

Effective Dose Radon 222 of the Tap Water in Children and Adults People; Minab City, Iran

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Abstract

²²²Rn is a radioactive, odorless, and colorless element which has a half-life of 3.83 days. One of ²²²Rn main resources are Groundwater (wells, springs, etc.). Hence, the use of groundwater with high concentration of ²²²Rn can increase the risk of lung and stomach cancers. Concentration of ²²²Rn in tap water of Minab city in two temperatures 5 and 15 °C was measured by radon meter model RTM1668-2. The effective dose was calculated by equations proposed by UNSCEAR. Geometric mean concentration of ²²²Rn in drinking water was found to be 0.78±0.06 and 0.46±0.04 Bq/l at 5 and 15 °C (p value<0.05), respectively. The effective doses were 0.006 and 0.003 mSv/y for adults, and 0.011 and 0.007 mSv/y for the children, respectively (p value<0.05). Besides, the effective dose for adult through inhaling ²²²Rn at 5 and 15 °C were estimated 0.0021 and 0.0012mSv/y, respectively. Geometric mean concentration in ²²²Rn drinking water and effective dose received from drinking water and inhalation of ²²²Rn is lower than WHO and EPA standard limits. Increasing temperature of drinking water will decrease the effective dose received. Annual Effective dose received from inhalation and consumption of ²²²Rn in drinking water in children is more than adults.

Keywords: Radon 222, Effective dose, tap water, child and adults humans

1. Introduction

Radon 222 (²²²Rn) is produced as a result of decay of Radium 226 (²²⁶Ra) in Uranium 235 (²³⁵U) chain. This element is radioactive, odorless, colorless, and water soluble and has a half-life of 3.83 days (Al-Khateeb, Al-Qudah, Alzoubi, Alqadi, & Aljarrah, 2012; Ju, Ryu, & Jang, 2012). Several studies indicate that ²²²Rn indoor air concentration have a significant relationship with lung cancer (Torres-Durán, Barros-Dios, Fernández, & Ruano-Ravina, 2014). Indoor air death rate from ²²²Rn has been announced approximately 21,000 people a year, 10 times more than air pollution deaths (Environmental Protection Agency, 2010). Studies have shown that ²²²Rn, received the annual effective dose 1.3mSv/y due to natural exposure (2.4 mSv/y) to dedicate (Over 50%) (Magill & Galy, 2005). United Nations Scientific Committee on the effects of atomic radiation (UNSCEAR) has expressed exposure standard effective dose received from natural radioactive 2.5 mSv/y, which is 1 mSv/y related to ²²²Rn (Mehra and Bala, 2013; Radiation, 2000). ²²²Rn in drinking water can enter the internal organs such as the stomach and cause cancer (Somlai, Tokonami, Ishikaw, Vancsur, Gáspár, 2007; Auvinen, Salonen, Pekkanen, Pukkala, & Ilus, 2005; Alizadeh, Mahvi, & Fakhri, 2014). Also ²²²Rn inhalation can cause damage to

DNA lung cells and leads to lung cancer in the population (Todorovic, Nikolov, Forkapic, Bikit, & Mrdja, 2012; Motesaddi, Fakhri, Alizadeh, Mohseni, & Jafarzadeh, 2014). European Commission and the World Health Organization has proposed concentration of ^{222}Rn in the drinking water, 100 Bq/l as the standard limit (WHO, 2006). EPA 11 Bq/l, has been suggested as the maximum concentration Level (MCL) of ^{222}Rn in drinking water (Environmental Protection Agency, may 2012). Many studies have shown that groundwater resources rather than surface water resources have much higher concentration of radioactive materials such as ^{222}Rn (Amin, 2013; Rožmarić, Rogi, Benedik, & Štok, 2012). The total indicative dose (TID) induced by radioactive substances (^3H , ^{40}K , ^{222}Rn) as well as those produced through ^{222}Rn decayed in drinking water is reported to be 0.1 mSv/y by WHO and the European committee (Somlai at al., 2007 ; Todorovic at al., 2012 ; WHO, 2004). Due to the exit of ^{222}Rn during water transfer in distribution network, water transfer from one container to another, storing and boiling water, determining the standardized effective dose induced by ^{222}Rn is difficult (Ishikawa, Tokonami, Yoshinaga, & Narazaki, 2005). Hence, the effective standard level dose 0.1 mSv/y is used for the analysis. In the present study, the effective dose of ^{222}Rn received by children and adult age groups in Minab drinking water was calculated.

