Araştırma Makalesi / Research Article

Soil radon gas emission on the Sivrice (Elazığ, Turkey) fault zone between 2007-2008 years

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Abstract
Soil radon gas measurements were made via a sensing system embedded in soil at radon monitoring station, which was established in Sivrice Fault Zone of Eastern Anatolia Fault Systems (DAFS) being one of the active fault system of Turkey. The occurrence times and magnitude of earthquakes at this zone were compared with the radon gas diffusion obtained online from the mentioned station and the results were interpreted in the light of data in the literature. In this study, it was seen that there is a relationship between the changes in soil radon gas emission and earthquakes. Additionally, according to the analyses on graphs which present the changes in soil radon gas emission taken from station and earthquake lists taken from AFAD (Republic of Turkey Prime Ministry Disaster and Emergency Management Presidency), it was seen that almost all of the earthquakes occur in a decreasing period following the increase in radon emission.

Keywords: Radon, statistics, fault zone.

2007-2008 Yılları Arasında Sivrice (Elazığ, Türkiye) Fay Bölgesinde Toprak Radon Gazı Emisyonu

Öz
Toprak radon gazı ölçümleri, Türkiye'nin aktif fay sistemlerinden biri olan Doğu Anadolu Fay Sistemleri (DAFS)'nin Sivrice Fay Zonunda kurulan radon izleme istasyonunda toprağa gömülü bir algılama sistemi ile yapılmıştır. Bu bölgedeki depremlerin meydana gelme süreleri ve büyüklükleri, söz konusu istasyondan çevrimiçi olarak elde edilen radon gazı difüzyonu ile karşılaştırılmış ve sonuçlar literatürdeki veriler ışığında yorumlanmıştır. Bu çalışmada, toprak radon gazı emisyonundaki değişiklikler ile depremler arasında bir ilişki olduğu görülmüştür. AFAD'dan temin edilen deprem listelerine ve istasyondan alınan toprak radon gazı çıkışlarındaki değişim grafiklerine bakıldığında yapılan analizlerde, radon yayılımındaki artışı izleyen dönemdeki radon yayılımının azalmaya başladığı dönemlerde; depremlerin neredeyse bütününün meydana geldiği görülmüştür.

Anahtar kelimeler: Radon, istatistik, fay zonu.

1. Introduction

One of the natural disasters which have affected, and scared societies for centuries through the human history earthquakes with different magnitudes. Therefore, anticipation of earthquakes has always been an item on the agenda for people. One of the seismic belts of the world begins from the Alps, passes through the Himalaya Mountains; Turkey takes place in the middle of this active seismic belt [1]. Being the most active earthquake zone of the world, Turkey has experienced earthquakes which lead to loss of property and lives.

Some very long-life radio nuclei such as ^{238}U (half-life $t_{1/2}$= 4.47×10^9 year and isotopic abundance = 0.9927) naturally exist in the world. ^{238}U decay chain has 15 elements consisting of a rare

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gas named ^{222}Rn which can skip out of pores in the soil and can be scattered in the atmosphere. Disequilibrium in the $^{238}U/^{226}Ra$ chain is the result of ^{222}Rn losses. The radon nucleus emerges from alpha particle emission of ^{226}Ra radium isotope with 86 keV reaction energy [2].

Radon is the single radioactive noble gas in the nature. It is generally mentioned with ^{222}Rn, a half-life, of which is 3.825 days. Radon has two more isotopes having a less half-life ^{220}Rn (54.5 sec) and ^{219}Rn (3.92 sec). ^{222}Rn is a motionless element of Uranium (^{238}U) decay series, which directly emerges from radioactive decay of ^{226}Ra and emits alpha particles. Before radon does decay to ^{210}Pb with a long half-life, it decays to radioisotopes such as ^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po. To conclude, three alphas, two betas, and many gamma rays are emitted through the radioactive disintegration of radon. The measurement of one of these rays (alpha, beta and gamma) is used to measure radon [3].

