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A Correlation Assessment of ^{222}Rn Gas Measurements from the East Anatolian Fault Zone

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ABSTRACT

Factors affecting the diffusion of radon (^{222}Rn) gas from the soil to the atmosphere have been examined in many studies. ^{222}Rn gas emission depends on the geological structure and meteorological parameters of a given region, and ^{222}Rn gas concentration is one of the precursors of earthquakes. In addition, it is an important gas in terms of health, because it can cause lung cancer. In this study, comprehensive statistical analyses of ^{222}Rn data was carried out on soil samples obtained from 16 stations located in the East Anatolian Fault Zone (EAFZ) in Turkey, and the ^{222}Rn characteristics of the region were investigated. A daily average of the data was taken between 2007 and 2010. The Kruskal-Wallis test was used to determine whether ^{222}Rn emissions in the study area varied according to the year and the station. Binary comparisons were made by grouping the ^{222}Rn data measured at the stations annually and significant results were obtained.

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1. INTRODUCTION

Radium (^{226}Ra), a product of Uranium (^{238}U) radioactive decay chain, undergoes alpha and gamma decay reactions to become stable. Radon (^{222}Rn), formed by the radioactive decay of ^{226}Ra (in 1600 years), is an invisible, colorless, odorless, radioactive gas. As a result of serial decay, it turns into radioactive elements such as Polonium (^{218}Po) and Polonium (^{214}Po). The half-life of ^{222}Rn gas is 3.82 days and it is an alpha emitter. It is an inert gas located in the noble gas group of the periodic table [1, 2].

^{222}Rn is naturally formed by the decay of uranium and radium in soil, rock and water, and it is released to the atmosphere from these sources [2, 3]. For this reason, it exists at different concentration levels depending on the geological structure of the region. Since it is soluble in water, it is also present in different amounts in groundwater and streams.

The diffusion rate of ^{222}Rn from soil to air depends on the structure of the soil, the humidity and the geology of the region. In addition, meteorological parameters such as precipitation, temperature and atmospheric pressure also affect the ^{222}Rn concentration. Many studies have been conducted on the effects of geological and meteorological factors on the concentration of ^{222}Rn [2, 4-7].

Although the alpha emitter ^{222}Rn has a carcinogenic structure, it can be utilized for many other useful purposes [3]. ^{222}Rn gas in soil is important for geology, seismology and protection from radiation. There are also studies showing that major soil ^{222}Rn gas anomalies may be a precursor of oncoming seismic activity [1, 4, 8-16].

In this study, the variation in the data for ^{222}Rn gas in the soil from each of the 16 stations observed over the EAFZ for a number of years was investigated. Also, it was checked whether the stations differed in comparison to each other. Consequently, the relationships of the stations to each other and the effects of each station on every other station were determined.

2. MATERIAL AND METHOD

This study was carried out in the East Anatolian Fault Zone (EAFZ), one of Turkey's major fault zones. It is known that the EAFZ is 30 km wide and approximately 580 km long; it starts in Karlıova and passes through Bingöl, Palu, Hazar Gölü, Sincik, Çelikhan and Gölbaşı, and it changes direction continuing with the faults forming Hatay Graben and merging with the Ölüdeniz fault. It consists of many left-lateral strike-slip faults that complement each other with different characteristics between Karlıova and Antakya. EAFZ is formed by 6 different segments, the lengths of which vary between 50 km and 145 km. These are the Karlıova-Bingöl segment (65 km), the Palu-Hazar segment (50 km), the Hazar-Sincik segment (85 km), the Çelikhan-Gölbaşı segment (50 km), the Gölbaşı-Türkoğlu segment (90 km) and the Türkoğlu-Antakya segment (145 km).

Since the EAFZ has a high earthquake risk, it is one of the most important fault lines in earthquake studies. Large earthquakes have been observed on this fault line over time. Some of these earthquakes include: December 4, 1905/Pütürge (Malatya) Magnitude scale (Ms) = 6.8, March 20, 1945/Ceyhan (Adana) Ms = 6.0, June 14, 1964/Sincik (Adıyaman) Ms = 6.0, May 22, 1971/Bingöl Ms = 6.8, May 5, 1986/Sürgü (Malatya) Moment magnitude (Mw) = 6.0, June 27, 1998/Yüreğir (Adana) Mw = 6.2, May 1, 2003/Bingöl Mw = 6.3, March 8, 2010/Kovancılar (Elazığ) Mw = 6.1. [17, 18]. Finally, on January 24, 2020, there was a 6.8 magnitude earthquake that lasted for about 40 seconds in the Sivrice district of Elazığ, confirming that the EAFZ has a high earthquake risk.

The study area consisted of 16 stations on and around EAFZ. The locations and coordinates of these stations are shown in Figure 1 and Table 1.

3. RESULTS AND DISCUSSIONS

Table 2 shows the Kruskal-Wallis test results that were carried out to check whether there was a difference between the CLIK, DMIR, ERGA, HELI, NURD, KZIL, OSMA, PALU, PTRG and SURG stations over time. Results indicated that significant differences were observed in most of the stations (p value <0.05) by year. In the table, * is used for years with no difference.