2. Materials and Methods

2.1 Study Area

Minab city with a population of approximately 90 thousand people is located in geographic coordinates $27^{\circ}06'40\text{N}$ and $57^{\circ}05'52$, at an elevation of 45 meters above sea level (Figure 1). The city is located in a hot and humid region and the water consumption per capital was high. The only water resources in this town are three deep wells (Groundwater source), the water of which is pumped out and distributed with no purification process.

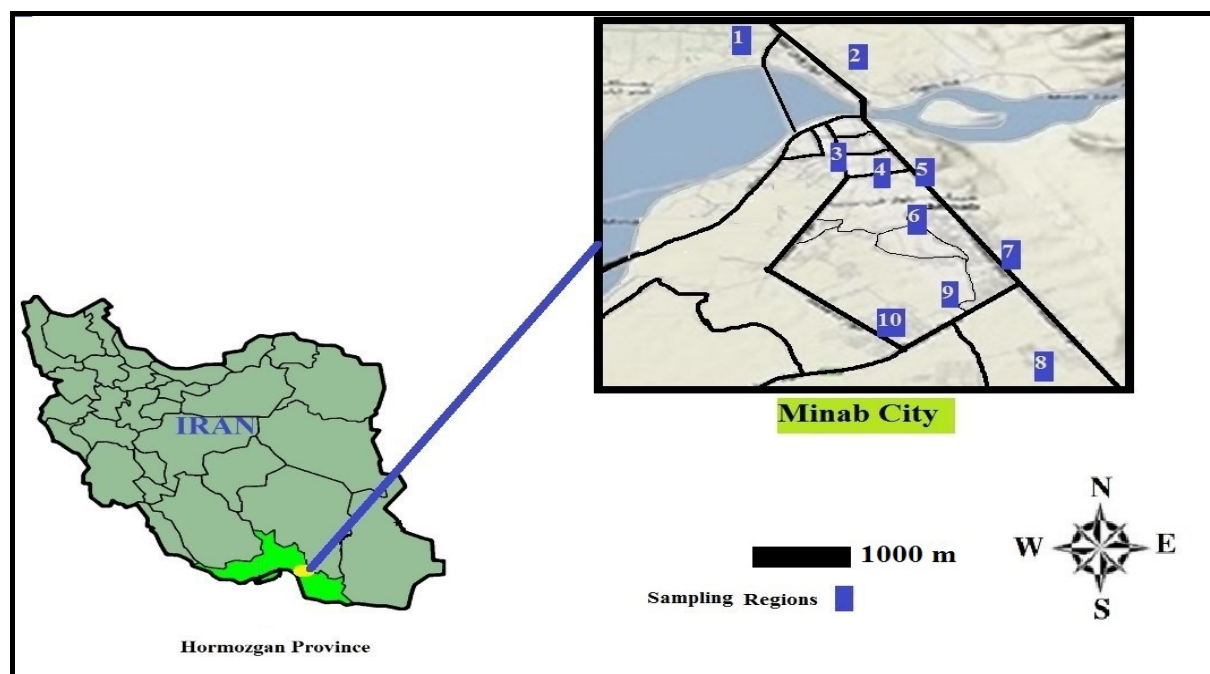


Figure 1. sampling regions of Minab in the East province of Hormozgan, Iran (2)

2.2 Sample Collection

Since the retention time of water in the distribution network is effective on the concentration of ^{222}Rn (Ishikawa, Tokonami, Yoshinaga, & Narazaki, 2005), thus, the sampled locations were determined from the beginning to the end of the distribution network. For 4 consecutive months, the sampling was done in 10 regions of the town. Meanwhile, 25 samples were selected from each region. During each stage of time, a total of 250 samples, each containing 2l of city tap water were obtained from 10 regions. Sampling was conducted according to the proposed method (EPA).