Radon sensors do not actually measure the concentration of this gas, but the number of α particles or the amount of the radiation emitted by radon and its daughter isotopes. The proportionality factor between the emissions detected by the sensors and the actual concentration of radon depends on the instrument, the radioactive equilibrium factor, as well as on the environmental and physical conditions at the monitoring site [4].

Since the initial observations in the 1960s and 1970s that radon anomalies could occur in groundwater and soils, prior to earthquakes, many attempts to have been made to use both as earthquake predictors [5-9]. However, whilst earthquake-related radon anomalies have been detected at distances on the order of hundreds of kilometers from the epicenter, so far these have proved to be unreliable as earthquake predictors [6, 10].

The reason for the high radon diffusion at fault zones is the fact that underground waters in this region could easily rise to the surface, and thus, uranium, or its cores dissolving in underground waters tend to accumulate in places closer to the earth [3].

An earthquake is a short-term instant movement of the earth's crust, which occurs as quaking, shaking, collapsing or moving of the earth. Movements related to the structure of the earth result in energy (stretching) accumulation in certain areas as a consequence of certain rules. When the accumulated energy abrades the resistance of rocks in the region, fracture occurs. The energy which discharges instantly due to the fracture diffuses as earthquake waves, also named as energy seismic waves and leads to quakes on the earth's crust during this diffusion process [11].

2. Material and Methods

The soil radon gas monitoring was conducted by the method of continuous measurement system and the measurements were made with a sensing system which consists of a Nuclear Spectroscopic System embedded in the soil of a certain place on the mentioned fault zone. The system consisted of a Si semi-conductor detector, and it was established in the Fault Zone. Radon gas activity was determined based on Nuclear Spectroscopic Method in consideration of the radioactive characteristics of radon. The radon gas measurement was recorded once in fifteen minutes by means of suitable software and stored in the system. The values stored in the system could be transferred to laboratory online through GSM or fixed telephone line by means of remote data transfer systems where necessary. The system was equipped with a cylindrical pipe that is approximately 0.3 m long and with a 0.05 m radius. The detector was mounted about 0.08 m below the end of the pipe (see Figure 1). At the top of the space at the bottom of the device (Alphameter 611, Figure 2), there was a silicon (diffused junction) detector located within steel tube that had a measuring range of $4x10^{-4}$ m^2, and it was sensitive to energy greater than 1.5 MeV. The alpha particles emitted to the medium from the decomposition of radon gas was relatively determined by the detector, and it was recorded to a built-in memory at 15 minute intervals with date information [12, 13].

The data recorded by the AlphaMeter appear more stable and sudden changes does not record. This indicates that the AlphaMeter sensors’ performance for long-term continuous monitoring of soil radon data is more satisfactory [12].

The data collected by AlphaMeter 611 sensors are given in counts per 15 minutes’ integration time. Calibration by the manufacturer provides for the conversion (calibration factor=2 $kBq/(m^3 \times counts)$) of the count rates into radon activity. For example, 10 counts per 15 minutes of integration time recorded by the AlphaMeter equals to about 20 kBq/m^3 soil gas [12].

