The Effects of Environmental Parameters on the Radon Exhalation Rate from the ground Surface in HBRA in Ramsar with a Regression Model

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Abstract: An important radioactive, colorless and odorless gas emitted from natural radium existing in the ground, radon is an element of the U^{238} chain. Based on conducted studies, Ramsar has been recognized as one of the most polluted areas in the world as far as the exhalation of radon is concerned. The most important resources of radon in Ramsar are soil resources, water resources, groundwater, surface water and hot springs. In this study, 50 stations in high radioactivity areas of Ramsar were selected and the position of each station in terms of latitude and longitude was recorded with a GPS device; then, radon exhalation and gamma dose rates were measured using an AlphaGuard device and a portable gamma spectroscopy system, respectively. Furthermore, some environmental parameters such as temperature, pressure, relative humidity, the distance of each station from the mineral hot springs, the time interval between the rainfall and the day of measurement, soil moisture status and also weather conditions at the time of measurement were recorded, and the effect of measured environmental parameters on the radon exhalation rate was subsequently evaluated using Spss software and finally modeled by linear regression method. The gamma dose rate was around 58-7100 n.sv/hr and the radon exhalation rate was about 9-15370 mBq/m^2.s. In this study, only the variables of gamma dose rate and soil moisture were effective on exhalation rate. The correlation between gamma dose and radon exhalation rate was significant and higher than the other variables. Results indicate that the estimated average annual effective Radon exhalation rate for the study area is much higher than the worldwide average figure of 16 mBq/m^2.s reported by UNSCEAR. It can therefore be concluded that an assessment of the radiological hazard of living these area is crucial.

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Background:

Humans, animals and plants are subject to the risk of natural radioactive radiations. In fact, the rate of this risk in the past was 3 times higher than today (1). There are regions of high natural radioactivity in the world that were under study for many years. One of these regions is Ramsar in the north of Iran (2). There are nine hot springs with different amounts of radioactive materials in this city. Based on conducted studies, it seems that the source of radioactive materials in the region is firstly mineral waters and secondly the deposition of travertine outcrops and high amounts of thorium and uranium found at the location of source of the hot springs (3). According to the studies conducted on natural radiation in some areas of Ramsar, including Talesh Mahalleh, the annual effective dose for each person has been reported as 132m.sv/year(4). The maximum annual amount of radiation is about 260 mGy. The annual effective dose emitted from natural and artificial resources in the world has been estimated as equal to 2.8 m.sv/year.If it is considered that 85% of this amount is from natural origins, the average annual natural radiation would be 2.4 msv/year (5), which varies from 1 msv/year to 10 msv/year depending on the altitude of the region and the nature of the soil (6). Radon is one of the colorless, tasteless, odorless and neutral radioactive gas emitted from natural radium in the earth, and an element belonging to the uranium 238 (U^{238}) chain released into the environment through surface waters, soil and rocks and naturally found in groundwater (7). Its half-life is 3.8 days; it is also converted into elements such as polonium, bismuth and lead, which are known as Radon daughters, and have high radioactivity properties (8). Radon spread easily due to its pressure gradient and concentration. Radon main gas sources in Ramsar are soil and groundwater, hot springs and surface waters (9). Nero et al. (1990) showed that 90% of the radon found in the homes comes from the soil resources (10). Also, Akerblom et al (1984) and Swedjemark (1985) showed that the high levels of radon in indoor spaces is associated with high levels of this gas in the soil (11).

Epidemiological studies have shown a clear link between breathing high concentrations of radon and incidence of lung cancer. Thus, radon is considered a significant contaminant that affects indoor air quality worldwide. According to the United States Environmental Protection Agency, radon is the second most frequent cause of lung cancer, after cigarette smoking, causing 21,000 lung cancer deaths per year in the United States. About 2,900 of these deaths occur among people who have never smoked. While radon is the second most frequent cause of lung cancer, it is the number one cause among non-smokers, according to EPA estimates (12). Therefore, this study was conducted to measure the radon exhalation rate from the ground surface in HBRA in Ramsar and to study the environmental parameters are effective on this issue through providing a regression model.