2.3 Measurement Concentration of ^{222}Rn

Measurement of radioactive substances in water, soil and air are done in various ways, such as alpha

spectrophotometry, inductively coupled plasma/mass spectrophotometer, gamma spectrophotometry and liquid Scintillation (Rožmarić, Rogi, Benedik, & Štok, 2012). Recently, many studies measure the concentration of ^{222}Rn portable devices, such as RAD7 RTM (Mehra and Bala, 2013; Ju, Ryu, Jang, Dong, & Chung, 2012; Todorovic, Jovana Nikolov, Sofija Forkapic, Istvan Bikit, & Dusan Mrdja, 2012; Lee & Kim, 2006). Hence, in this study a model of portable alpha spectrophotometry RTM1688-2 was used to measure ^{222}Rn in drinking water. To determine the effect of water temperature on the diffusion rate ^{222}Rn of water, measurements was done at 5 and 15°C temperatures. According to measurement of 300 mL, after the sample size reached the intended temperature, the device was placed in a closed cycle (Figure 2). The time for balance between concentration of ^{222}Rn and its decay products (daughters ^{222}Rn) is 4 hour approximately (Ju, Ryu, & Jang, 2012; Mehra & Bala, 2013; Lee & Kim, 2006). Hence, the 4 hour mean concentration of ^{222}Rn (Bq/l) and the initial temperature (°C) was recorded.

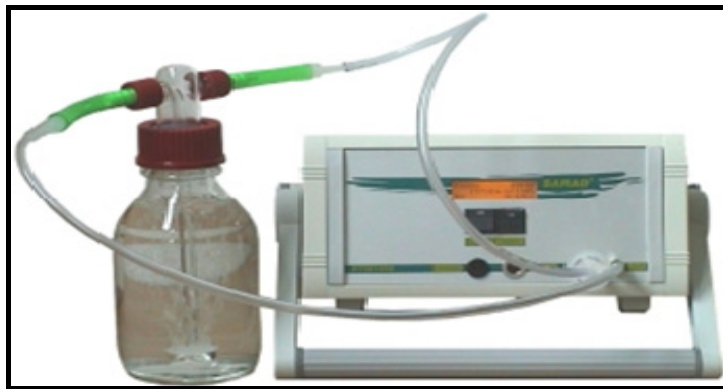


Figure. 2. Measurement water ^{222}Rn levels by RTM 1688-2 device, manufactured by Sarad corporation in Germany.

2.4 Calculation of effective dose (Ingestion)

To determine ^{222}Rn annual effective dose received in the stomach from water consumption, Equation 1 was used (Sarad, 2009). In this equation E: the annual effective dose received by mSv/y, K: Coefficient conversion concentration of ^{222}Rn to effective dose According to mSv/Bq, KM: Annual water consumed l/y, C: the concentration of ^{222}Rn depending on Bq/l and T: the period of water consumption in the study, here was 365 days (Somlai, Tokonami, Ishikawa, Vancsura, & Gáspár, 2007).

$$E=K\times C\times KM\times T \quad (1)$$

Conversion factor for adults and children were 1×10^{-8} Sv/Bq and 2×10^{-8} Sv/Bq, respectively (Amin, 2013; WHO, 2004). KM is daily consumption which is considered 2 l/d.

2.5 Calculation of the Effective Dose (Inhalation)

In order to estimate the effective dose received annually through inhaling ^{222}Rn of underground water, the conversion coefficient of 2.8 $\mu\text{Sv}\cdot\text{lit}/\text{Bq}$ was used (Radiation, 2000). The annual geometric mean concentration of ^{222}Rn (Bq/l) was multiplied by the coefficient 2.8×10^{-3} , and the effective dose received annually through inhaling ^{222}Rn was estimated in mSv/y.

