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The correlation of the seismic activities and radon concentration in soil gas

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Abstract

Radon is a radioactive, colorless, odorless, tasteless noble gas, produced by alpha decay of the Radium (^{226}Ra). Radon is found in nature in three different isotopes: ^{220}Rn, member of ^{232}Th series, with a half-life of 54.5 s; ^{219}Rn, member of ^{235}U series, with a half-life of 3.92 s; and its most stable isotope, ^{222}Rn, has a half-life of 3.8 days. As radium decays, radon is formed and released into small air or water-containing pores between soil and rock particles. It usually migrates freely through faults and fragmented soils, and may accumulate in caves or groundwater. Migration of radon depends on many factors: the porosity, the moisture content of the soil, the pressure and temperature differences of the soil, and atmospheric air. In environmental researches, measurement of radon is most frequently used among all inert natural gases. Besides, radon is a preferred earthquake precursor, because it is easily detectable. The origin and the mechanisms of the radon anomalies and their relationship to earthquakes are yet poorly understood, although several in situ and laboratory experiments have been performed. In this study, the radon concentration in soil gas, transported from soil (1 m depth), is measured in Karahayıt, continuously for 9 months. The earthquake data of measurement region has been recorded simultaneously and compared with radon anomalies for investigation of the effects of the earthquakes on radon emanation.

Keywords Radon · Radon anomalies · Earthquake prediction

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Introduction

Earthquake prediction is a complicated process based on observation and investigation of geophysical variables such as crustal movements, geomagnetic fields and conductivity, groundwater and sea levels, tides, seismic wave types and velocities, and content of radon, hydrogen, and carbon dioxide in soil gas or groundwater. However, the precursors give pseudo signals by the effect of other geological and meteorological parameters; many previous studies have shown that the radon anomalies are highly correlated with the earthquakes (Okabe 1956; Wakita et al. 1980; Teng 1980; Hauksson and Goddard 1981).

Radon is a naturally occurring radioactive gas and one of the densest substances that remains in gas form under normal environmental conditions. Also, it is the only gas that has no stable isotopes. The most stable one, radon-222, has a half-life of 3.8 days (Ertugral et al. 2015). The production of ^{222}Rn depends on the concentrations of ^{226}Ra in the earth's crust. Radon which is emanated from solid grains transports in soil pore filled with air and water. Then, it is transported by diffusion and advection through fractures in soil in order to exhale into the atmosphere (King et al. 1996). The measurement of radon concentration in soil gas can be used as an experimental way to detect buried close-subsurface geological faults because concentrations are generally higher over the faults (Nazaroff 1992).

Most of the earthquake prediction researches, including current study, are centered on the theory of dilatancy. It has been

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noticed that when a rock is stressed, it begins to expand and dilate. Micro-cracks and fractures in this stressed rock open up and become larger and this event allows diffusion of radon into soil gas. The propagation of energy caused by the stressed rock triggers the creation of fractures and this occurrence in the soil creates a lot of local radon anomalies (Tomer 2016). The purpose of this study is to make probability calculations using radon anomalies, which were observed before earthquakes. These calculations will allow an assessment of the availability of radon data in earthquake predictions.

Materials and methods

Study area

The measurement point was located in Karahayıt (37° 57′ 48″ N 29° 06′ 16″ E) nearby the Pamukkale Fault Zone in the west of Anatolia. Karahayıt district is accessed thorough Pamukkale and located 20 km in the north of Denizli. Thermal springs in Karahayıt are formed as a result of active geologic activities of Aegean region. The travertine and thermal springs emerging in the area are sited in the Çürüksu graben, which belongs to the extensive Büyük Menderes graben system (Simsek et al. 2000). The Great Menderes Graben is an E-W depression zone bounded to active normal faults with a length of 150 km and a width of 10–20 km (Fig. 1) (Brogi et al. 2014).

The Pamukkale Fault Zone located in Denizli Horst-Graben System is located on the northern border of this system. Near the Karahayit Village, two fault segments overlap with a 2-km-wide stepped zonal, where the irregularly sloping Neogene sediment expresses the relay ramp (Çakir 2014).

Sampling and measurements

Measurements have been performed by a portable device, AlphaGuard PQ 2000PRO, which is designed for long-term monitoring of radon gas concentration. AlphaGuard is an ionizing chamber which measures radon via alpha spectrometric techniques. It has several probes for different applications. The soil gas unit was used for this study. The probe was placed 1 m depth in soil and it had provided the transportation of soil gas into the chamber continuously. The radon concentration was recorded by AlphaGuard over 10-min intervals continuously for 9 months between May 2012 and January 2013.

