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Determination of radon concentration in drinking water of Bam villages and evaluation of the annual effective dose

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▶ ***Original article***

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ABSTRACT

Background: Radon is one of the most important radioactive elements which is released by natural decay of available uranium and radium in the ground. The presence of radon gas is common, wherever those faults are located there. Radon concentration of various drinking water resources of Bam villages; located near Bam fault; was measured. ***Materials and Methods***: This cross-sectional study was conducted in the spring of 2014. Samples were collected from 27 water resources (wells and canals) as well as 5 water storage tanks of Bam villages of Kerman province. The radon concentrations were determined by RAD7 device. The annual absorbed dose was also calculated according to the measured radon levels. ***Results:*** The average of minimum radon concentration in water resources was 1.2 BqL^{-1}; which was related to a water tank in Baravat; and the average of its maximum amount was calculated as 9.88 BqL^{-1} which was related to a private home well in Baghchamak village. The maximum annual effective dose for adults was 30.82 $\mu SvY^{-1}$and the lowest was calculated as 3.74 μSvY^{-1}. ***Conclusion:*** Based on the achieved results, radon concentration of drinking water resources is lower than permitted concentration of EPA and also WHO guidelines.

Keywords: *Radon, drinking water, effective dose, Bam.*

INTRODUCTION

Half-life of radon (Rn-222) is 3.82 days [1]. This element is a part of U-238 chain and has been identified as the main source of natural radioactivity in residential areas with short-lived products of mentioned chain decay, including Po-214, Bi-214, Pb-214 and Po-218 [1-4]. In the United States of America, exposure to radon is the second cause of lung cancer after smoking. This element is a major environmental carcinogen material [5]. According to presented report by the International Commission on Radiation Protection (ICRP); Rn-222 isotope is a major source of internal radiation in human life [6]. The effect of radon on human health through breathing is lung cancer and through digestive tract is leading to gastro-enteric cancers [1, 2, 5, 7].

Awareness of radon levels in household water supplies and groundwater is vital in order to protect human against effects of exposure. Dueto this, radon value measurement plays an important role in community health assessment [5]. The studies on Radon level available in water resources has been increasing in the last two decades [8].

In Iran the water used by households are supplied from various sources. In many regions well water has greatest role in domestic water supplies. In some parts, only the surface water and in some other parts, groundwater and surface water are as domestic supply water simultaneously [2]. In Bam city, the main source of water for domestic use is groundwater especially aqueducts.

Since the lifetime of radon is short, its migration from the soil or rock by diffusion is limited. Cracks and fractures play an important role in radon emissions. High radon concentrations can be seen often in areas with crushed stone such as geological faults and active volcanoes [9, 10]. According to EPA, the maximum allowable level of radon in drinking water is 11.1 BqL^{-1}. Gas concentration guidelines set by the World Health Organization's is 100 BqL^{-1} [2].

A study was conducted in 2005 in Mexico City by Villalba and colleagues on 114 well water samples and 255 municipal water samples. The radon concentration was higher than the EPA standard in 50% of well water samples and 48% of municipal water [11].

A study was conducted in 2014 in Iran by Malakootian and colleagues on 56 samples of drinking water in villages surrounding Rafsanjan fault in order to evaluate radon concentration and calculate the annual effective dose of consumption water. Radon concentration in 8 samples was higher than the limit set by the EPA. High concentration of radon gas is due to presence of Rafsanjan fault and fine faults in the study area [12].

Malakootian and colleagues conducted another study on 44 samples of drinking water collected from villages nearby Lalehzar fault and evaluated the annual effective dose. Range radon concentration was 26.88 and 0.74 BqL^{-1}, respectively. Radon concentration in 15 samples of drinking water (34.04 %) was more than permitted level set by EPA [13].

A research was performed in 2012 by Todorovic and colleagues in order to measure the radon concentration in some drinking water sources in Serbia. Radon rate was measured by using the RAD7 device. The average radon concentration was 100BqL^{-1}. The large amount of radon in water resources was due to emitted gamma radiation along the alpha ray radiation from radon [14].

A study was conducted in 2011 by Khattak *et al.* to measure the radon concentration of drinking water supplies in University of Peshawar and its surrounding areas in Pakistan.36 samples of drinking water from deep wells and taps were done at the main campus of university.11 cases showed the radon concentration higher than recommended limit. Effective doses obtained between 0.0043 - 0.0496 $mSvY^{-1}$ [15].

