Research Article

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The role of radon in drinking water pollution in Bukan (North West Iran)

Abstract

the radiological risk to human health due to consumption of contaminated drinking water. The present study an electronic solid state Radon monitor, which is the most sophisticated and versatile measuring device has been used for estimating the Radon content in some drinking water samples taken from Bukan (North West Iran). The Radon concentration in water samples has been found to vary from 0.79±0.18Bql-111.87±1.43Bql^{-1}. The values of Radon concentration in these samples were found below the recommended limit and slightly unhealthy for drinking. The values of annual effective dose were also calculated for these water samples and ranged from1.27μSvy^{-1} to 32.67μSvy^{-1}. These values lie within the infrequency safe limit. The study suggests that drinking water in Bukan slightly contaminated by radon.

Keywords: RAD7, radon concentration; bukan, water pollution

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Introduction

Radon has been measured in water in many parts of the world, mostly for the risk assessments due to consumption of drinking water.[1,2] Radon gas is odorless, tasteless and colorless, and therefore cannot be detected by the human senses.[3] It is an inert and noble gas, with atomic number 86, has highest density 9.73kgm^{-3} among all noble gases. Because it is denser than air, Radon gas in the environment tends to settle in lower areas where the air is still and can concentrate in poorly vented rooms and basements. Radon is the only alpha-emitting radio-active gas. It is produced after the alpha decay of radium, which is further the decay product of U-238. This means the concentration of Radon depends on the concentration of U-238 in any source. When radium decays, it produces an alpha particle with 4.78MeV energy and recoiling Radon-222 with recoil energy of 86KeV.[4] Radon has three isotopes i.e.

i. Radon-219 or "actinon" is a part of U-235 decay chain. It is never encountered in indoor air due to its short half-life (3.4sec).

ii. Radon-220 or "thoron" is a part of Thorium-232 decay chain. Its half-life is more than actinon but less than 1min (54sec). Due to this half-life, it found in indoor air, particularly near Radon entry points and more often in soil gas.

iii. Radon-222 or familiar "Radon" is a part of the U-238 decay chain. Its half-life is 3.8 days. Due to this half-life, it is detected in indoor air, outdoor air and soil gas.

Radon is also soluble in water. This means that Radon exists in three states of matter i.e. solid (in soil grain), gas (in atmospheric air) and liquid (in drinking water). As Radon decays, it produces a new radioactive element called Radon daughters or decay products i.e. Po-218(3.05min), Pb-214 (26.8min), Bi-214 (19.9min), Po-214 (164μs) and Pb-210 (22yrs).Unlike the gaseous Radon itself, Radon daughters are solids and stick to the surface. When Radon undergoes alpha decay, Po-218 with alpha particle has energy 5.49 MeV produces. This produced alpha particle has 39μm alpha range in water and 4.08cm alpha range in air.[5] The mean distance travelled[6] by Radon-222 over its half-life (3.8days) indifferent medium is shown in Table 1 and shows Radon in water moves slower than Radon in air. The distance that Radon moves before most of it decays is less than 1 inch in water-saturated rocks or soils, but it can be more than 6 feet, and sometimes tens of feet, through dry rocks or soils. Because water also tends to flow much more slowly through soil pores and rock fractures than air does, Radon travels shorter distances in wet soils than in dry soils before it decays.

Table 1 Mean Diffusion distances of Radon in different media

Medium	Mean distance Rn^{222} (cm)
Air	220
Water	2.2
Porous soil	155
Saturated porous soil	1.55

Most of the radio nuclides present in drinking water are from natural sources. Naturally occurring radionuclides are created in the upper atmosphere and are found in the earth's crust. They are found in certain types of rocks that contain trace amounts of the radioactive isotopes (forms) of uranium, thorium and actinium. As these rocks destroy, the resulting clays and other materials may transmit radionuclides into drinking water. Higher levels of radionuclides tend to be found more often in groundwater, such as wells, than in surface water, such as lakes and streams. Drinking water containing Radon also presents a risk of developing internal organ cancers, primarily stomach cancer. Based on national and worldwide investigations, several agencies have concluded that Radon is a known cancer causing agent in humans and is the second most common cause of lung, skin and leukemia cancers after smoking.[7] However this risk is smaller than the risk of developing lung cancer from Radon released into air from tap water. Based on a National Academy of Science

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report, EPA estimates that Radon in drinking water causes about 168 cancer deaths per year: 89% from lung cancer caused by breathing Radon released into the indoor air from water and 11% from stomach cancer caused by consuming water containing Radon.[8] In this study, we are interested in finding the Radon concentration in water by using RAD7. The limit of Radon concentration in water samples is 300pCi/l or 11Bq/l as recommended by US Environmental Protection Agency.[9] The UNSCEAR has suggested a value of Radon concentration in water for human consumption between 4 to 40 Bql^{-1}.[10]

