the estimated lung cancer risk [45].

According to England Department of Health between 2700 to 3150 of the annual deaths are due to the exposure to radon and daughters occurs [6]. As EPA, The National Academy of Sciences, has announced that radon in drinking water causes about 168 deaths annually in the United States, 89% of lung cancer from breathing radon released from water into indoor air and 11% stomach cancer is caused by drinking water containing radon [37].So far, the United state Environmental Protection Agency (USEPA) has not released any standard for the accepted level of the radon in the water. Only one standard known as the Maximum Contamination Level (MCL) for public drinking water supplies with a value of (11.1Bq L^{-1}, 300pCi L^{-1} or 11.1 $KBqm^{-3}$) has been suggested [46].

Regarding the harmful effects of Radon in the water, it is essential and vital to recognize the water sources highly polluted by Radon and therefore avoid using them as the water source for the domestic residents.

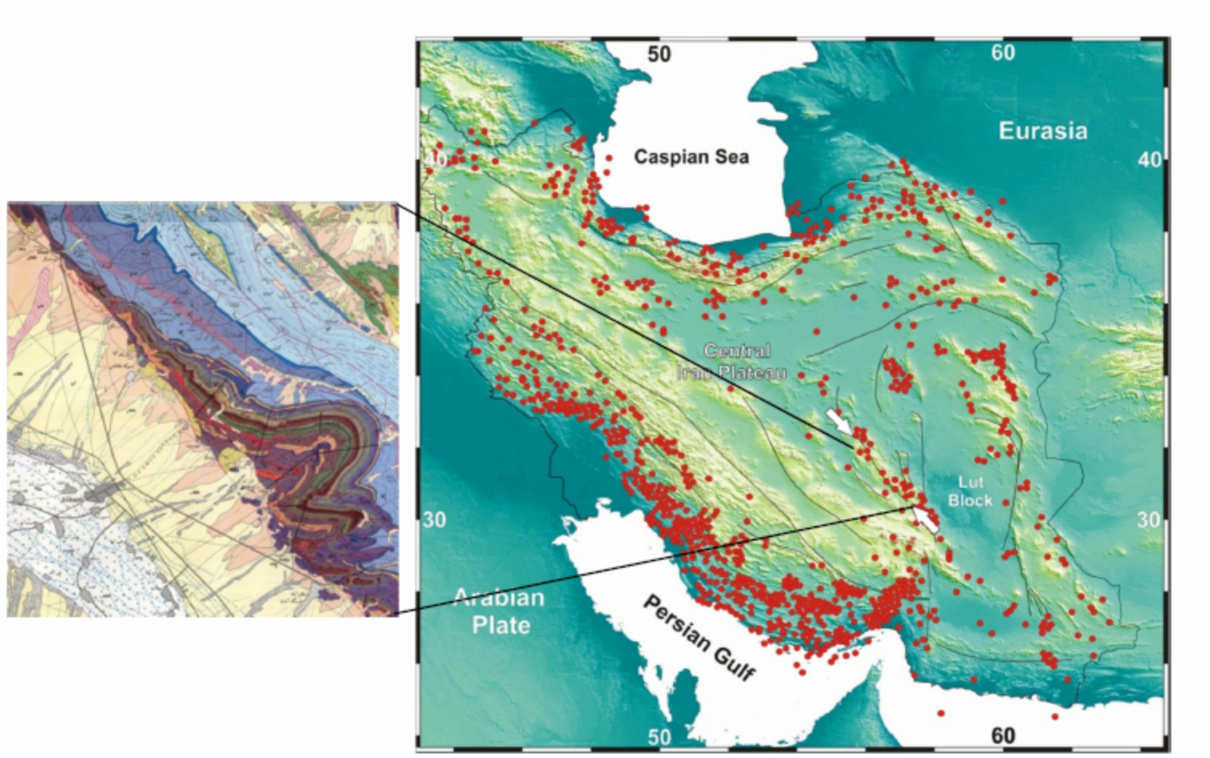

Figure 1. Distribution of earthquakes epicenter in Iran from 2000-2010 (Seismic data after from International Institute of Earthquake Engineering And Seismology) Kouhbanan fault has been showed by the white arrows.

Since the fault zones, are very good places for Radon to exist, we chose Kouhbanan fault zone located in Kerman to investigate the concentration of radon in the spring water and Qanat and estimate the resident's health risks associated with radon. Due to the effects of this radionuclides on the stomach, lungs and the whole body by consuming through either ingestion or breathing, the average annual effective dose is computed and the maximum value is compared with the proposed world's standards.