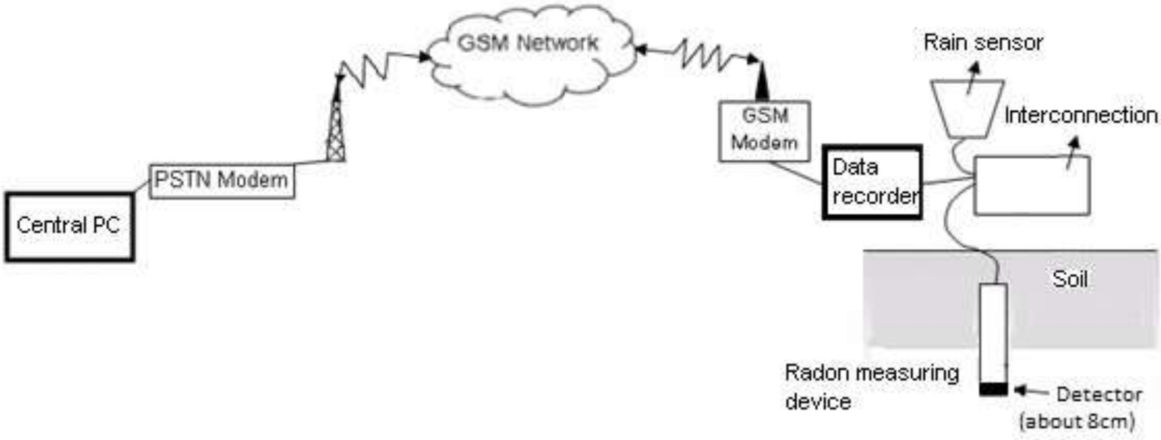

Figure 1. Active radon measuring system.

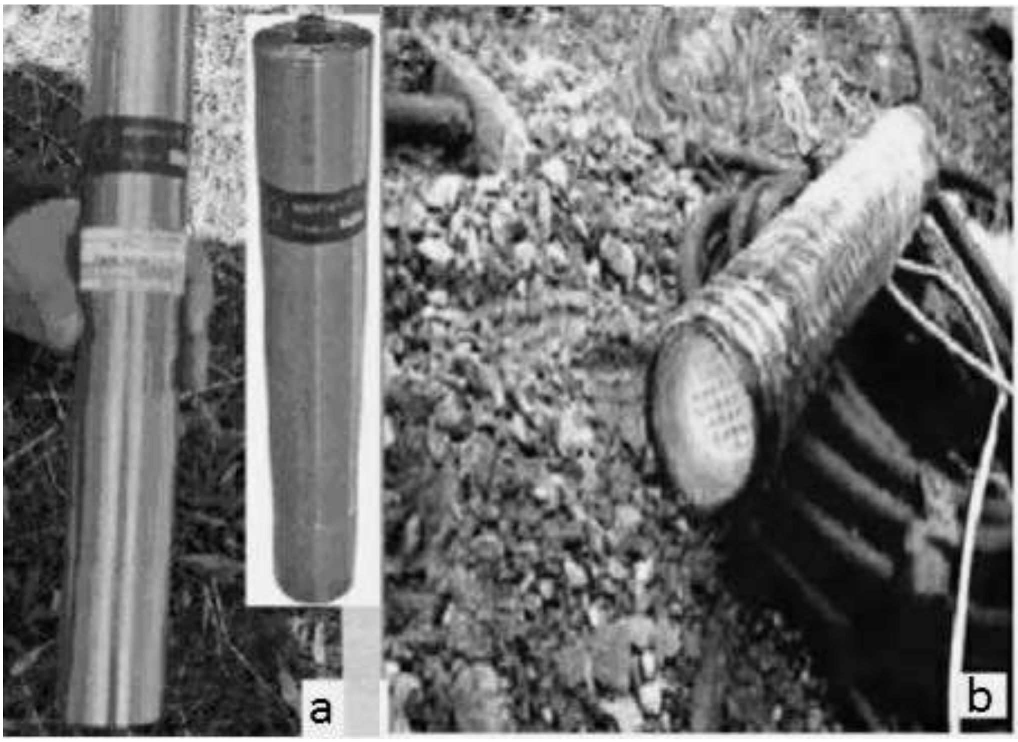

Figure 2. (a) Alphameter 611 model, (b) Prepared to bury the Alphameter probe.

3. Results and Discussion

The monthly variation in the radon gas taken from the Soğukpınar station at Sivrice Fault Zone for a year is presented in Figure 3-Figure 6, respectively. When examined monthly changes of radon data received from the station; approximately 500 kBq/m^3 of which radon emission in September had been starting to increase in October. The emission of radon starting from November until mid-April had been gradually decreasing. The radon emission had been beginning to increase again after the first of June. In the July and August; maximum emission values from measurements taken from one year appears as peaks (approximately 1100-1200 kBq/m^3) and emission values of radon was averagely falling to 600-650 kBq/m^3 in September.