2.6 Statistical Analyses

Statistical analyses were done via SPSS 16, using One-way ANOVA method and correlation coefficient. The results were also stated in mean and standard deviation forms.

3. Results

Geometric mean and range of concentration of ^{222}Rn in drinking water was measured 0.78 ± 0.06 Bq/l and 0.19-1.7 Bq/l at 5 °C and 0.46 ± 0.04 Bq/l and 0.16-1.45 Bq/l at 15 °C, respectively (p value<0.05). (Tables 1 and 2).

Table 1. Geometric mean (GM±SE), Middle, maximum and minimum concentration of ^{222}Rn tap water samples in the temperature of 5 °C (Bq/l) (n=250; Note 1)

Regions	Minimum	Maximum	Middle	Geometric mean
1	0.96	1.8	0.24	1.17±0.1
2	0.77	1.71	0.5	1.14±0.1
3	0.68	1.08	0.98	0.93±0.08
4	0.78	1.15	0.9	0.92±0.08
5	0.48	0.96	0.87	0.77±0.06
6	0.65	0.89	0.76	0.72±0.06
7	0.42	0.69	0.56	0.57±0.5
8	0.43	0.85	0.72	0.65±0.5
9	0.26	0.65	0.46	0.47±0.4
10	0.2	0.65	0.54	0.49±0.4

Table 2. Geometric mean (GM±SE), Middle, maximum and minimum concentration of ^{222}Rn drinking water samples in the temperature of 15°C (Bq/l) (n=250)

Regions	Min	Max	Middle	Geometric mean
1	0.6	1.14	0.78	0.81±0.6
2	0.54	1.45	0.76	0.86±0.7
3	0.26	0.82	0.59	0.53±0.4
4	0.48	0.88	0.62	0.62±0.5
5	0.17	0.75	0.53	0.48±0.4
6	0.19	0.75	0.47	0.43±0.3
7	0.18	0.49	0.32	0.33±0.2
8	0.16	0.49	0.39	0.37±0.3
9	0.17	0.54	0.29	0.27±0.2
10	0.2	0.42	0.26	0.27±0.2

The percent of concentration frequency distributions of ^{222}Rn in drinking water of 10 regions of Minab city in temperatures 5 and 15 °C are shown in Figures 3 and 4. The maximum and minimum frequency distribution concentration of ^{222}Rn at the temperature of 5 °C was observed in the range of 0.6-0.9 Bq/l and >0.4 Bq/l, respectively. At the temperature of 15 °C, they were observed in the range of >0.4 Bq/l and 1.1-1.3 Bq/l.

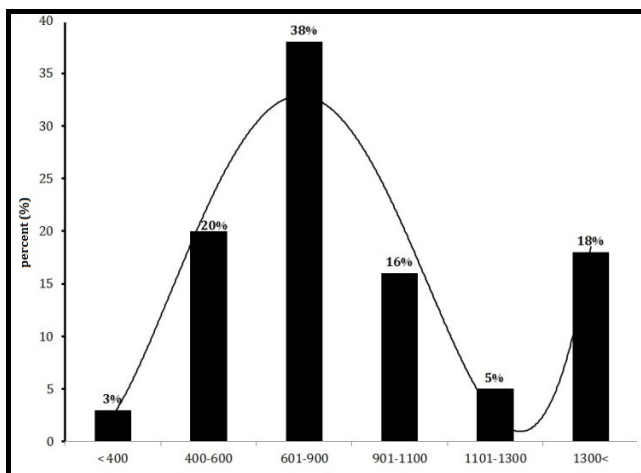


Figure 3. Percent of frequency distributions concentration of ²²²Rn Drinking water temperature in 5 °C