Method of analysis

The data of the earthquakes that has occurred in the area during the measurement period were taken from three different resources, then compared and registered. In this study, an ideal magnitude (Mi) has been calculated by using the first criterion (Hauksson and Goddard 1981) depending on the distance (D) between epicenter and measurement point. The effect of earthquake (Me) to the measurement point has been defined and calculated according to closeness of Mi and the real magnitude of earthquake (M). M_{max} is the calculated value of magnitude for the furthest distance of epicenter that has been considered for this study;

$$M \geq 2,4 \log D - 0,43 \quad \text{ve} \quad M \geq 2 \tag{1}$$

$$M_e = M_{max} - (M_i - M) \tag{2}$$

The analysis of data is conducted on a graphical user interface that developed with Java object-oriented programming

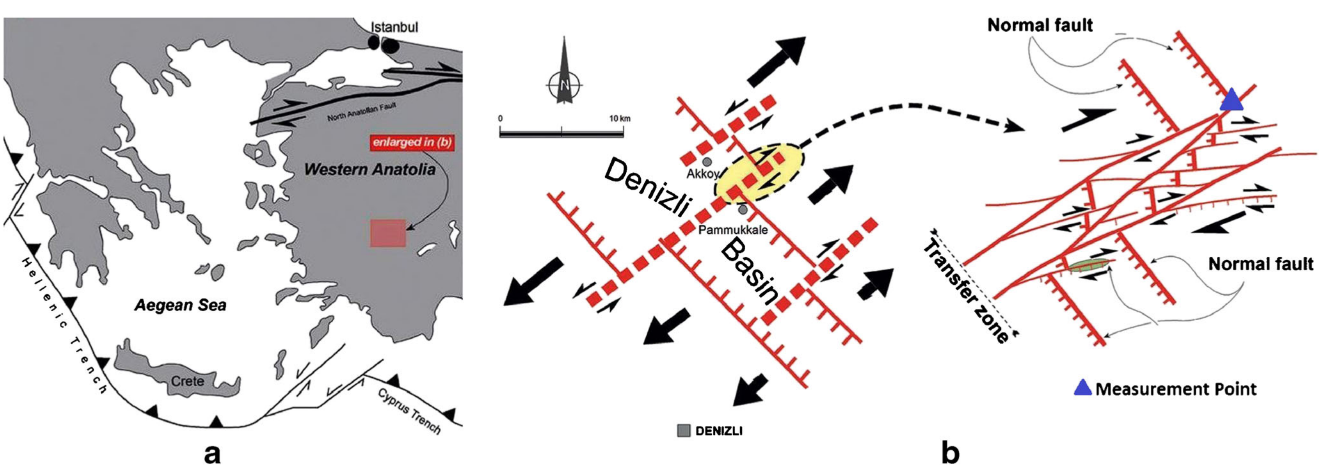


Fig. 1 The study area (**a**). Location of measurement point in Denizli Basin (**b**)