Materials and Methods

Ramsar lies along the Caspian Sea, in the north of the Alborz Mountains. This city is located between 36 ° 34 'to 36 ° 58' north latitude and 50 ° 21 'to 50 ° 46' east longitude from the Greenwich meridian (Fig. 1) (13). Ramsar, with the highest level of natural radioactive radiation risk in the world, has been the focus of many studies (14). This study was performed on 50 stations in different areas high radioactivity in Ramsar. First, latitude and longitude coordinates were recorded by a GPS device. Then, any weeds, roots and gravel were removed from the relevant location after finding the measuring station.

Subsequently, the radon exhalation rate from the soil surface was estimated using an AlphaGuard PQ2000Pro device. The AlphaGuard radon monitor, is an example of an active electronic device that uses an ionisation chamber that allows for detection through alpha spectroscopy. It has the added option to pump air into a 0.56-liter cell or by means of diffusion. The two common isotopes of radon^{222}Rn and ^{220}Rn can be identified through their respective energies from the alpha decays. The signal arising from the alpha detection is then filtered and then converted to a digital output that can be readily processed with the AlphaGuard or relayed to a PC via a RS-232 cable. It can be used for radon exhalation, radon soil-gas, indoor, outdoor, in mining environments and in water storage radon measurements(15).

The Radon Box is used as a container to collect radon to measure the radon exhalation rate. This box has been designed so that its useful surface has the highest possible sample taken from the studied surface and roughness cannot result in the uncertainty of more than 10 percent in its useful volume. Air Sampling Pump and AlphaGuard system were used to measure radioactivity concentration of Rn^{222} and a Hall plastic tube was used to create a closed cycle (Figure 2). Following the localization of the measured points using GPS devices and clearing the relevant surface of any grass, gravel and plant roots, the radon collection chamber was placed on the soil surface from its open side; then a closed cycle was created between the air of collection chamber, the AlphaGuard and the alpha pump, which resulted in the discharge of the air from the chamber to the AlphaGuard volume with the rate of 1Lit/min for a period of 90 minutes. In this method, changes in the radon concentration in the chamber were used as a function of time to estimate the exhalation rate from the ground surface(Fig3).

An AlphaGuard device continuously records the concentration in the chamber every ten minutes. Radon exhalation rate from ground surface is obtained from the following equation as an estimation of radon level changes in the collecting box related to the time which is increasing as an exponential function:

$$\phi = \frac{\Delta C}{\Delta t} . \frac{V}{S} \Longrightarrow P\frac{V}{S} = \mathrm{P}.\omega$$

$$\rightarrow \qquad \omega = \frac{V}{S}$$

$$\mathrm{P} = \frac{\sum[(ti-\bar{t})Ci]}{\sum(ti-\bar{t})^2} \qquad (16)$$

It is noteworthy that the reverse release and air movement have been neglected in this equation.

$\emptyset$: Radon Surface exhalation rate, in Becquerel per square meter per second

Δc: variation in radon activitiy concentration during the time interval, in Becquerel per cubic metre

V: Useful volume,in cubic metres

S:Useful surface ,in square meters

P: slope of the straight line fixed to the increasing radon concentration points in the exhalation box.

Δt: Period in which the radon concentration changes were occurred,per second.

The gamma dose rate is measured at one meter above the ground by means of a portable gamma spectrometer (Model GR-130 Mini Spec (Exploranium)). The system is regulated in the dose meter condition; therefore, we will have an average of 5 data in this period of time. Finally, an average of 15 data was considered as the dose rate at this location. It is noteworthy that the environmental parameters such as temperature, pressure and relative humidity were recorded by the device during the period of measuring each station. Also, the distance between each station and the nearest hot spring was obtained using existing maps. Meanwhile, the weather conditions such as cloudy, partly cloudy and sunny weather and also the length of time between the last rainfalls until the day of measurement were considered in the calculations.