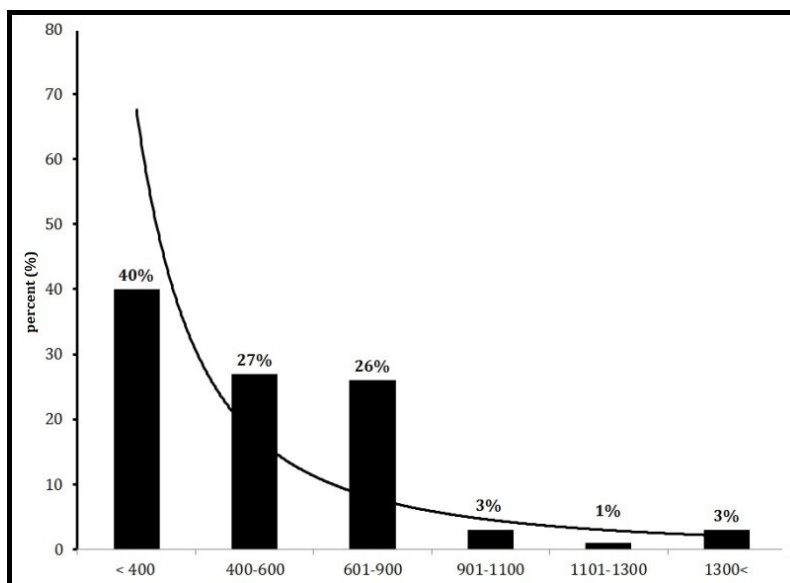


Figure 4. Percent of frequency distribution concentration of ²²²Rn in drinking water at 15 °C

The effective dose received annually through drinking water at the temperature of 5 °C in the children and adult groups was 0.011 and 0.007 mSv/y, respectively. At the temperature of 15 °C it was 0.007 and 0.003 mSv/y (p value<0.05). The effective dose received annually through inhaling ²²²Rn in drinking water at the temperatures of 5 °C and 15 °C were 0.0021 and 0.0012 mSv/y, respectively (p value<0.05).

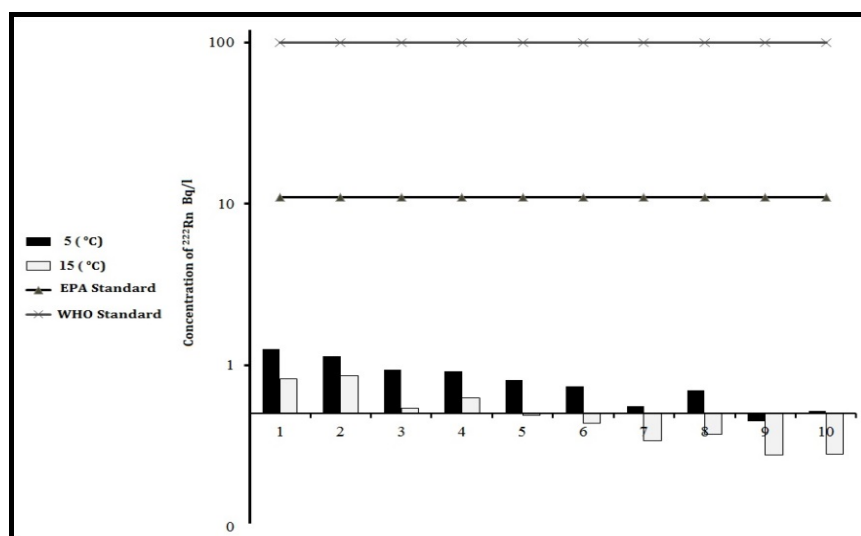


Figure 5. Geometric mean concentration of ^{222}Rn drinking water in 10 regions of Minab at the temperatures of 5 °C and 15 °C

4. Discussion

Geometric mean concentration of ^{222}Rn of drinking water at 5 °C (0.78 ± 0.06 Bq/l) is greater than of 15 °C (0.46 ± 0.04 Bq/l). P value < 0.05 between concentration of ^{222}Rn of drinking water in temperatures 5 and 15 °C, indicate a significant difference. Consistent with our results, several studies reduce emissions ^{222}Rn where the effect of reduced water solubility was observed as the temperature increased (Yalcin, Gurler, Akar, Incirci, & Kaynak, 2011; Galip Yuca & Gasparonb, 2013; Oner, Yalim, Akkurt, & Orbay, 2009).