According to records of investigations in this field, it can be concluded that it is most probable that the underground water resources along faults are contaminated with high levels of Radon [16]. A study conducted on Bam fault in Iran in 2002, Negarestani (2002) concluded that changes in radon concentration during the occurrence of aftershocks are different from its changes before main earthquake. Also difference between the seismic environmental properties before and after the earthquake is the main reason for this difference. Changes in radon concentration usually are visible a few days before the earthquake [16]. Radon concentration in groundwater, surface water resources and air surrounding the fault increase due to occurrence earthquake on faults, fractures and cracks on the ground [16]. In this study, the drinking water sources near active Bam fault was selected and evaluated to measure radon concentration.

MATERIALS AND METHODS

This cross-sectional study was conducted in the spring of 2014 on 32 samples of drinking water sources of Bam-Baravat fault including 12 samples from aqueduct, 15 samples from wells and five samples from water storage tank supplier. Bam fault along the north, North West - South, South East and approximate length of 65 km, is located in 4 km east of the Bam city (between Bam and Baravat). This fault is started from North, North East of Bam city and its southern end terminated in North of Jabal-e-Barez mountains. The sampling points were determined by using GIS software and topographic and geological maps.

Temperature, pH and conductivity of water were measured in sampling locations. Latitude and longitude of sampling location and elevation above sea level were recorded by GPS device. 250 cc vials with teflon caps were used for sampling that prevents from entering and exiting of air, completely. Sampling from private well was done with permission from owners. Water samples from the wells and subterranean were taken from water depth to be reagents and desirable in terms of radon concentration in the water sample.

Sampling from water sources was conducted in conditions that had minimal contact with air and sampling container was filled with water with no empty space. After this stage, samples were collected immediately, at minimal possible time (less than 12 hours) and at standard conditions were transferred to International Center for Advanced Science and Technology and Environmental Science and Graduate University of Advanced Technology of Kerman in order to measure radon concentration. The equation $A = A_0 e^{(-0.693 / T)t}$ was used In order to enforce half-life of radon according to the period of time between sampling and testing where:

A: Rn-222concentration at reading time BqL^{-1}.

A_0: Rn-222 concentration at sampling time (actual concentration) BqL^{-1}.

T: The half-life of Rn-222 equal to 3.8 days or 91.2 hours.

t: period of time between sampling and testing.

Measurement of radon concentration in the collected samples was performed by RAD7 device. RAD7 device works according to alpha particles 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 the 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.

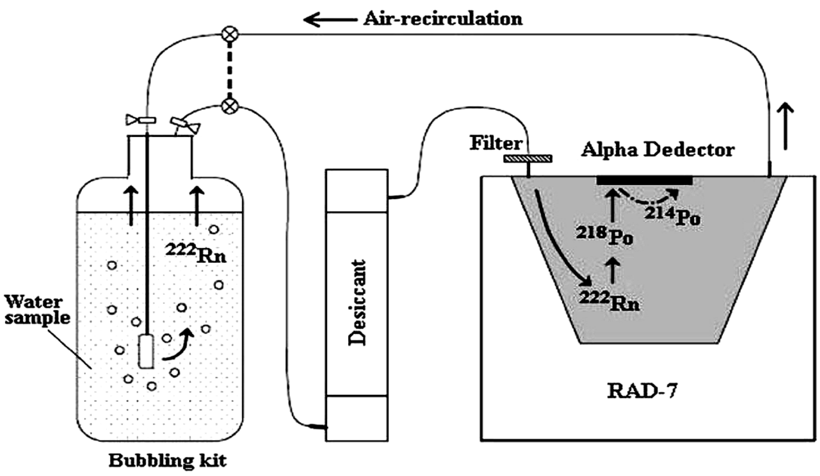

Figure 1. Schematic diagram of RAD7.

This device has two glass bottles of 40 and 250 cc that two protocols (wat 40 and wat 250) are defined based on it. In this study wat 250 protocol was used. According to this protocol, the first 5 min of bubble blowing was carried out automatically. During the bubble blowing phase, 94 % of radon gas dissolved in water was removed and the pump stopped automatically after 5 min. The system waited for 5 min for gas to reach equilibrium. Alpha particles were then counted and the first reading done after 5 min. actually, 15 min after the start of work, first reading was done. It meant radon concentration was measured during the four stages of the 5 min. Nuclei of Rn-222 decay in the compartment of RAD7 and produces positive charged ions of Po-218. Electrical field in the compartment cause drifting the ions toward the detector. Nuclear of Po-218 with a short half-life decays on the active surface of detector and emits alpha particle. This particle will enter to the detector and the machine generates signal proportional to the intensity of alpha particles. Then the device records the alpha particle according to its relevant energy and determined radon concentration according to number of recorded particles (Pb-214 and Po-210 emits alpha particles in addition to Po-218). To remove radon from the device, it was in purge phase for 10 min after each sample reading. In fact, the time required for each sample, including the time needed to purge was 40 min. 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 is 0.2 BqL^{-1}.