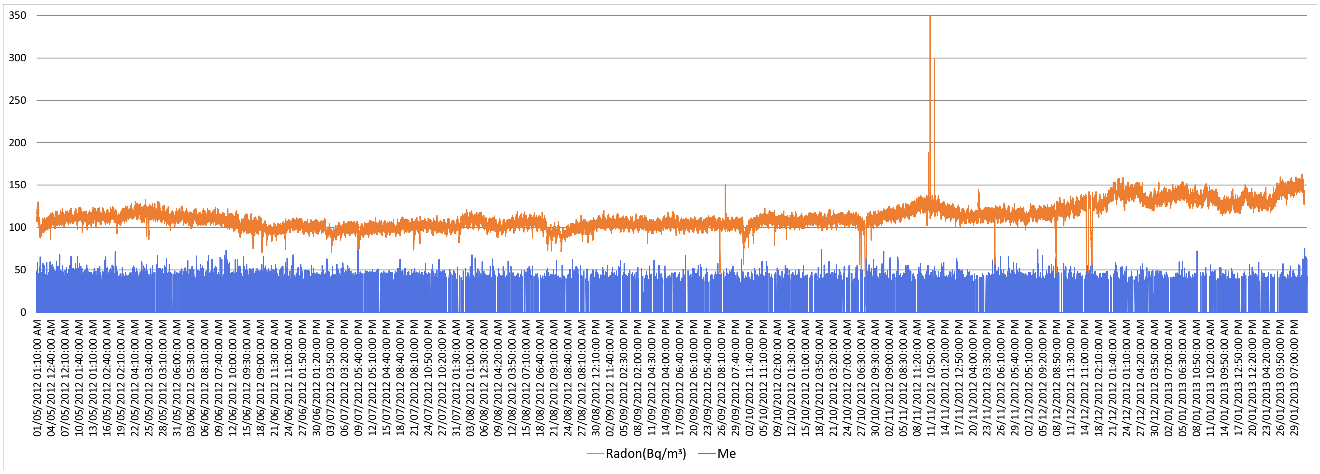


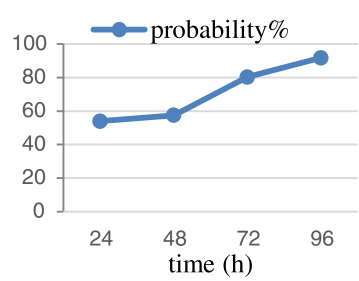
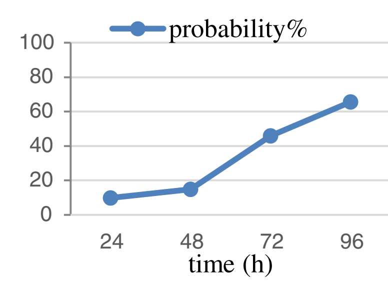
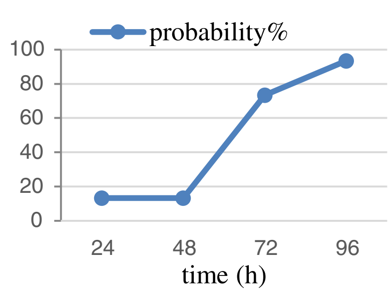
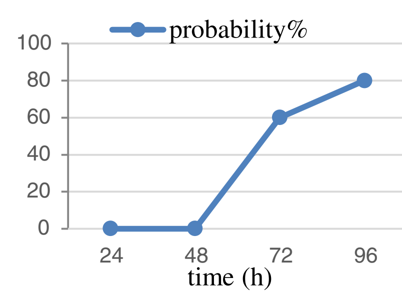
Fig. 2 Rn concentrations - M_e (as columns) values for 9 months

language. This application reads the radon concentration measurement and earthquake data and gets the calculation parameters from the user. There exists a need to find radon average values in order to detect anomalies. Radon measurement values fluctuate daily; therefore, anomaly detection period parameter was added to the application. The radon value fluctuations reach peak values in daily basis and anomaly initial value is used to exclude these daily peaks. The anomaly final value is added to exclude the irrational radon values in the radon dataset. The M_e initial and final values are used to define the M_e variance beginning from the radon anomaly time. Detection period is used to set the earthquake search period after the radon anomaly detection. The program "Radon Anomaly Observer (RAO)" provides the probability of the earthquakes according to the provided data and parameters.

Results

Radon concentrations of the soil gas varied between 50 and 350 kBq/m^3 during the measurement period. Relatively higher radon values were observed in winter depending on the high

Table 1 Probability analysis

<table>
<tr><th>Anomaly Type</th><th>M_e>5</th><th>M_e>6</th></tr>
<tr><td>Low Rn Anomaly (12%)</td><td>
</td><td>
</td></tr>
<tr><td>High Rn Anomaly (15%)</td><td>
</td><td>
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moisture content of the soil. Winter provides better conditions for migration of radon due to its high solubility in colder subsurface fluids (Zenginerler et al. 2016). The monthly average radon concentration is 135.68 kBq/m^3 in January and 99.21 kBq/m3 in July.

Long-term variation in radon content of soil gas and the effect of the earthquake to measurement point (M_e) has been shown in Fig. 2; positive anomalies have been observed on radon concentrations before the earthquakes, besides the seasonal and daily fluctuations. The dataset is analyzed by RAO for the investigation of correlation between two series.

The average radon values were calculated over 24-h periods and the percentage of anomaly was calculated according to daily fluctuations on daily average. As a result of the calculation, 12% and higher peaks were defined as anomaly and 15% and over peaks as significant anomalies. Two major M_e values (low distance or high magnitude) are chosen for evaluation because the high frequency lowers. The probability of the earthquakes was calculated for 24, 48, 72, and 96 h respectively (Table 1). The probability of the earthquake for the first 24 h was over 50% and gets higher in the following days for lower anomalies of radon if $M_e > 5$. It traces a similar rise starting from a lower level if $M_e > 6$. For high radon anomalies, results indicate that probability of the earthquake is quite low in the first 2 days but growing rapidly in the following days for both M_e values.

Conclusion

The continuous measurement of radon in soil gas and the surveillance of regional seismic activity provide a considerable data for the survey of the correlation between radon anomalies and the earthquakes. However, the evaluation of the data via graphical analyses is convenient for major earthquakes and is not functional for the great number of earthquake series. Radon Anomaly Observer enables users to evaluate these series with the probability of earthquake occurrence following anomaly.

The proposed M_e provides the means of predicting the earthquake occurrence with the use of radon anomalies since the M_e is defined with both earthquake magnitude and distance of epicenter to the radon measurement point. In the present study, two kinds of anomalies are evaluated with two magnitudes (5, 6) of M_e. Due to high seismic activity of region, M_e has a continuous pattern, if M_e is chosen under 5, the occurrence of an earthquake is almost certain.

The results obtained with the Radon Anomaly Observer showed that the probability of earthquake occurrence is high after the low anomalies, whereas high anomalies increase the probability of earthquake occurrence in a longer time when compared to the low anomalies.

As future work, the radon observations obtained from water will be used. Additionally, Radon Anomaly Observer will be improved with more parameters like meteorological values and with more educated algorithms for prediction and anomaly observation.

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