Geology and tectonics setting

According to previous studies, Iranian continental crust consists of two micro plate which called 1: Iran Central plate and northwest micro plate, which are under pressure by Arabian plate from the South and Eurasia plate from the north [46]. Central Iran micro plate comprises several block that are separated by intra continental and strike slip faults. As like Kouhbanan, Lakarkooh and Nayband fault systems. The mentioned fault system join together in west of Lut plain. Kouhbanan fault is as one of the main faults of the basement faults in central Iran micro plate.Its length is 280Km and is aligned from Bahabad city in north-west to the Kerman city in south-east (fig 1) [47].Some evidence of the activity of this fault system are young morphotectonic structures[48] and earthquake events along of this faults [47].

Kouhbanan fault zone is ideal for this study because:

1. The vicinity of active faults near water sources because increasing the concentration of dissolved radon in water [14, 26-31].

2. Variety of geological formations in this area can lead to significant changes in radon' concentration.

3. Due to formation of fault barriers along of Kouhbanan fault, there are about 96 springs and Qanat that only 39 of them are used for drinking. Although all villages, have access to the tap water at their houses, but based on an old tradition they believe that the springs and Qanats water are purified, safe, and clean drinking water therefore they tend to use this water for drinking and take it in sealed containers from the source of water, daily.

This study is the first determination of the concentration of dissolved radon in underground water around of Kouhbanan fault and calculation the annual effective dose to the whole body in the area.

Materials and Methods

As a first step topographic map files of the area were provided, and then using the data of these files and by

Table 1. Location of water samples on Kouhbanan fault system

S. no.	Site Locality	Source/Lithology	Sample's location
1	Houtk	Spring/sandstone	N 30°.34′.30″ E 56°.34′.30″
2	Hazratabad	Qanat/ Sand dunes	N 30°.39′.37″ E 56°.55′.56″
3	Lanjan	Qanat/ Sandstone,shale	N 30°.40.′17″ E 56°.54′.17″
4	Gourchouiyeh	Qanat/ Sandstone	N 30°.40′.31″ E 56°.48′.56″
5	Khanouk	Qanat/ Dolomite, limestone	N 30°.43′.36″ E 56°.46′.45″
6	Deh asghar	Qanat/ Dolomite	N 30°.45′.32″ E 56°.45′.34″
7	Dahoiyeh	Spring/ Dolomite,Shale,Gypsum	N 30°.45′.31″ E 56°.45′.34″
8	Gatkhoiyeh	Spring/ Dolomite, Gypsum	N 30°.48′.00″ E 56°.42′.20″
9	Ab pangoiyeh	Spring/ Dolomite,Tuff	N 30°.50′.09″ E 56°.39′.33″
10	Deh aghaie	Qanat/ Dolomite, Gypsum,conglomrate	N 30°.50′.13″ E 56°.39′.25″
11	Gisk	Qanat/Sandstone,Dolomite, limestone	N 30°.51′.33″ E 56°.38′.12″
12	Bab tangal	Spring/ Sandstone,Dolomite	N 30°.55′.51″ E 56°.36′.10″
13	Deh ahangar	Qanat/ Sandstone,Dolomite, Tuff, Gypsum	N 30°.57′.42″ E 56°.32′.22″
14	Dezo	Qanat/ Sandstone,Dolomite, Tuff, Gypsum	N 30°.58′.14″ E 56°.31′.41″
15	Rashk oleya	Qanat/ Dolomite,Limestone	N 31°.03′.28″ E 56°.28′.27″
16	Rashk vosta	Qanat/ Sandstone,Dolomite	N 31°.03′.47″ E 56°.27′.44″
17	Rashk sofla	Spring/ Dolomite	N 31°.04′.31″ E 56°.27′.06″
18	Se bodak	Spring/ Sandstone,Limestone,Shale	N 31°.06′.02″ E 56°.26′.10″
19	Khan makan	Spring/ Sandstone,Dolomite	N 31°.07′.09″ E 56°.25′.20 ″
20	Serah hashoni	Spring/Sandstone, Shale	N 31°.11′.22″ E 56°.21′.46″
21	Gavar	Qanat/clay,silt,fine conglomerate	N 31°.21′.56″ E 56°16′.58 ″
22	Deh salar	Qanat/ Dolomite	N 31°.24′.57″ E 56°.15′.26″
23	Dare gask	Spring/sandy conglomerate	N 31°.22′.20″ E 56°.11′.37″
24	Cheshme khezr	Spring/ Dolomite	N 31°.24′.43″ E 56°.17′.04″
25	Darekhom	Qanat/sandstone	N 31°.35′.11″ E 56°.08 ′.25″