Table 3. Range concentration of ^{222}Rn in tap water of Minab city compared with some other cities

Country / City	Water source	Range	References
Pakistan/Islamabad	Groundwater	25.9-158.4	(Ali, Khan, Akhter, Khan and Waheed, 2010)
Italy/Umbria	Groundwater	5.9-65.7	(Borio, Rongoni, Saetta, Desideri and Roselli, 2005)
Turkey/Amasiya	Groundwater	0.39-1.17	(Oner, Yalim, Akkurt and Orbay, 2009)
China/Bovaji	Groundwater	12-41	(Xinwei, 2006)
Iran/Tehran	Groundwater	27.7-74.3	(N.Alirezazadeh, 2005)
Iran/Minab	Groundwater	0.16-1.7	This Study

As it can be seen in Table 3, the range concentration of ^{222}Rn in drinking water of Amasiya (0.39-1.17 Bq/l) is within the range concentration of ^{222}Rn drinking water of Minab (0.16-1.7 Bq/l). The range concentration of ^{222}Rn in drinking water of Tehran (27.7-74.3 Bq/l), Buvaji (12-41 Bq/l), Uberiya (5.9-65.7 Bq/l), and Islamabad (25.9-158.4 Bq/l) are much greater than Minab and Amasiya cities. Difference concentration of ^{222}Rn in these towns (Amasiya and Minab) may be due to different factors such as concentration of ^{222}Rn in the water source, geological substrate type, water retention time and temperature during the measurement (Yiğitoğlu, Öner, Yalim, Akkurt, Okur, 2010). Groundwater resources (springs, wells, etc.) due to contact with the various layers of the earth, has more Total Dissolved Solid (TDS), including radioactive materials relative to surface waters (rivers, lakes, etc.). Layers of earth containing igneous rocks (granite) are larger, with higher concentration of radioactive material ^{235}U (Rožmarić, Rogi, Benedik, & Štok, 2012; Rezaei & Jalili-Majreshin, 2011). Since the ^{222}Rn is the product of series of ^{235}U decay, it can be expected that concentration in groundwater which cross from substrate type, are higher (Przylibski, Mamont-Ciesła, Kusiak, Dorda, & Kozłowska, 2004). Drinking water sources in Tehran, Buage, Umbria and Islamabad are of underground type similar to Minab and Amasia. However, concentration of ^{222}Rn in the drinking water of Minab and Amasia is different. This could be due to differences in geological structure, measuring temperature and retention time of water. The effective dose received by

children age group at the temperature of 5 °C (0.011 mSv/y) was 1.57 times more than of that at 15 °C (0.006 mSv/y). For adults it was 2 times bigger. Since the mean concentration of ^{222}Rn at 5 °C ($0.78 \pm 0.06 \text{ Bq/l}$) is more than that of 15 °C ($0.46 \pm 0.04 \text{ Bq/l}$), the effective dose received is higher at this temperature. The effective dose received annually by adults and children from drinking water at 5 and 15 °C was below the standard 0.1 mSv/y. The activated coefficient of converting ^{222}Rn to effective dose is higher in children group than adults (Somlai at al., 2007). The effective dose received from drinking water in this age group at the temperatures of 5 and 15 °C are 1.83 and 2.33 times bigger than adults'.