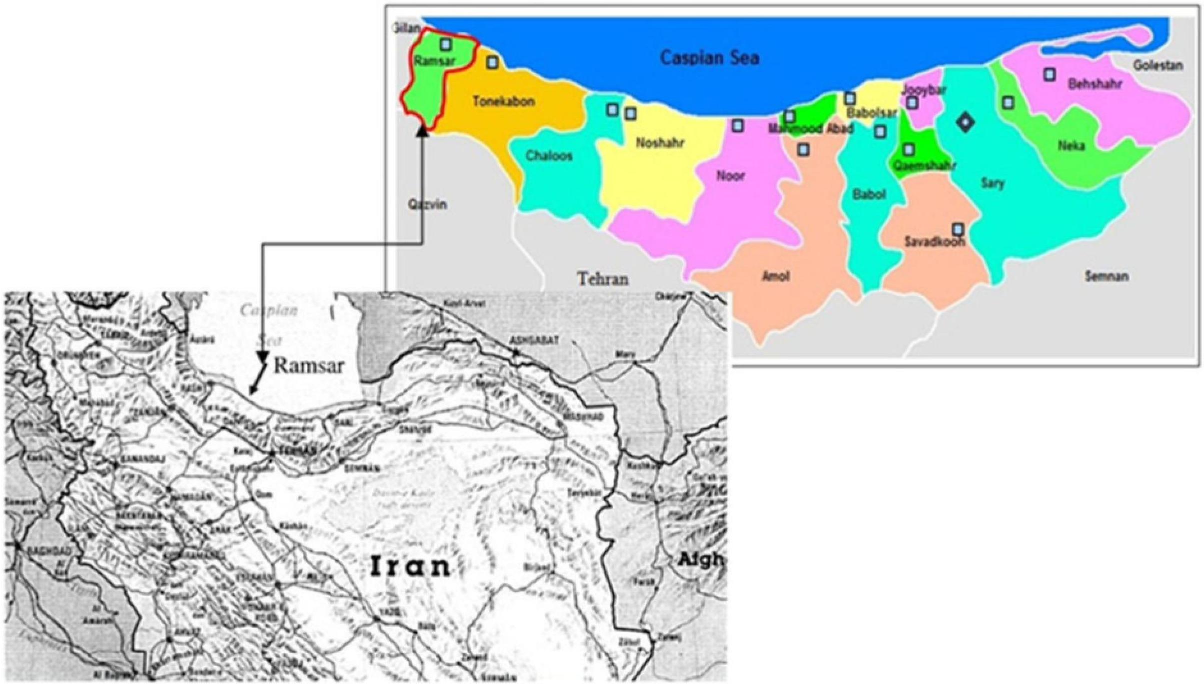

Fig1. Location of Ramsar in Iran and Mazandaran province.

Results and Discussion

Table 1 shows the effect of environmental parameters on 50 measurement stations. Table 2 demonstrates statistical indices of radon exhalation rate and gamma dose rate. Based on Figures 4 and 5, due to the severe skew of variables related to the radon exhalation rate from the soil and gamma dose rate, and also the elimination of the effect of scrubbing values of these two variables, base-10 logarithm variable changes were used, which resulted in the establishment of the changed variable normality of the gamma dose rate and radon exhalation rate from the ground surface. The average of radon exhalation rate and also the new average measure of gamma dose were obtained as equal to 2.5 ± 0.7 and 2.3 ± 0.5 respectively. Table 3 shows the Spearman correlation between the radon exhalation variable in the primary scale and the Pearson correlation of this variable in the new scale with other variables measured on a quantitative scale. As can be seen in Table 3, the correlation between the gamma dose rate and the radon exhalation rate was significant and higher than the other correlations. Furthermore, although negative correlation between the radon exhalation rate and the distance from hot springs is significant (i.e. with increasing distance from hot springs, radon exhalation rate decreases), the correlation level is low. Therefore, After the change of variable ,the ANOVA test showed no significant relationship between the radon exhalation rate and the length of time from the last rainfall until the day of measuring the stations (p = 0.15). But there is a statistically significant relationship between this variable and soil type as far as moisture ($p < 0.001$) and weather conditions are concerned ($p = 0.046$) (Table 4). The linear regression model was used to model and to indicate the simultaneous effect of independent variables on the radon exhalation rate. Hence, variables identified as effective in the study of their relationship with radon exhalation (in the new scale, p-value<0.25) were applied in the regression model, and the model was fitted using the backward method. However, it should be noted that since variables such as soil type and weather conditions were significantly correlated with each other ($p < 0.001$), we only used the soil moisture variable, which has a lower p-value in order to enter into the regression model. Table 5 shows the results of fitting the linear regression model.