Arcmap software, the locations of fault, villages, springs, Qanats and roads were spotted and the result was a map that showed the locations of 96 springs and Qanats on Kouhbanan fault. Because the weather condition can affect the amount of dissolved radon [26], the samples were taken in both summer and winter seasons. The first part of sampling was done in the warm season, July 2012. During field sampling, we noticed that from the 96 water resources that the software, only 39 springs and Qanats, previously specified the residents for drinking and bathing use their locations. So samples were taken from the 20 qanat, 18

Table 1. Continued

26	Darejeze	Spring/ Dolomite,Redsandstone	N 31°.32′.18″ E 56°.11′.48″
27	Babhowz	Spring/ Dolomite,shale,sandstone,microcongramrate	N 31°.33 ′.11″ E 56°.11′.01″
28	Charmiz	Spring/ Dolomite	N 31°.33′.34″ E 56°.10′.11″
29	Bidan	Qanat/sandstone	N 31°.35′.11″ E 56°.08′.25″
30	Botebid	Spring/ Dolomite,Redsandstone	N 31°.35′.38″ E 56°.08′.37″
31	Dashtkhan	Qanat/ Dolomite	N 31°.37′.23″ E 56°.06′.13″
32	Patgigan	Qanat/ Dolomite,Limestone	N 31°.39′.51″ E 56°.06′.13″
33	Beheshtabad	Qanat/ Dolomite,Limestone	N 31°.39′.43″ E 56°.05′.50″
34	Babroiyeh	Spring/Shale, Marl	N 31°.40′.13″ E 56°.05′.38″
35	Banestan	Qanat 1/ Dolomite, Sandstone	N 31°.43′.19″ E 56°.04′.18″
36	Banestan	Qanat 2/ Dolomite, limestone	N 31°.43′.45″ E 56°.04′.08″
37	Bahabad	Bore/Plain sediment	N 31°.52′.16″ E 56°.00′.44″
38	Bamo	Spring/ Dolomite,Sandstone,Shale	N 31°.50′.19″ E 55°.58′.13″
39	Neyzar	Spring/ Dolomite,Sandstone,Shale	N 31°.51′.03″ E 58°.58′.05″

springs and 1 tube well located on the Kouhbanan fault. Table 1 indicates the locations of these water sources. A standard method was used to take the samples. 250 ml vials with Teflon caps were used to save the water samples. The vial was filled with water below the water surface and the cap was placed on it under the water. The samples shouldn't have any air bubbles, therefore the sample vial was hold upside down and if any air bubbles were observed, the sampling would be repeated. The sample vials were labeled with time and place of sampling and then stored in cool containers until they were transferred to the laboratory. Water samples were analyzed for radon for less than 24 hours in laboratory. At the sampling location, the water temperature and geological characters of the area were recorded and analyzed by a geologist. A second round of sampling was conducted in the cold season, January 2013.

Radon measurement

The RAD 7(alpha detector made by American Durridge Company) was used for monitoring the concentration of radon in drinking water samples that were collected from different water sources along the Kouhbanan fault. Figure 2 is a picture of this device, which has the ability to determine the energy of each alpha particle electronically. RAD 7 is connected to an accessory called RAD H2O that the amount of radon in water is measured with high accuracy. RAD H2O setup consists of three components: A) Radon Monitor, B) A tube of desiccant that in its middle part a wider tube containing humid absorbent mat (Silica gel) is embedded, C) the water vial with aerator. RAD 7 set up has two different protocols, wat40 and wat250, which are related to the vials sizes: 40ml and 250ml. The extraction efficiency for a 250 ml sample vial is 94% and for the 40 one is 99%, so in this study, vials with the capacity of 250 ml were used. The water was sampled carefully to avoid exposing to the air and during the sample analyzes to determine the radon concentration, appropriate protocol (Wat250) was selected for the project.