Table 4. Annual effective dose received by age groups of children and adults caused by the inhalation ^{222}Rn and ingestion of tap water Minab (Iran) and other cities

City / Country	Annual effective dose		Inhalation (lung) mSv/y	References
	Drinking water (stomach) mSv/y			
	Childs	adults		
Minab/Iran ¹	0.011	0.006	0.0021	This study
Minab/Iran ²	0.007	0.003	0.0012	This study
Mashhad/Iran	-	0.00029	0.0004	(Binesh, Mohammadi, Mowlavi, & Parvaresh, 2010)
Tehran/Iran	0.000129	0.00066	0.01	(N. Alirezazadeh, 2005)
Bovaji/China			0.03-0.14	(Xinwei, 2006)
Balaton/Netherlands	0.0004	0.0002		(Somlai at al., 2007)
Australia		0.005		(Kralik, Friedrich and Vojir, 2003)
Gotaya/Turkey	-	0.000122-0.0003	0.00014-0.00003	(Sahin, Çetinkaya, Saç, & İçhedef, 2013)
Kastomono/ Turkey	-	0.00032-0.00093 ³ 0.00049-0.0008 ⁴	-	(Yalcin at al., 2011)

¹ 5 °C Temperatures water;

² 15 °C Temperatures water;

³ Summer season;

⁴ Spring season.

Effective dose due to inhalation of ^{222}Rn from drinking water is much lower than the standard 1mSv/y effective dose due to ^{222}Rn inhalation (Villalba, Sujoa, Cabrera, Jime´neza, & Villalobos, 2005). Effective dose received from ^{222}Rn inhalation from drinking water at 5 °C, is 1.82 times bigger than that of temperature 15 °C. As can be seen in Table 4, the effective dose received by children (0.011 and 0.007 mSv/y) and adults (0.006 and 0.003 mSv/y) at a temperature 5 and 15 °C of drinking water of Minab city is greater than Tehran (0.000129 and 0.00066 mSv/y), Balaton (0.0004 and 0.0002 mSv/y), Mashhad (0.00029 mSv/y for adult), Australia (0.005 mSv/y for adult), Gotaya (0.000122-0.0003 mSv/y) and Kastomono (0.00032-0.00093 mSv/y in summer and 0.00049-0.0008 mSv/y in the spring). ^{222}Rn concentration range in drinking water of Tehran (27.7-74.3 Bq/l) is more than Minab City (0.16-1.7 Bq/l). However, due to the low effective dose conversion factor activity ($0.35 \times 10^{-8} \text{ Sv/Bq}$) and capital annual consumption of water (children 75lit and adults 100lit), a lower effective dose is received by people of Tehran (N. Alirezazadeh, 2005). Lower effective dose in other cities can be due to low concentration of ^{222}Rn , conversion factors and capital water consumption. Effective dose of induced inhalation in Minab (0.0021 and 0.0012 mSv/y) is higher than cities of Mashhad (0.0004 mSv/y), Gotiya (0.00003-0.00014 mSv/y) and is lower than cities of Tehran (0.01mSv/y), and Bovaji (0.03-0.14 mSv/y). However, effective dose of inhalation activity conversion factor of Minab (2.8 $\mu\text{Sv/y}$) is higher than Tehran cities and Bovaji ($1.8 \mu\text{Sv/y}$) (Xinwei, 2006; N. Alirezazadeh, 2005), but due to the higher concentration of ^{222}Rn in tap water, inhalation effective dose is higher in Minab city.

5. Conclusion

Geometric mean concentration of ^{222}Rn in drinking water at temperatures 5 and 15 °C (0.78 ± 0.06 and 0.46 ± 0.04

Bq/l) are lower than EPA and WHO standard limits. Annual Effective dose received from inhalation and consumption of ^{222}Rn in drinking water in children is more than adults (p value < 0.05). Also, effective dose received in both age groups, are much lower than EPA and WHO standard limits. Increasing the temperature reduces the effect on concentration of ^{222}Rn in drinking water, followed by a reduction in received effective dose. Hence, it is recommended to reduce the effective dose received in the cities with high concentration of ^{222}Rn in drinking water, water ingestion be at higher temperature.

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Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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