Study area

The present study was carried out in Bukan (Figure 1). Bukan is located south of Lake Urmia about 1,300 meters above sea level and lies between 36° 31' 19" north latitude and 46° 12 40" east longitude. It lies in the West Azarbaijan Province of Iran. The town is situated on the eastern bank of the Simineh River, known locally as ČōmīBukan, on the road between Saqqez and Miandoab. Bukan is inhabited by Kurds, who speak the Sorani, or central, dialect of Kurdish. The rural population is engaged in farming, gardening, and animal husbandry. Environmentally and climatically, Bukan is a highland with snow-capped mountains which looks like as beauty queen of Kurdistan. As regard to the history of the area, according to the archaeological findings, it should be said that from the earliest time the district of Bukan had been populated by ancient tribes, who were inhabited in the foothills of Zagros mountain chain.

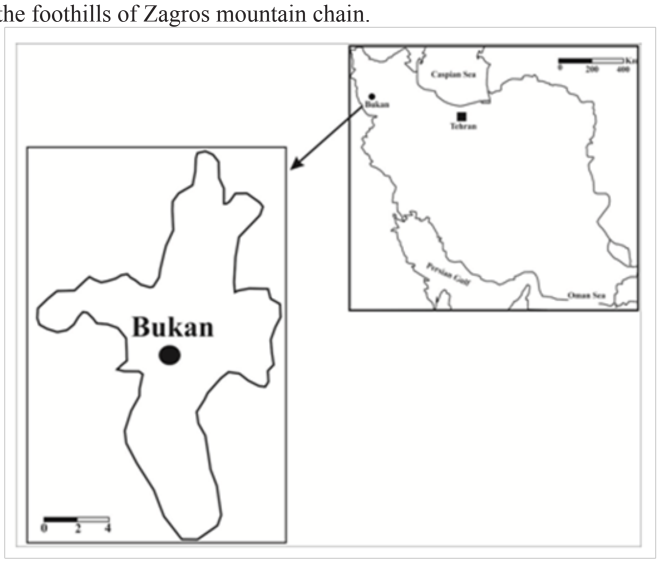

Figure 1 Simplified map of the studied area.

Methodology

Water samples were collected from different sources such as hand pumps and submersible pump of Bukan state. These water samples were collected 20hours before calculating Radon concentration. They were stored in 250 ml vial properly so that no air particles remain in vial. This makes it possible to calculate Radon concentration only due to water rather than combination of air and water. These water samples were analyzed by using RAD7 (Durridge Company) which is an online Radon monitor for calculating the Radon concentration (Durridge company). RAD7 is a continuous Radon gas monitor. It is based on Solid State Silicon Detector. It contains a hemisphere dome in the middle of device, called internal cell.[11] The volume of internal cell is 0.7 litres. At the centre of hemisphere, Silicon Alpha Detector is placed. It is a sophisticated and versatile measuring device capable of complex measurements of Radon in soil, air and water. It is simplest, easiest and portable computer driven electronic instrument to use. The task of RAD7 is divided into two categories:

Purging of RAD7: Before using RAD7, the first step is to do purging which means to remove undesired moisture and humidity from measurement chamber. This can be done by connecting gas purifier GAS PURIFIER to RAD7 instrument with tubes. The DRIERITE Gas Purifier is an all-purpose drying unit for the efficient and rapid drying of air. It is used to maintain a dry atmosphere in storage spaces, vaults and commercial packages. In the present study, we are using INDICATING DRIERITE. Indicated Drierite is impregnated with cobalt chloride. It is blue when dry and changes to pink upon absorption of moisture. The need of purging is only to obtain relative humidity less than 10%, so that we can collect accurate result. Purging can be simply done by just connecting the inlet of RAD7 at bottom of dessicant drying unit and outlet of RAD7 at the top of dessicant drying unit as shown in Figure 2A. If relative humidity becomes less than10% which implies that RAD7 is now ready for use.[12]