The test started by connecting the sample vial to RAD7. Then the air pump on the radon monitor was turned on to remove the dissolved radon from the water and move it to the air loop. This airflow through the water will continue until systems H2O RAD reaches to

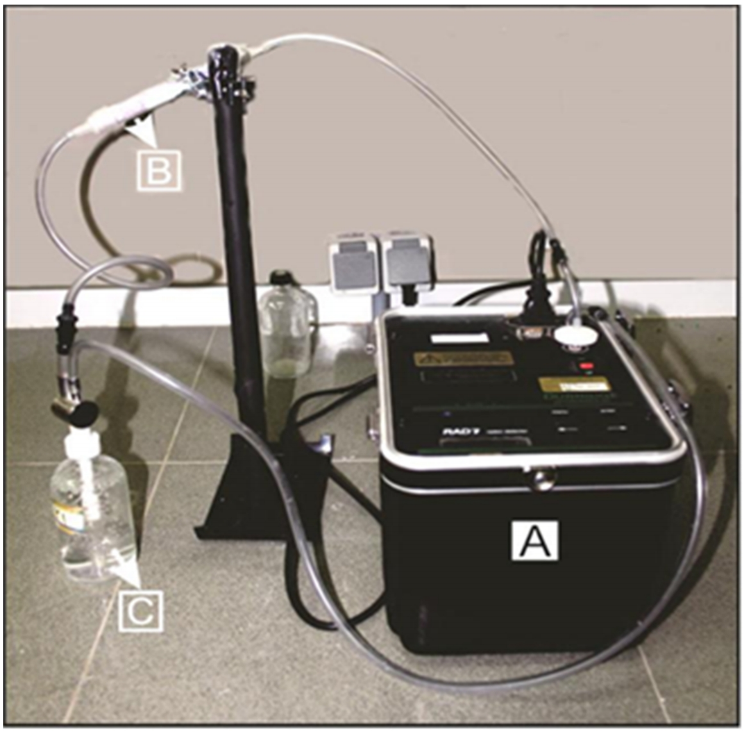

Figure 2. Diagram showing arrangement of device for measuring radon content in water sample

equilibrium and no radon can come back to the air loop after this equilibrium, meanwhile the humidity of the pumped air will be absorbed by silica gel through this circulation. After the aeration process, which takes about 5 minutes, the pump stops automatically and then the system wait for a period more than 5 minutes. The device will continue counting and the data will be stored every 5 minutes. At the end of the process, which takes 30 minutes in total, RAD7 device every 5 minutes provides a report for 4 cycles. These reports indicate the average concentration of radon produce by Po $_{218}$ activity, which shows the alpha decay during this period.

Average annual radon dose estimation

It seems that the radiation dose to the public from radon transport by water is a very serious threat than other water pollutions [49, 50]. Radon in drinking water can deliver a radiation dose to the stomach and lungs through both ingestion and inhalation.

To calculate the annual mean effective dose of radon from inhalation and ingestion the established parameters by UNSCER in report 2000 are suitable [51]. Therefore, we use the following formula 1 [7]:

$$E_{WIg}\ (mSva^{(-1)}) = C_{RnW} \times C_w \times EDC \qquad (1)$$

E_{WIg}: Effective dose for ingestion

C_{RnW}: Radon concentration in water (kBq m^{-3}or Bq L^{-1})

Cw: Estimated weight of used water (60La^{-1})

EDC: Effective dose coefficients for ingestion (3.5 nSv Bq^{-1})

In addition, the following formula can be used to calculate the effective dose for breathing (formula 2) [7]:

$$E_{WIh}\ (mSva^{(-1)}) = C_{RnW} \times R_{aw} \times F \times O \times DCF \qquad (2)$$

E_{WIh}: Effective dose for inhalation

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

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

O: The mean residence time of indoor belongs to each individual (7,000 ha^{-1})

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

The annual effective dose from 1Bq/L radon ingestion would be equivalent to 0.21msv/y, for adults considering usage of 60 litter of water in a year. Water that contains Radon releases Radon in the surrounding air, therefore the air around the water has radon gas too, so the annual effective dose coefficients for inhalation of radon 1Bq/L is equivalent to 2.52msv/y. Thus, for adults, the transferred radon concentration in the water for 1Bq/L is equal to 2.73mSv/y.

Table 2. Radon concentration in drinking water samples from springs, Qanats and Tube well on the Kouhbanan fault system