Wet soil was considered as a base line. As can be seen in Table 5, only log-gamma variables and soil type are effective on radon exhalation rate. Therefore, the model derived from this study is as follows:

Log_{10}(radon exhalation rate) = -0.71 + 0.82 Log_{10} (gamma dose)+ 0.83(dry soil)+ 0.66(semi-moist soil)

After fitting the above-mentioned model, reminders were evaluated and their normality was confirmed by the Shapiro-Wilk test (P = 0.72). In addition, the rate of the adjusted R^2 resulted from the fitting of this model to all of the data was equal to 0.67, showing that the model has a good fitting.

Among the measured stations, only 2 percent had relative humidity less than 40 percent; 36 percent had humidity above 70 percent and the rest of them had relative humidity between 70-40 percent.. The time length between the last rainfall and the day of measurement was less than 10 days for 54% of stations, 10 to 20 days for 24% of stations and more than 20 days for the rest of the stations. On the measurement day, the soil was dry in 52% of the stations, semi- moist in 38% of the stations and moist in only 10% of the stations. Weather conditions on the day of measurement were partly cloudy for 50% of the stations, sunny for 40% of the stations and cloudy for 5% of the stations.

Based on the conducted studies, it is observed that with reduced soil moisture and weather conditions changing into sunny weather, radon exhalation rate increases. Meanwhile, we have come to the conclusion that there is a significant difference between the radon exhalation rate from dry soil and moist soil ($p < 0.001$) and between moist and semi-moist soil ($p = 0.002$) and also between sunny and cloudy weather ($p = 0.04$).

Fig 2. AlphaGuard system and Radon box [21]

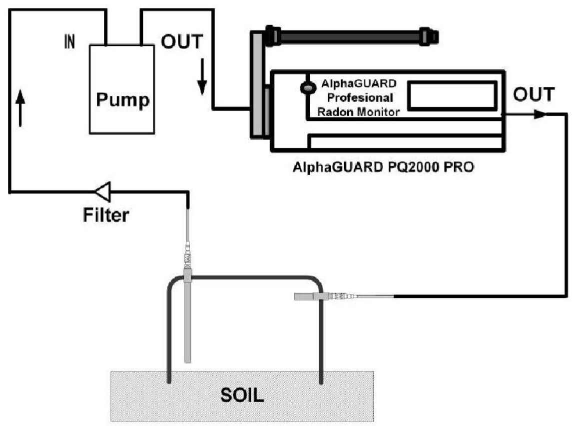

Fig3. Schematic of Radon exhalation rate measurment

Table 1. Effect of environmental parameters on 50 measurement stations

Median	Max	Min	Mean±Sd	Variable
30	40	22	30±4.2	Temperature(c°)
1008	1022	1001	1008.6±4.4	Pressure(m.bar)
65.5	90	40	64.8±11.2	Humidity
570	1368	76	592±391.8	Distance from hot sptings(m)
80.5	126	-6	68±40.3	Altitude (m)