Determination of radon concentration: Radon concentration was calculated by using RAD7 (Figure2b).[13,14] Set RAD7 at wat 250 modes for finding Radon in water samples. The RAD7's pump will run for five minutes. During the five minutes of pumping, more than 95% of the available Radon is removed from the water. This removed Radon gas is sucked through filter into the inlet and reaches the measurement chamber. The voltage of 2000 to 2500 V is applied between detector and hemisphere, creating an electric field throughout the volume of cell. This electric field drifts the positively charged particles onto the detector. Inside the chamber, Radon-222 decays into a positively ionized polonium-218. This positively ionized Po-218 will be accelerated towards the detector. The produced Po-218 has half-life of 3minutes. When the short lived Po-218 nucleus decays upon the detector's active surface, its alpha-particle (6MeV) energy have 50% probability of entering the detector and producing an electrical signal proportional in strength to the energy of alpha particle. This signal is amplified electronically and transformed into a digital signal. This signal further processed by a microprocessor and helps to produce the spectrum. The Radon concentration in internal cell of RAD7 can be calculated by following differential equations:[15]

$$\frac{dC(t)}{dt} = -\lambda C(t) \quad (1)$$

$$dC_{Po}(t)/dC = \lambda_{Po} C(t) - \lambda_{Po} C_{Po}(t) \quad (2)$$

Where C (t) is the Radon concentration in the internal cell of RAD7, λ is the density constant of Radon, C_{Po} (t) is Po-218 concentration and λ_{Po} is Po-218 decay constant and equals to $0.00379s^{-1}$. After certain duration of pumping, the Radon concentration in internal cell of RAD7 equals to that of the environment C_0. Equation (2) becomes as:

$$dC_{Po}(t)\ dt = \lambda_{Po} C_0 - \lambda_{Po} C_{Po}(t) \quad (3)$$

The initial condition is $C_{Po}(0)=0$ (4)

The solution of equation (3) is $C_{Po}(t)=C_0(1-e^{-\lambda_{Po}t})$ (5)

If the time is much longer than the half-life of Po-218, equation (5) becomes

$$C_{Po}(t)=C_0 \quad (6)$$

Radon concentration can be calculated from equation (6) and this is the measurement principle of RAD7.

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Evaluation of mean annual effective dose

The dose due to Radon can be divided into two parts. First is dose from ingestion and second is dose from inhalation. The annual mean effective dose for ingestion and inhalation were calculated according to parameters introduced by UNSCEAR report is calculated as:10

Ingestion Dose (mSv) = Rn^{222}conc. $(Bql^{-1})\times 60ly^{-1}\times 10^{-3}m^{3}l^{-1}\times 3.5nSvBq^{-1}$ (7)

Inhalation Dose (mSv) = Rn^{222}conc. $(Bql^{-1})\times 10^{-4}\times 7000hy^{-1}\times 0.4\times 9nSv\,(Bqhm^{-3})^{-1}$ (8)

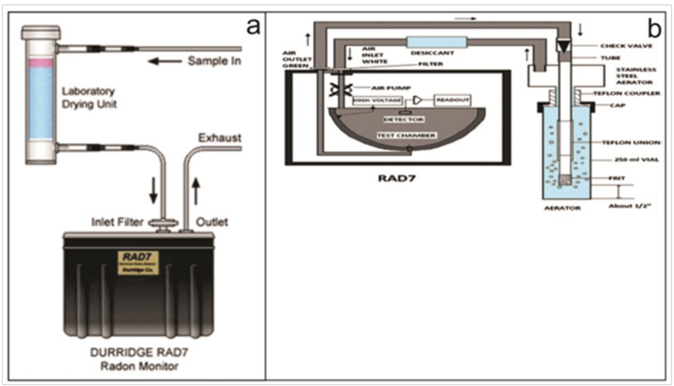

Figure 2 A) Showing the purging process of RAD7; B) Schematic diagram of RAD H2O assembly.

Results and discussion

The results of Radon concentration in water samples taken from 17 locations of Bukan are shown in Table 2. The results show that the higher activity of Radon was 11.87±1.40Bql^{-1} in sample no. 14 and low activity was 0.79±0.18Bql^{-1} in sample no. 11 with mean value 03.75Bql^{-1}. Figure 3 shows the bar chart of mean Radon concentration in the studied dwellings. The US Environment Protection Agency has suggested that the maximum allowed concentration level of Radon concentration in water is 11Bq l^{-1}.[15] The United Nations Scientific Committee on the effects of Atomic Radiation has given range of 4 to 40Bq l^{-1}.[16] The recommended limit of the protection of the public against exposure to Radon in drinking water supplies (2001/928/Euratom), which recommends action level of 100Bq l^{-1} for public water supplies and 100011Bq l^{-1} for private water supplies as recommended by European Commission.[17] The values of Radon concentration obtained in groundwater were compared with regions of other districts of Bukan. The value of Radon concentration in groundwater samples of Bukan varies from 1.9-5.3Bql^{-1} and 1.23-4.24Bq l^{-1}. A few values of Bukan are higher than other districts as reported in Table 3. The high value of Radon concentration in Bukan may be due to high value of uranium content in drinking water samples. All values of Bukan were well within the permissible limit suggested by UNSCEAR and USEPA. The Radon concentration values were also compared with the European Commission limit; all values were found to be well below the level and hence slightly unhealthy for drinking purposes. The reason for variation in Radon concentration in some areas may be due to the depth of water sources.