Sample No.	**Radon Concentration (Bqm^{-3}) in summer**		**Annual effective dose ($mSv\ a^{-1}$) in summer**			**Radon Concentration (Bqm^{-3}) in winter**		**Annual effective dose ($mSv\ a^{-1}$)**		
	Mean	SD	Ingestion	inhalation	Total effective dose	Mean	SD	Ingestion	inhalation	Total effective dose
1	28,100	1060	0.005901	0.070812	0.076713	18,400	3,620	0.003864	0.046368	0.050232
2	1,660	703	0.0003486	0.0041832	0.004532	1,110	375	0.0002331	0.0027972	0.00303
3	5,960	368	0.0012516	0.0150192	0.016271	934	236	0.00019614	0.00235368	0.00255
4	747	319	0.00015687	0.00188244	0.002039	311	285	0.00006531	0.00078372	0.000849
5	1,970	513	0.0004137	0.0049644	0.005378	1,520	253	0.0003192	0.0038304	0.00415
6	52,200	5,650	0.010962	0.131544	0.142506	59,900	4,490	0.012579	0.150948	0.163527
7	6,290	538	0.0013209	0.0158508	0.017172	5,330	1,420	0.0011193	0.0134316	0.014551
8	276	77.3	0.00005796	0.00069552	0.000753	173	133	0.00003633	0.00043596	0.000472
9	2,840	430	0.0005964	0.0071568	0.007753	1,800	113	0.000378	0.004536	0.004914
10	9,430	1,020	0.0019803	0.0237636	0.025744	8,900	1,450	0.001869	0.022428	0.024297
11	507	348	0.00010647	0.00127764	0.001384	1,990	530	0.0004179	0.0050148	0.005433
12	77,400	3,220	0.016254	0.195048	0.211302	88,800	1,570	0.018648	0.223776	0.242424
13	415	118	0.00008715	0.0010458	0.001133	1,570	454	0.0003297	0.0039564	0.004286
14	138	113	0.00002898	0.00034776	0.000377	2,030	180	0.0004263	0.0051156	0.005542
15	4,790	1,570	0.0010059	0.0120708	0.013077	1,110	629	0.0002331	0.0027972	0.00303
16	3,540	728	0.0007434	0.0089208	0.009664	2,110	535	0.0004431	0.0053172	0.00576
17	17,300	1,050	0.003633	0.043596	0.047229	13,500	1,600	0.002835	0.03402	0.036855
18	6,020	1,010	0.0012642	0.0151704	0.016435	138	118	0.00002898	0.00034776	0.000377
19	4,960	1,070	0.0010416	0.0124992	0.013541	899	288	0.00018879	0.00226548	0.002454
20	2,250	641	0.0004725	0.00567	0.006143	450	132	0.0000945	0.001134	0.001229
21	3,470	643	0.0007287	0.0087444	0.009473	1,590	473	0.0003339	0.0040068	0.004341
22	7,860	1,180	0.0016506	0.0198072	0.021458	4,880	709	0.0010248	0.0122976	0.013322
23	9,650	2330	0.0020265	0.024318	0.026345	6,540	413	0.0013734	0.0164808	0.017854
24	9,710	1,370	0.0020391	0.0244692	0.026508	17,800	2,200	0.003738	0.044856	0.048594
25	1,550	289	0.0003255	0.003906	0.004232	2,490	207	0.0005229	0.0062748	0.006798
26	1,560	640	0.0003276	0.0039312	0.004259	1,520	210	0.0003192	0.0038304	0.00415
27	2,260	25.4	0.0004746	0.0056952	0.00617	8,100	1,410	0.001701	0.020412	0.022113
28	11,800	1,260	0.002478	0.029736	0.032214	15,400	2950	0.003234	0.038808	0.042042
29	277	750	0.00005817	0.00069804	0.000756	380	207	0.0000798	0.0009576	0.001037
30	5,290	1,040	0.0011109	0.0133308	0.014442	Dried	Dried	-	-	-
31	2,740	803	0.0005754	0.0069048	0.00748	1,570	658	0.0003297	0.0039564	0.004286
32	4,660	557	0.0009786	0.0117432	0.012722	899	80	0.00018879	0.00226548	0.002454
33	4,790	1,350	0.0010059	0.0120708	0.013077	3,420	413	0.0007182	0.0086184	0.009337
34	11,400	912	0.002394	0.028728	0.031122	14,500	2,510	0.003045	0.03654	0.039585
35	5,959	711	0.00125139	0.01501668	0.016268	1,310	179	0.0002751	0.0033012	0.003576
36	1,790	188	0.0003759	0.0045108	0.004887	725	522	0.00015225	0.001827	0.001979
37	2,790	310	0.0005859	0.0070308	0.007617	3,460	200	0.0007266	0.0087192	0.009446
38	2,390	977	0.0005019	0.0060228	0.006525	692	106	0.00014532	0.00174384	0.001889
39	1,790	572	0.0003759	0.0045108	0.004887	1,440	947	0.0003024	0.0036288	0.0039312

Results and Discussion

In this study, Radon concentrations in 39 samples of drinking Qanats and fountains water in rural (in both summer and winter) were measured and then the annual effective doses to the stomach, lungs and whole body for each individual were calculated (Table 2). The results are provided as a bar graph in Figure 3, and sampling locations are plotted on the satellite image of the fault (Figure 4). Considering the temperature, none of the springs were among the hot springs. Lithology of the locations of all water samples in the area under study consists of sandstone, shale, marl, limestone and dolomite. The results show that solution radon concentrations is in the range between 138 Bqm^{-3} to 88800 Bqm^{-3}.