Table 2. Statistical indices of radon exhalation rate and gamma dose

97 percentile	Third percentile	Max	Min	Median	Mean±sd	Variable
10402.8	12.71	15370	9	294	1062.5±2357.6	Radon exhalation rate($mBq/m^2.s$)
6688.2	60.6	7100	58	158.5	572.2±1336.1	Gamma dose rate(n.sv/hr)

Table 3. The Spearman correlation between the radon exhalation variable in the primary scale and the Pearson correlation of this variable in the new scale with other variables measured on a quantitative scale

Pearson 's correlation(p.value)	Spearman 's correlation(p.value)	Variable
0.175(0.23)	0.159(0.27)	Temperature(c°)
0.036(0.8)	-0.04(0.78)	Pressure(m.bar)
-0.13(0.36)	-0.16(0.27)	Humidity
-0.32(0.025)	-0.27(0.06)	Distance from hot springs(m)
0.17(0.25)	0.016(0.91)	Altitude (m)
0.75(<0.001)	0.71(<0.001)	Gamma dose(nsv/hr)

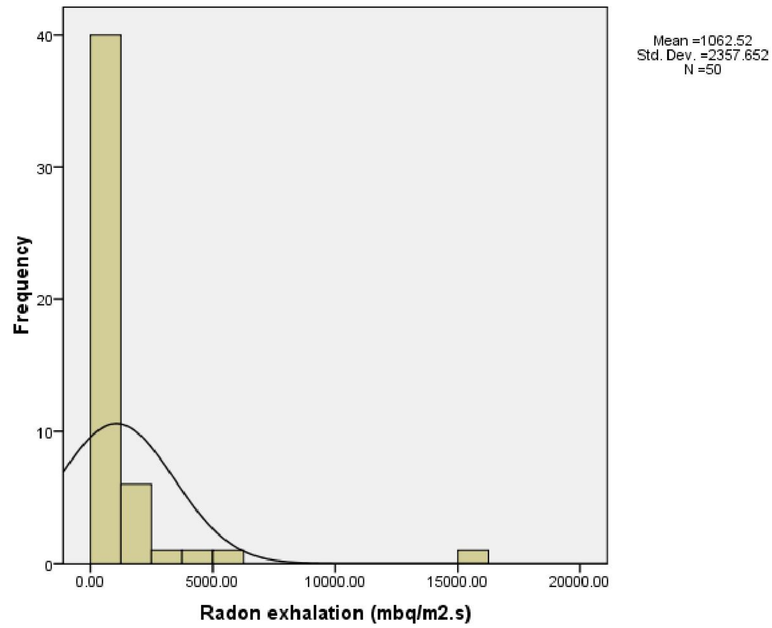

Fig 4. Frequency distribution of Gamma dose rate in Ramsar

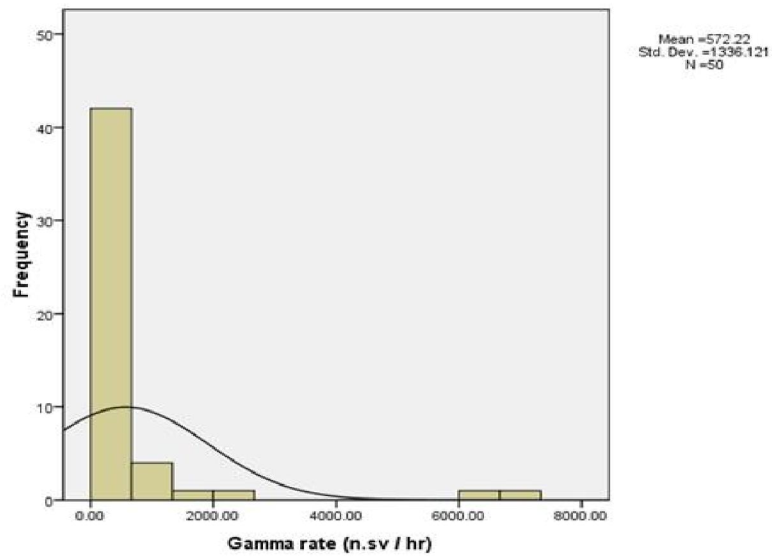

Fig5. Frequency distribution of Gamma dose rate in Ramsar

Table 4. Correlation between the radon exhalation rate and Rainfall interval and soil moisture and weather conditions after change of variable.