Received dose from present radon in drinking water is divided into two parts consisting: 1) received dose from inhalation of radon and 2) received dose from ingestion of radon. The average annual effective dose from ingestion and inhalation of radon in water is determined by using the documentation of United Nations Scientific Committee Effects of Atomic Radiation (UNSCEAR) and equations 1 and 2 [15, 17-21].

$$C_{inh}^{Rn} = C_{w}^{Rn} \times R_w \times F \times T \times D_f \qquad (1)$$

C_{inh}^{Rn}: The annual effective dose from inhalation of radon released from water into air μSvY^{-1}

C_{w}^{Rn}: Radon concentration in waterBqL^{-1}

R_w: ratio radon released to air when water is used to radon in water(10^{-4}).

T: The average residence time of individual in the interior (7000 hy^{-1})

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

D_f: The conversion dose factor 9nSv $(Bqhm^{-3})^{-1}$

$$C_{ing}^{Rn} = C_{w}^{Rn} \times I_a \times D_f \qquad (2)$$

C_{ing}^{Rn}: The annual effective dose from drinking water containing radon (SvY^{-1})

C_{w}^{Rn}:Radon concentration in water BqL^{-1}

I_a: water consumption rate LY^{-1}

D_f: The ingesting dose conversion factor ofRn-222 nSv Bq^{-1}

The ingesting dose conversion factor of Rn-222(D_f) for adults and children is 10^{-8}nSv Bq^{-1} and 2×10^{-8}nSv Bq^{-1} respectively [14, 22, 23]. And the amount of water is also intended for adults and children 2 and 1.5 liters per day (Equal to 730 and 547.5 liters per year) [14, 22-25].

There have been controversies over the amount of annual water intake in a year. The total annual water intake for so called "ICRP Standard Man" equals to 2 or 730 Ly^{-1} but this cannot be considered in calculations because radon release quickly by boiling or heating. More realistic value of 60 Ly^{-1} for the weighted direct annual consumption of tape water has been proposed by UNSCEAR[26].Consequently, this amount has been applied for calculations of ingestion dose in this paper. It is notable that in some references considered 3.5 $nSvBq^{-1}$ as received dose factor (D_f) for calculating the absorbed dose resulting from drinking water in equation (2) and Commission on Life Sciences, National Research Council of America (NRC) has approved 3.5 $nSvBq^{-1}$ as (D_f) value. But recently, a conservative value 1×10^{-8} $SvBq^{-1}$ is recommended[26].

World Health Organization (WHO) and the Council of Europe Union (EU) have determined the permitted level of annual effective dose in drinking water as 0.1$mSvY^{-1}$ (100μSvY^{-1}) for annual effective dose level in drinking water [6, 12].

RESULTS

Figure 2 shows sampling points of water sources in Bam fault zone. Coordinates of the sampling location, the average radon concentration in water resources of Bam-Baravat fault (BqL^{-1}), the total absorbed dose (lung and stomach), electrical conductivity of water (EC) according toμscm^{-1}, PH, temperature in terms of degrees Celsiusare presented in table 1.

The average radon concentration of studied samples ranged from 1.2 to 9.88 BqL^{-1} which is lower than EPA permitted standard and WHO guidelines [1]. The minimum and maximum radon concentration in water of Bam-Baravat fault zone is related to a water reservoir in Baravat and private home well in BaghChamak