Measurements showed only 6 of 18 samples of spring water and one out of 20 samples of subterranean water, Radon concentrations were more than MCL, 11.1$kBqm^{-3}$. 6 springs with the highest average concentration (In the range 11.4 - 88.8$KBqm^{-3}$) were located in Houtk‹Babtangal, Rashksofla, charmiz, Babroiyeh, Neyzar villages. The Qanat with high radon levels was located near the Dehasghar village.

Source that is located near Houtk village, enters an indoor pool and the water flows into an outdoor pool. A huge number of people in this region use this water for swimming and drinking in the summer. The

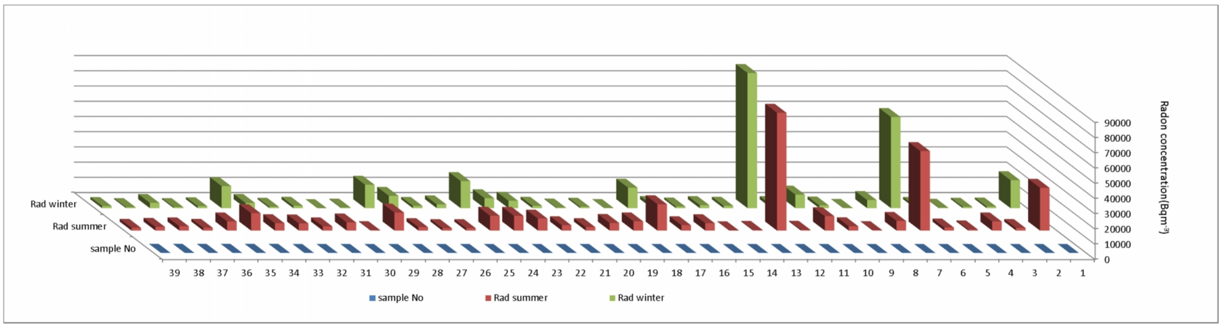

Figure 3. Radon concentrations of water samples in summer and winter from different location along Kouhbanan fault

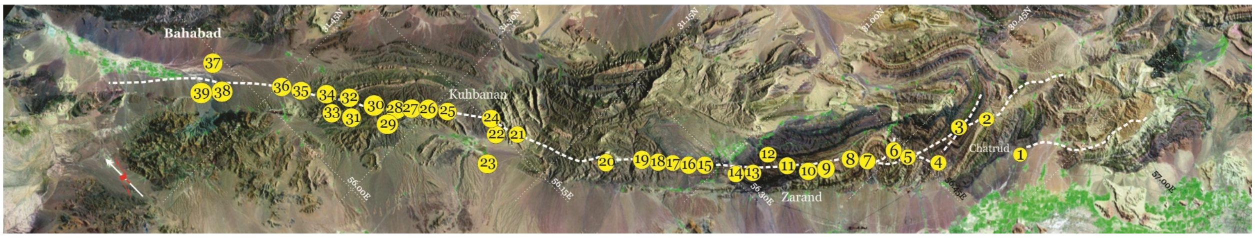

Figure 4. The Position of fountains and Qanats along the Kouhbanan fault where Radon level is measured.

measurements show that radon concentration in the indoor pool in the hot season is 28.1KBqm^{-3} that is almost 2.5 times higher than the proposed amount by the Environmental Protection Agency of America. Many residents of this area take their drinking water in sealed containers from the mentioned spring, daily. This site is located in a Dolomite-Sandston zone with recumbent folds structure. At this location, the Kouhbanan fault shows evidence of strike slip activity well.

Babtangal village is a site with the highest radon in Kouhbanan fault such that radon level of this spring in the summer is 77.4 kBqm^{-3} and in the winter is 88.8 KBqm^{-3}. This amount is almost eight times more than the amount recommended by EPA. The site is where an earthquake of 8.5 Richter occurs in December 1977 and the result was 600 fatalities. Geology of the area can confirm Sandstone and Dolomite.