	p-value	mean±sd	Groups	Variable
	0.15	801.5±1334.3 493.7±305.2 2323.7±4492.5	<10 10-20 >20	Rainfall interval
		1494.2±3005.8	Dry	
	<0.001	739±1384.1	Semi moisture	Soil moisture
		47±48.8	moisture	
	0.046	851.1±1329.2 1480.2±3405.7 449±878.8	partly cloudy sunny cloudy	Weather conditions

Table 5. Results of fitting the linear regression model

p-value	standardized	SD	Un standardized	Variable
<0.001	0.63	0.11	0.82	Gamma logarithm
<0.001	0.64	0.19	0.83	Dry soil
0.002	0.50	0.19	0.66	Moist soil
0.79	_	0.27	-0.71	Constant coefficient

Conclusion

This model has a good fitting, but it shows that there are variables that are effective on the radon exhalation rate from ground surface, but have not been studied. Various parameters such as soil porosity and Co_2 concentration in the soil and surface uranium content are also effective on changes in the radon levels in the soil. Porosity of the soil is defined as the ratio of the pore volume to the total volume of the soil. It gives a measure of the storage capacity of the material. According to Nazaroff et al., there are two very important components; the textural pore space and the structural pore space(15). The movement of water in soil is usually a fair sign of the permeability to gas movement. Soil with a fair amount of water that is free to move through the pore space, leaves low permeability of gas flow, on the other hand. From this follows that if the soil is much dryer, the permeability for the gas would be higher, and the wet soil, much lower. The emanation of radon in the pore space of the soil is enhanced in the presence of low to moderate moisture content and rather restricted at higher levels(17). Moisture content most certainly influences the radon emanation coefficient

Soil moisture can increase the radon exhalation rate from the soil, but once saturated soil pores, radon exhalation rate is stopped. As a carrier gas, Co_2 acts to move the radon in the soil and can thus increase the concentration of radon in the soil atmosphere; it can be slowly released from the stagnant water through molecular diffusion. Heating or stirring this gas will lead to the acceleration of its release and transfer to the environment. Radon is soluble in water and therefore can be easily transferred to a indoor environment. Surfacewaters contain less radon in comparison with Radon than groundwaters. The groundwater level in Ramsar is high so radon can easily release into the environment. Meanwhile, hot springs of this city do not have the same activities. Studies carried out by Amiri et al. (2012) to measure the concentration of radon in hot springs of Ramsar using liquid scintillation method showed that the hot springs of Talesh Mahalleh and Ramsar Hotel have the highest concentration of radon, and the Mahmoud Garmab spring, which is near some of the stations measured in this study, has low concentrations of this gas (18).

Therefore, the evaluation and measurement of other environmental parameters affecting the radon exhalation rate from the ground surface seems to be necessary in future studies. Results indicate that the estimated average annual effective Radon exhalation rate for the study area is much higher than the worldwide average figure of 16 $mBq/m^2.s$ reported by UNSCEAR. It can therefore be concluded that an assessment of the radiological hazard of living these area is crucial. Therefore based on the proposed EPA retrofitting homes against the Radon is necessary.The methods of reducing the amount of radon accumulating in a house are:

1. Sub-slab depressurization (soil suction) by increasing under-floor ventilation;
2.Improving the ventilation of the house and avoiding the transport of radon from the basement into living rooms;
3.Installing a radon sump system in the basement;(12,19)

An effective method to reduce radon levels in homes involves covering the earth floor with a high-density plastic sheet. A vent pipe and fan are used to draw the radon from under the sheet and vent it to the outdoors. This form of soil suction is called sub membrane suction, and when properly applied is the most effective way to reduce radon levels in homes(20).

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