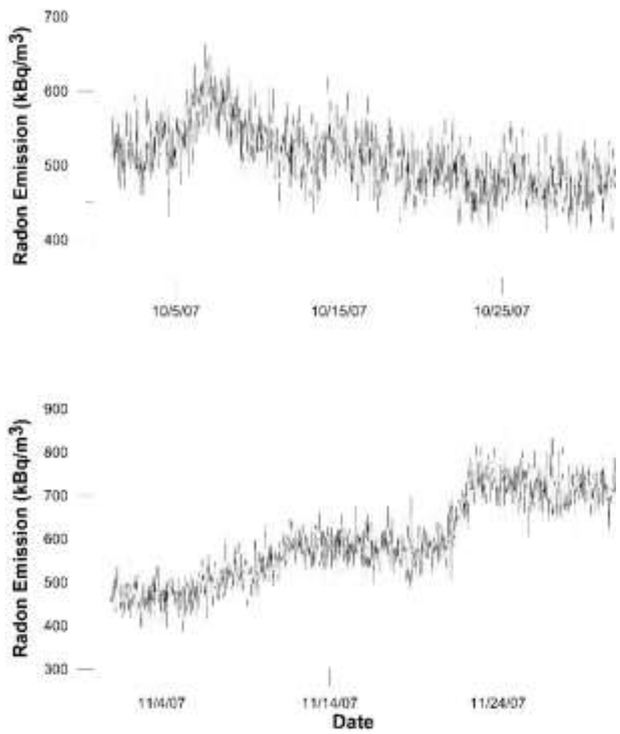

Figure 3. Assessment of the data obtained from Soğukpınar station on October 2007 and November 2007

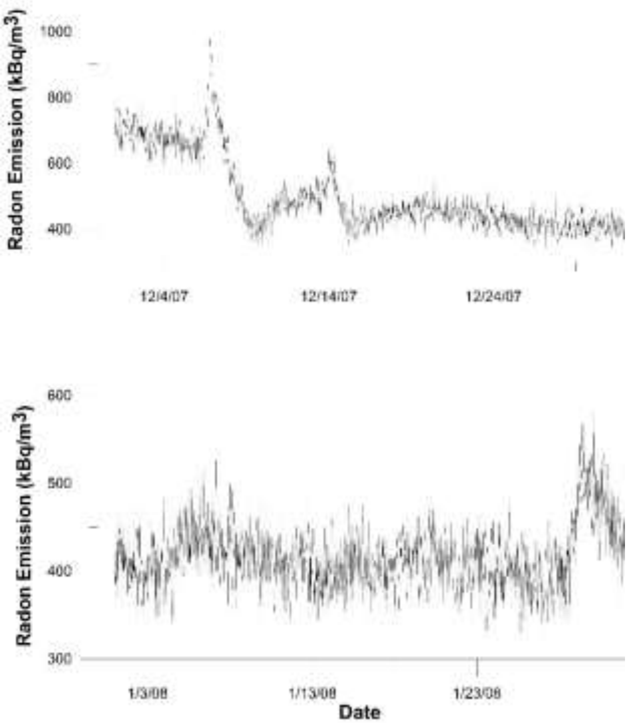

Figure 4. Assessment of the data obtained from Soğukpınar station on December 2007 and January 2008