Radon levels in Qanat of Dehasghar village in both warm and cold seasons respectively are 52.2 KBqm^{-3} and 59.9 KBqm^{-3}. It seems that these high levels of radon in this qanat with dolomite lithology are because of the proximity of the qanat exit to the water collection section. When the length of conveyance section is not so long, the groundwater that exiting are less exposed to the fresh air and therefore has less chance to lose the radon. This site is 4 km away from the epicenter of an earthquake measuring 6.4 on the Richter scale that hit Dahuieh village in February 2005 and killed 600 people. In all the six sites that had high radon readings, there is no tap water supply system. And situated near an active segment of kouhbanan fault (Dahuieh thrust)

From the Tectonic point of view, both charmiz and Babroiyeh sites are located in a fault valley. The maximum radon at these two sites was measured in the winter with the values of 15400 KBqm^{-3} and 14500 KBqm^{-3}, respectively.

Therefore, it is obvious that 33.3% of spring water samples and 5% of Qanat water radon concentrations is more than the MCL proposed by the EPA. Union Council of Europe and the World Health Organization have offered o.1 mSva^{-1} for the reference level of the annual effective dose received from drinking water [7]. According to WHO, If the dose is higher than 0.1 mSva^{-1}, preventive care is required to reduce the radon level and if the dose is less than or equal to 0.1 mSva^{-1}, water is safe to drink.

In this study, there are two places where the average annual dose ingested (stomach), Inhalation (lungs) and all the body (ingestion and inhalation) are above the reference level of 0.1mSva^{-1} suggested by WHO. One of them is an Qanat near the Dehasghar village where radon level is the highest in the winter and the annual effective average dose of ingestion, inhalation, and the entire body of drinking water, respectively, are calculated as 0.012579,0.150948, 0.163527 mSva^{-1}.

The second site is Babtangal springs where Radon level is the highest in the winter too, With a value of 88.8mSva^{-1} and the annual effective average dose of ingestion, inhalation, and the entire body of drinking water equal to 0.018648,0.223776, 0.242424 and mSva^{-1} respectively. The annual effective dose to the whole body in all the cases in summer and winter are shown as a bar graph In Figure 5.

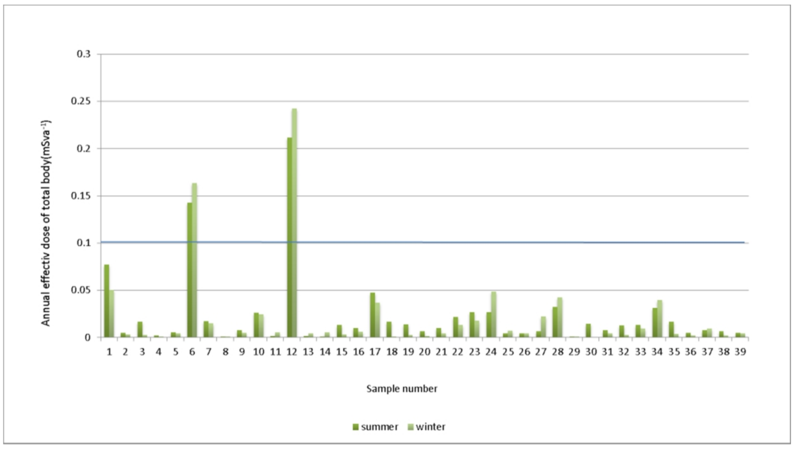

Figure 5. The average of annual effective dose to the whole body in summer and winter

UNSCEAR has also prepared and introduced acceptable doses of radon in water, which are not harmful to the body. These values are 0.002mSva$^{-1,}$ the average dose of radon through ingestion and 0.025mSva^{-1} through inhalation [1]. The average doses of radon captured in this study are shown and compared with the average of annual effective dose (0.002mSva^{-1}) provided by UNSCEAR in figure 5. The diagram related to the ingestion in the summer shows that in 8 sites the average doses radon are equal to or higher than the accepted level. These sites are sites number 1, 6, 12, 17, 23, 24, 28, and 34 (figure 6A). The calculation of the average dose related to the inhalation of radon at the same season at sites 1, 6, 12, 17, 28, 34 is higher than the accepted level (0.025 mSva^{-1}) (figure 6B).