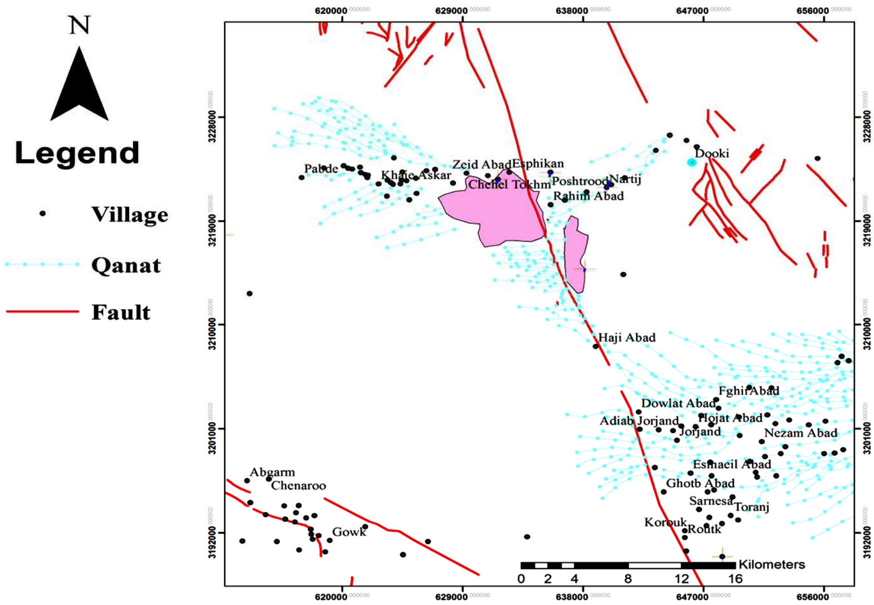

Figure 2. Sampling points on the Bam fault.

Table 1 Coordinates of the sampling location, the average radon concentration in water resources of Bam-Baravat fault (BqL^{-1}), the total absorbed dose (lung and stomach), electrical conductivity of water (EC) according to μscm^{-1}, PH, temperature in terms of degrees Celsius.

sample	Resource Type	Latitude (N)	Longitude (E)	The average radon concentration (BqL^{-1})	The total absorbed dose (lung and stomach) μSvY^{-1}	Electrical conductivity μscm^{-1}	PH	temperature (°c)	(people)
1	mosque well	2942166	5737758	5.79	18.06	685	7.9	26.4	35
2	Restaurant well	2923047	5752579	6.83	21.03	630	7.3	26.2	17
3	outlet	2920449	5756569	8.01	24.99	757	7.5	26.1	87
4	private home well	2908289	5814622	7.71	24.05	485	7.9	25.5	8
5	private home well	2906733	5822052	7.67	23.93	475	7.9	29.1	5
6	private home well	2906850	5822050	6.41	19.99	621	7.7	27.8	7
7	Water tank (Bam old Citadel)	2905720	5821280	6.1	19.03	810	7.9	28.2	26
8	outlet	2904154	5824003	4.74	14.78	940	7.3	27.2	51
9	Restaurant well	2942179	5737784	2.11	6.58	624	7.3	23.8	24
10	private home well	2936237	5742955	1.77	5.52	688	7.3	24.6	9
11	outlet	2932870	5746790	3.99	12.44	800	7.6	27.3	62
12	private home well	2928945	5749747	2.89	9.01	565	7.2	26.2	5
13	private home well	2922770	5752744	5.63	17.56	690	6.9	26.8	4

continue of Table 1. Coordinates of the sampling location, the average radon concentration in water resources of Bam-Baravat fault (BqL^{-1}), the total absorbed dose (lung and stomach), electrical conductivity of water (EC) according to μscm^{-1}, PH, temperature in terms of degrees Celsius.

sample	Resource Type	Latitude (N)	Longitude (E)	The average radon concentration (BqL^{-1})	The total absorbed dose (lung and stomach) μSvY^{-1}	Electrical conductivity μscm^{-1}	PH	temperature (°c)	(people)
14	outlet	2920442	5756578	2.56	7.98	870	7.1	24.6	107
15	private home well	2916511	5800508	6.96	21.71	1090	7.9	27.1	9
16	Water tank (Zaid abad)	2913094	5805408	5.99	18.68	790	7.6	28.2	29
17	Water tank (Poosht rood)	2910056	5810315	3.6	11.23	950	7.6	27.4	16
18	private home well	2908270	5814685	8.95	27.92	1150	7.9	27.4	7
19	Water tank (Baravat)	2908179	5816281	1.2	3.74	920	7.9	27.1	12
20	outlet	2908249	5816438	6.58	20.52	865	7.7	28.3	38
21	outlet	2908639	5816396	5.64	17.59	745	7.3	27.7	94
22	outlet	2908229	5816683	3.89	12.13	960	7.9	24.6	137
23	outlet	2908194	5817007	4.79	14.94	840	7.9	24.3	69
24	private home well	2907887	5815754	3.76	11.73	885	7.4	26.2	6
25	private home well	2908389	5816501	5.89	18.37	780	7.2	26.6	10
26	outlet	2908390	5816489	2.13	6.64	1280	7.8	27.7	217
27	Water tank (Haji abad)	2904334	5823391	1.8	5.61	1060	7.4	29.1	34
28	private home well	2903646	5824204	9.88	30.82	1650	7.9	26.4	11
29	outlet	2903421	5824672	4.76	14.85	1085	7.9	27.5	74
30	outlet	2906971	5821982	6.4	19.96	1100	7.8	26.8	108
31	outlet	2906971	5822081	3.27	10.2	870	7.4	27.6	153
32	private home well	2905830	5821571	6.79	21.18	950	7.6	28.7	5