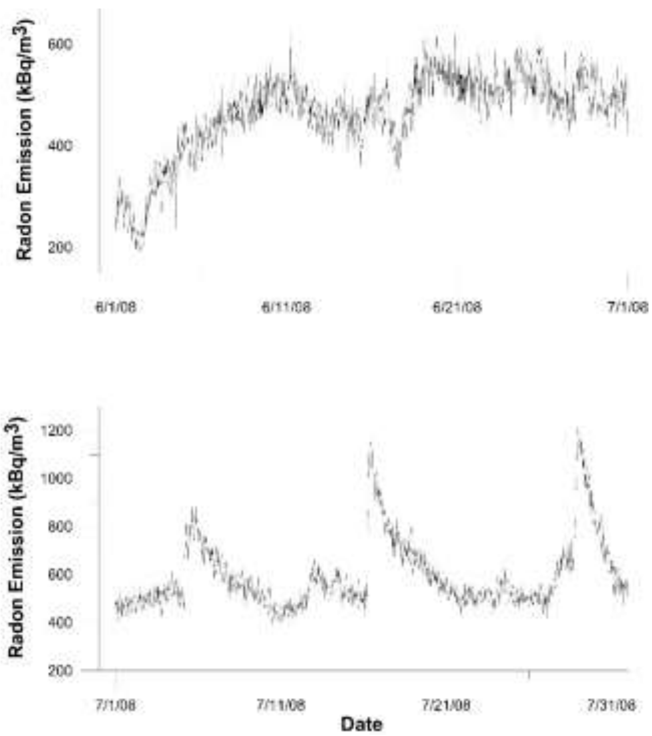

Figure 5. Assessment of the data obtained from Soğukpınar station on June 2008 and July 2008

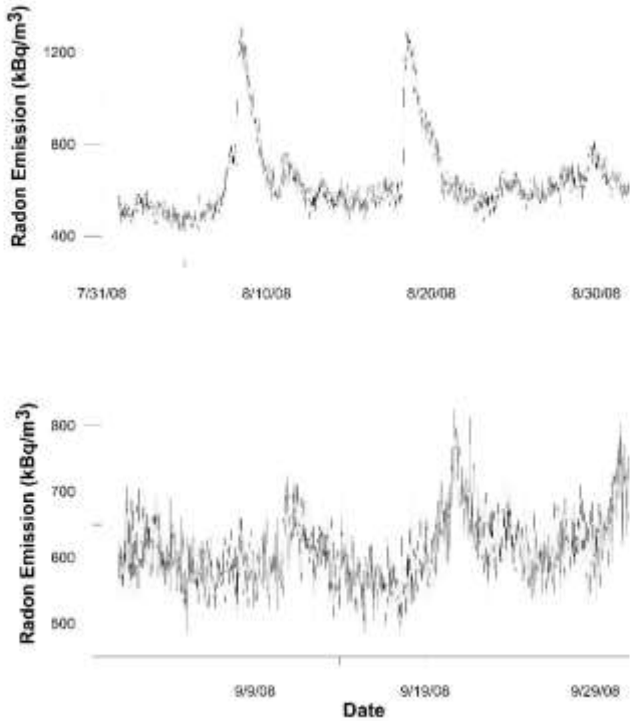

Figure 6. Assessment of the data obtained from the Soğukpınar station on August 2008 and September 2008

Along with active fault zones, deformations in the earth's crust and depending on secondary fractures and cracks in rocks, shaping the earth crust increase, and this increase accelerate the radon expansion. In periods when earthquakes occur within short ranges, the increase in soil radon gas expansion is less compared to earthquakes occurring within long ranges. This case indicates that the fractures, and cracks in rocks within region before the earthquake are controlled by the fault movement [14].