Figure 7 shows the average effective dose for ingestion (figure 7A) and inhalation (figure 7B) of radon in the winter. The average dose for ingestion and inhalation of radon is above the provided standard by UNSCEAR (0.002mSva^{-1}) for sites 1, 6, 12, 17, 24, 28,

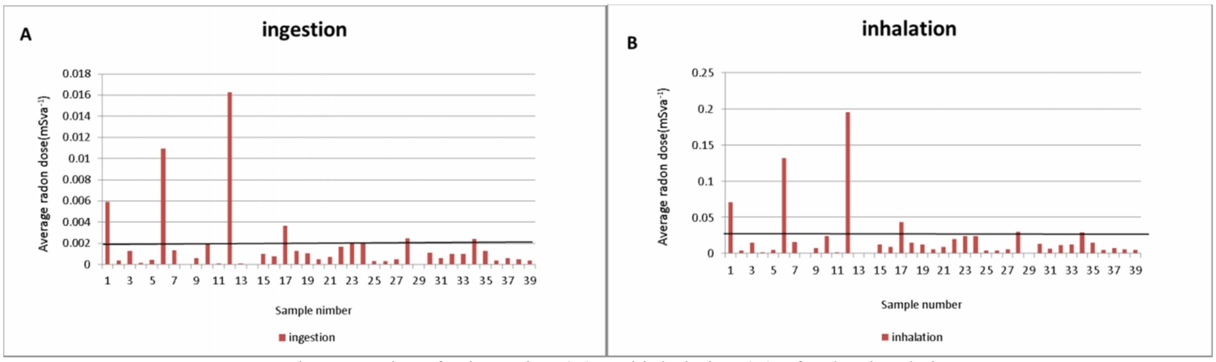

Figure 6. The mean dose for ingestion (A) and inhalation (B) of radon levels in summer

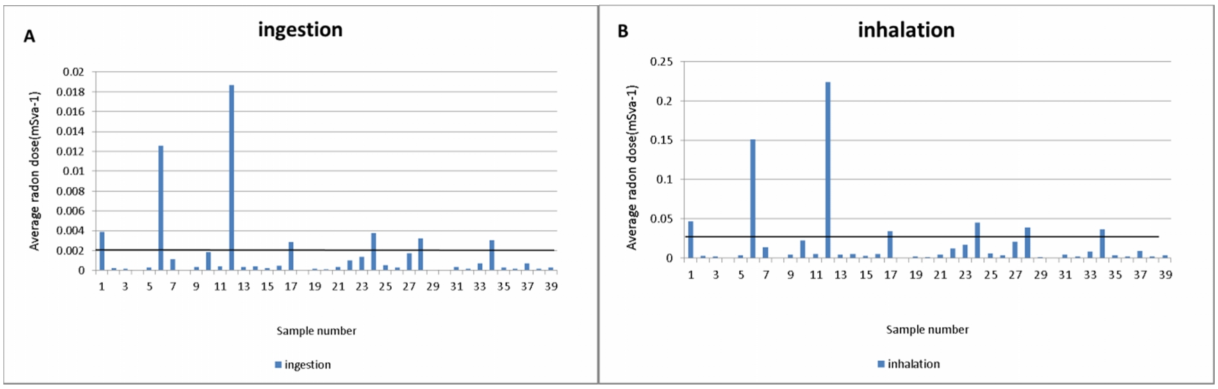

Figure 7. Mean values for ingestion (A) and inhalation (B) of radon effective dose in winter

34, 39 in the winter.

Therefore, in these sites, water is not safe to drink and to prevent serious health problems some decisions should be made. To reduce the risks associated with radon, there are several methods for removal of natural radioactivity from the drinking water. Examples of these methods are aeration, granular activated carbon filtration, iron-manganese removal techniques, Ion exchange techniques, and membrane techniques [50]. In these water sources, boiling water in an open atmosphere to transfer radon gas from water to the air is the cheapest and easiest way to reduce radon risks related to ingestion.

Conclusions

As this investigation showed, ^{222}Rn's concentrations is various in different places due to the sampling time, geographic factors, and geological and sampling locations.

1. The results of this study show that Radon concentration in drinking water samples near an active Kouhbanan fault, In 6 Springs and 1 of Qanat actually used by residents is greater than the level recommended by EPA(11.1kBqm^{-3}).

2. According to the recommendations of the World Health Organization and the Council of Europe EU, The averages of annual effective dose received from two samples are more than 0.1 mSVa^{-1}.

3. Also according to the mean dose of radon in water to swallow (0.002mSva^{-1}) and inhalation (0.025mSva^{-1}) by UNSCEAR, the mean dose for ingestion and inhalation of radon in 6 samples is more than the recommended amount.

4. 33.3% of water samples from springs and 5% of water samples Qanat have the Radon concentration more than MCL provided by EPA.

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