village, respectively.

Groundwater sources are main water supplies of Bam city. Based on the achieved results, radon concentration in these sources is less than the recommended guidelines by WHO and EPA.

DISCUSSION

Range of radon concentration in water resources of Bam-Baravat fault zone was high. The maximum amount of radon concentration was related to well water resources. High radon concentrations in mentioned sources can be caused by granitic rocks in studied area and lack of air-water contact in well [(2)].

A study conducted by Joseph *et al.* 2011 in Iraqi Kurdistan showed Radon concentration in groundwater of study area less than the EPA standard limit [(27)]. Another study by Khattak and colleagues performed in Pakistan on 36 samples of drinking wells water and tap water of Peshawar University and its surrounding areas showed elevated radon concentration for 11 cases according to the recommended level by

EPA [15]. The absorbed dose was reported from 0.496 to 0.0043 $mSvY^{-1}$. These researches compared the high concentration of radon in water supply of Peshawar city with Islamabad city and came to the conclusion that high radon concentration of groundwater resources due to present of water resources in land rich in uranium and also major fault (MBT) and several other active faults. These faults are permeable channels and easy way to radon migration and escape of excessive radon from deeper groundwater resources [15].In another study conducted by Alirezazadeh and colleagues in Tehran in 2005, it was observed that radon concentration in surface water and tap water of urban networks is less than the standard allowance that are consistent with present results [2].

A study conducted by Abdallah *et al.,* on wells water resources and springs showed radon concentrations of collected samples more than 11 BqL^{-1} [8]. Similar study conducted in Mashhad revealed radon concentration in 70% of drinking water samples were more than EPA permitted standard [1]. High temperature in Bam -Baravat region is a reason for different measured radon concentrations of this study and studies investigated. Average temperature of Bam, Mashhad and study area of Lebanon is 21.8, 15.7 and 11.3, respectively.

Iranmanesh *et al.,* conducted a study in 2014 to estimate annual effective doses of radon in springs and qanats nearby Kouhbanan active fault system in Iran. In six out of 39 water samples, radon levels were more than proposed 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 which was attributed to the earthquake of 8.5 Richter occurred in December 1977. Furthermore, high levels of radon in the qanat with dolomite lithology were 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 [28].

Another study was conducted on radon level in drinking water in Mehriz villages and the annual effective absorbed dose was measured. This study indicated that apart from two samples related to the aqueduct of Malekabad village and a private well in Dare Miankooh village, Radon concentrations of other samples used by people of Mehriz villages as drinking water was low and less than permitted limit set by the Environmental Protection Agency of United States of America. The water of these aqueducts passes through different veins of granitic rocks that could be the reason for high radon concentration in water [29].

Currently the health risks posed by high concentrations of radon gas does not threat consumers and emergency measures to remove it. The last affective earthquake in this area occurred over a decade ago, so low radon concentration in water resources is justifiable. The absence of heavy radioactive radiation in Bam-Baravat fault zone can be another reason for low radon concentration in the area. Also results of this study indicate the high range of radon concentration in this study area. This could be due to differences in temperature and geological features [3, 11, 14, 16]. Lack of heavy radioactive radiation, inactivity of fault after the earthquake in 2003, and high environmental temperature can cause this phenomenon.

CONCLUSIONS

When the radon concentration is high, the water storage tanks should be used for aeration and radon removal in order to protect people and reduce the consequences of exposure to this gas; or should be avoided for using as household water sources. Hence, having knowledge about radon values of household water resources is very important. Achieved values of radon concentration in studied samples were less than limit set by EPA and WHO. Therefore, in the present circumstances any necessary action is not required to reduce the radon concentration in water resources of Bam-Baravat fault.

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