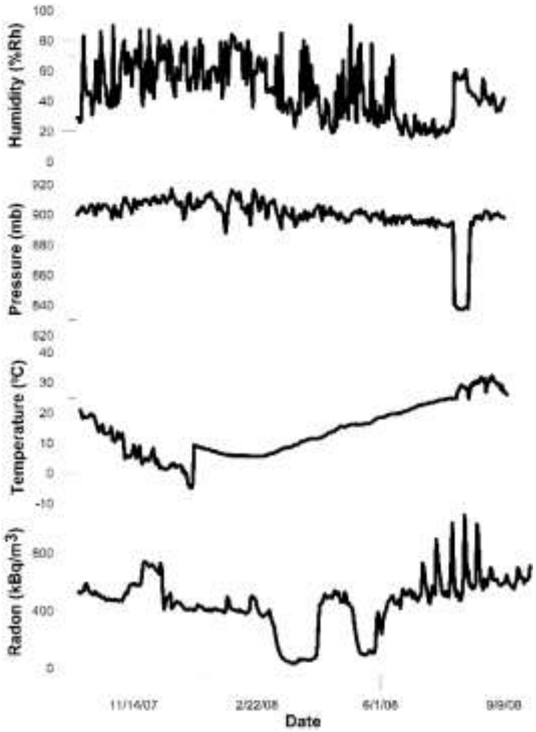

Figure 7. Radon concentration in soil, air temperature, barometric pressure and humidity versus time.

When Figure 7 is examined, it has been seen that temperature, humidity and pressure parameters also have a little effect on radon expansion. Changes of radon gas with especially pressure and humidity has been seen to be not parallel. The pressure causes atmospheric pumping in the soil near the surface, so that it increases the expansion of soil radon gas. The humidity increases binding to the carrier (groundwater, other gases, etc.) of soil radon gas. Thus, the humidity provides an enhancement to the radon gas expansion. The temperature also increases the diffusion of radon gas like the other gases [3].

Statistical variations of the Soğukpınar station whose radon concentration, temperature, pressure, humidity, and earthquake magnitude were determined in Table 1.

Table 1. The relevant information with earthquakes that occurred within a radius of 150 km centered Sivrice at March - May 2008.

Parameters	N	Minimum	Maximum	Mean	Std. Deviation
Radon (kBq/m^3)	366	34.2	1063	455.4	185.4
Temperature (^{0}C)	346	-4.9	32.0	13.9	8.7
Pressure (mb)	346	837.0	917.1	900.0	13.2
Humidity (%Rh)	346	16.0	90.0	47.5	18.6
Magnitude (Md)	61	2.0	4.0	2.8	0.4

For more clearly understood of Figure 7 and to an examination of the relationships among the radon concentration, meteorological parameters (temperature, pressure and humidity) and earthquake magnitude; the matrix scatter chart of radon concentration, meteorological parameters (temperature, pressure and humidity) and earthquake magnitude are given in Figure 8. The relationships among radon, temperature, humidity and pressure in Figure 7 are more clearly seen.

When Figure 8 is examined, it can be seen that the connection among radon, earthquake magnitude and pressure are more regular than the relationship between other parameters. However, the link between radon-pressure can be seen much more regular than the link between radon- earthquake magnitude. Relationship with other parameters of pressure was found to be separately regulated. Moreover, it can be seen that the relation with only pressure among other parameters of temperature are to be regular. Regularity between parameters, the parameter indicates the relationship with each other.