Table 2 Radon concentration and annual effective dose in water samples at different locations

Sample No.	Radon concentration in water samples (Bq l^{-1})				Annual effective dose (μSv/y)		
	Min.	Max.	Mean	S.D.	Lungs	Stomach	Total
1	08.65	10.69	09.44	00.88	23.78	01.98	25.76
2	05.88	09.39	07.84	10.52	19.77	01.65	21.42
3	04.20	07.03	05.50	10.22	13.86	01.15	15.01
4	02.58	03.15	02.80	00.24	07.06	00.59	07.64
5	04.10	05.40	04.80	00.58	12.09	01.01	13.10
6	01.80	02.87	08.20	01.40	05.54	00.46	00.60
7	02.73	03.44	08.09	00.31	07.79	00.65	08.44
8	02.05	02.86	09.43	00.37	06.12	00.51	06.63
9	07.51	09.28	08.87	00.37	04.71	00.39	05.10
10	00.66	09.94	00.96	00.12	01.97	00.16	02.13
11	00.37	00.64	00.79	00.11	01.34	00.11	01.45
12	01.27	01.71	01.50	00.24	03.78	00.32	04.10
13	01.51	02.01	01.70	00.23	04.28	00.36	04.64
14	09.90	12.69	11.87	01.40	28.22	02.35	30.57
15	02.08	02.43	02.25	00.15	05.67	00.47	06.14
16	02.06	03.49	02.75	00.21	05.67	00.47	06.14
17	02.98	03.51	03.15	00.24	07.94	00.66	08.60
Average	03.19	04.91	03.75	01.62	09.45	00.79	10.24

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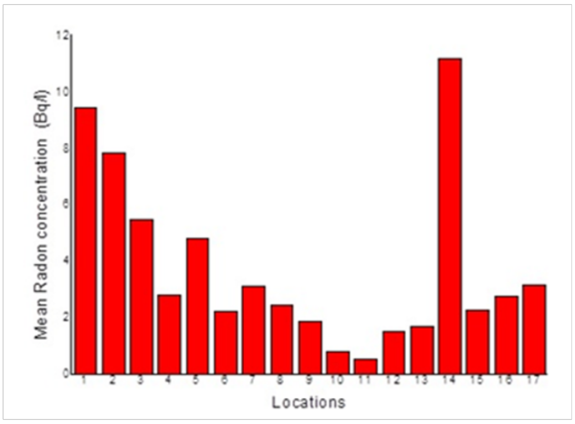

Figure 3 Mean Radon concentration in water samples.

The annual effective dose in the stomach and lungs per person was also evaluated in this study. The values of the annual effective dose per person caused by different water samples in this study are in Table 2. The average annual effective dose from ingestion of Radon in drinking water was 0.79μSvy^{-1} and that of inhalation of water-borne Radon was 9.45μSvy^{-1}. So the annual effective dose due to inhalation of water-borne Radon was higher than those from Radon ingestion from water. It is concluded that not the ingestion of Radon in drinking water but inhalation of Radon escaping from water is a substantial part of radiological hazard. The estimated total annual effective dose ranged from 1.27μSvy^{-1} to 32.67μSvy^{-1}.The measured values of annual effective dose per person were found to well below their commended limit of 100μSvy^{-1}.[18,19]

Table 3 Comparison of Radon concentration in ground water with surrounding cities

Other Regions of Some Districts	Radon Concentration in Water (Bql^{-1})	
	Range-	Mean value
Saqqez	00.40-04.90	3.68
Mahabad	00.40-05.10	2.63
Miyandoab	00.23-02.10	0.88
Shahindej	00.56-07.75	2.14
Bukan	00.79-11.87	5.73

Conclusion

i. The results of the Radon concentration in drinking water samples in Bukan area were below the safe limits recommended by USEPA and UNSCEAR. The water of these locations is slightly hazardous for us.

ii. The variation of Radon concentration may be due to the depth of the water source, geological structure of the studied area and may be due to high value of uranium content in drinking water.

iii. The value of average annual effective dose from ingestion of water and inhalation of water-borne Radon was 0.79 µSvy^{-1} and 9.45 µSvy^{-1}. It is concluded that not the ingestion of Radon in drinking water but inhalation of Radon escaping from water is a substantial part of radiological hazard.

iv. The estimated total annual effective dose also lies within the safe limits as recommended by the WHO and EU.

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None.

Conflict of interest

The author declares no conflict of interest.

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