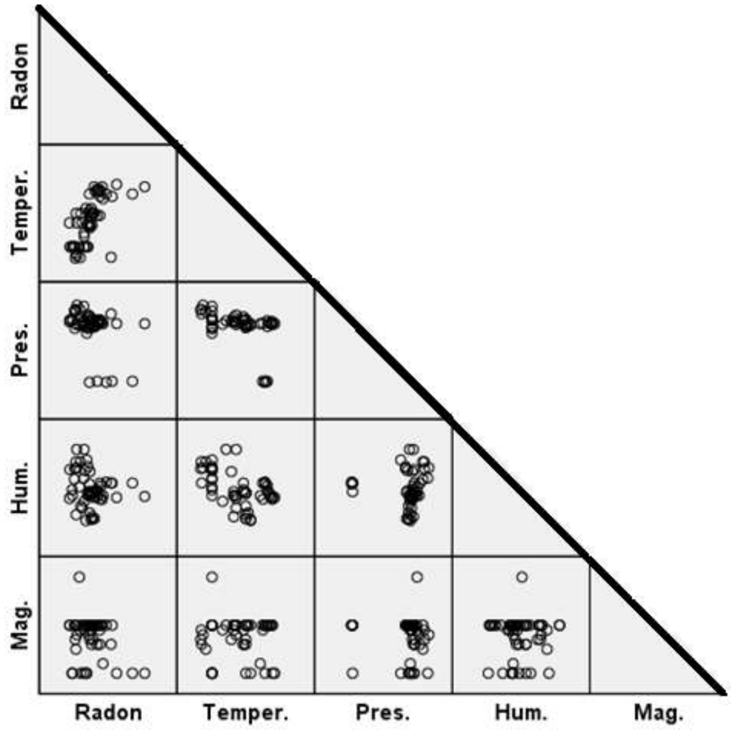

Figure 8. Matrix scatter chart of radon concentration (kBq/m^3), air temperature (^{0}C), barometric pressure (mb), humidity (%Rh) and earthquake magnitude (Md)

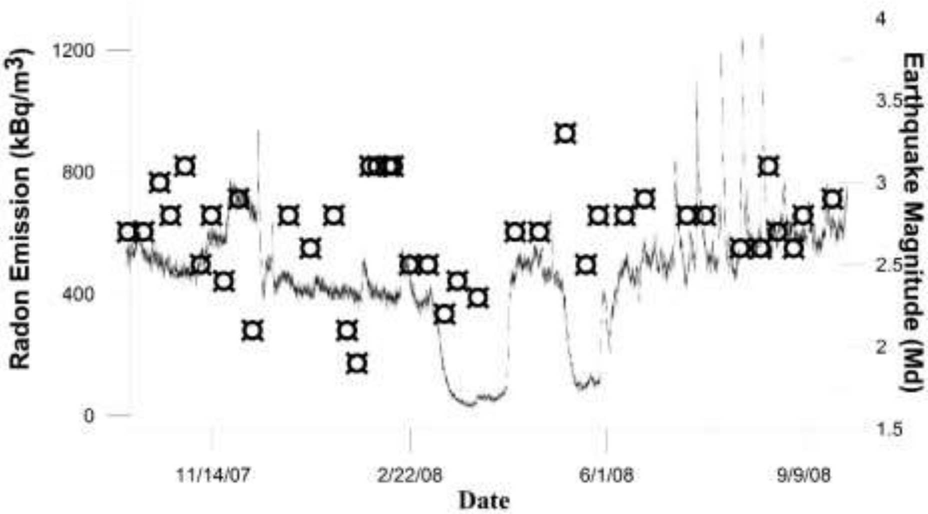

Figure 9. The relationship between radon diffusions recorded in Soğukpınar station and the earthquakes

According to Figure 9 which presents the relationship between radon diffusion and earthquakes, it can be seen that in periods when the changes (increase/decrease) in soil radon gas outlets, earthquakes generally occur as well.

4. Conclusion

It was concluded that the change in soil radon gas could be used as a significant parameter to predict earthquake on condition that it is observed regularly and continuously in consideration of fault character, rock and soil type across the fault zone.

While earthquakes are occurring, an increase or decrease can be seen in the expansion of radon gas accumulated under soil due to the movement, collapse or elevation of rocks. The data recorded in this study showed that changes occurred in soil radon gas expansion and according to the comparison with data obtained from AFAD, it is observed that these changes are generally parallel with earthquakes even though they have low magnitude [3, 15]. There was a relationship between the changes in soil radon gas expansion and earthquakes, but it was also found that other parameters (temperature, humidity and pressure) were effective on radon expansion as well. Therefore, it is considered that changes in soil radon gas expansion can be used as a useful parameter in the prediction of earthquakes.

According to the analyses on graphs which presented the changes in soil radon gas expansion taken from station and earthquake lists taken from AFAD, it was seen that almost all of the earthquakes occurred in a decreasing period following the increase in radon expansion. This case can be explained by the increase in secondary cracks which increase the permeability of rocks as a result of the deformations that cause energy accumulation across the fault zone before the earthquake. After the stretching accumulation reaches the highest value, the increase in radon expansion stops, and in the following decrease period, an earthquake occurs [3].

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Author’s Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest among the authors.

Statement of Research and Publication Ethics

The rules of research and publication ethics were followed in the research.

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