Table 1 Locations of the stations in the study area

Station Number	Station Code	Latitude	Longitude	Location
1	PALU_DR	38.69131	39.93932	Elazığ (Palu)
2	HELI_DR	38.46342	39.55242	Elazığ (Maden)
3	SGPR_DR	38.41944	39.25726	Elazığ (Sivrice)
4	ERGA_DR	38.33917	39.69952	Diyarbakır (Ergani)
5	PTRG_DR	38.18974	38.76733	Malatya (Pötürge)
6	SURG_DR	38.04108	37.8848	Malatya (Doğanşehir)
7	KASI_DR	37.99086	38.15603	Adıyaman (Kasımlar)
8	CLIK_DR	37.70035	37.50898	Adıyaman (Çelikhan)
9	KZIL_DR	37.37069	36.81721	Kahramanmaraş (Kızıleniş)
10	NURD_DR	37.16434	36.70757	Gaziantep (Nurdağı)
11	OSMA_DR	37.08418	36.29781	Osmaniye
12	YAKA_DR	36.95122	35.62737	Adana (Yakapınar)
13	KOZA_DR	37.44426	35.80364	Adana (Kozan)
14	CAML_DR	37.16443	34.5706	Mersin (Çamlıyayla)
15	YUVA_DR	36.68707	36.45314	Hatay (Hassa)

16	DMIR_DR	36.27637	36.35749	Hatay (Demirköprü)

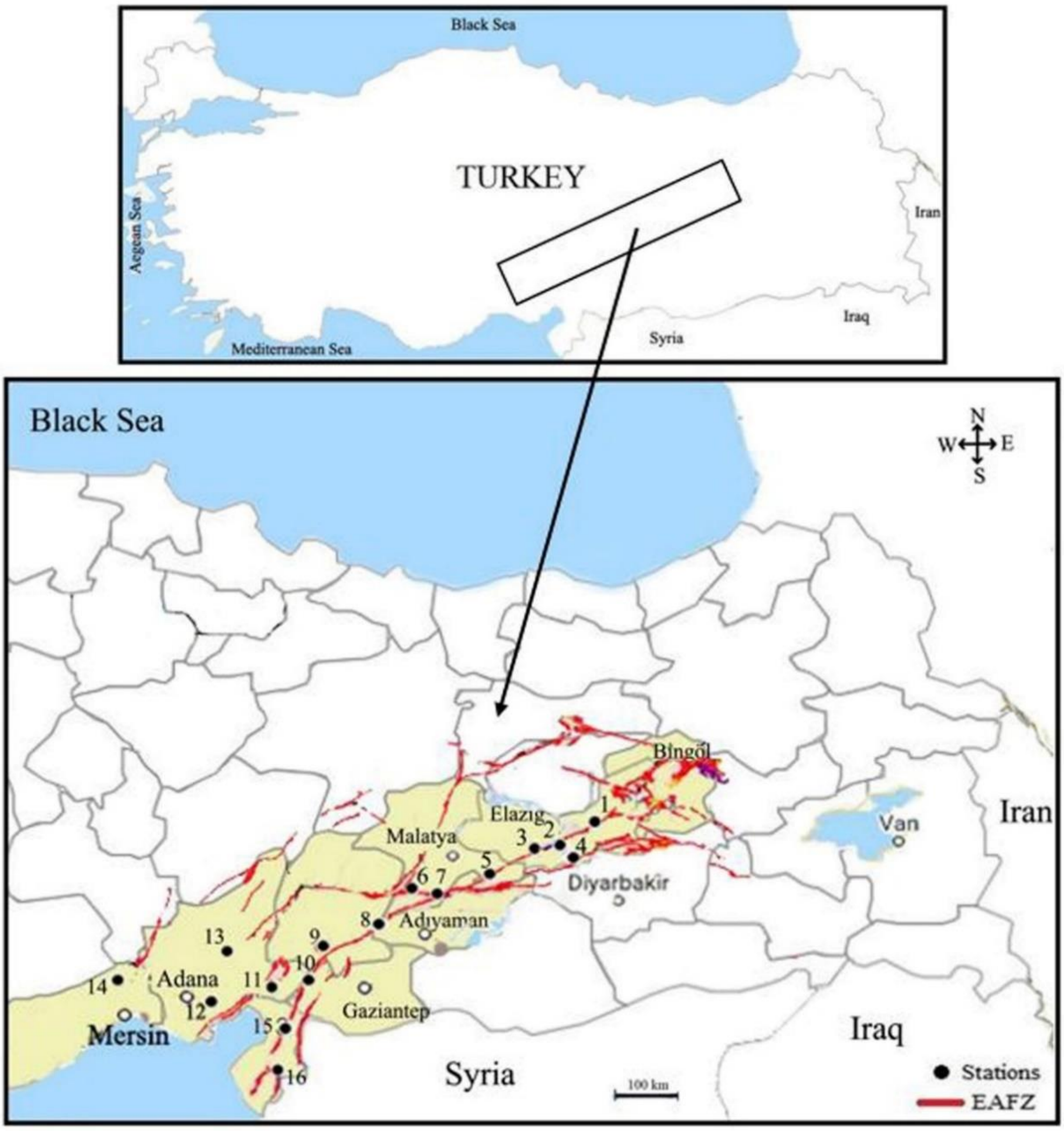

Figure 1 Study area

Table 2 Kruskal-Wallis Test for each station and binary comparisons grouped by years

Station	Kruskal-Wallis H	*df*	*p*-value	Binary Comparison		
				Group	Test Statistics	*p*-value
CLIK	25.845	2	0.000	2007-2008*	49.420	0.099
				2007-2009	116.797	0.000
				2008-2009	67.378	0.007
DMIR	373.544	3	0.000	2007-2008	325.238	0.000
				2007-2009*	−22.312	1.000
				2007-2010	462.783	0.000
				2008-2009	−347.550	0.000
				2008-2010	137.544	0.000
				2009-2010	485.095	0.000
ERGA	417.839	2	0.000	2007-2008	−188.497	0.000
				2007-2009	−467.916	0.000
				2008-2009	49.420	0.000

HELI	103.607	3	0.000	2007-2008	−154.705	0.000
				2007-2009	−258.870	0.000
				2007-2010	−292.059	0.000
				2008-2009	−104.165	0.003
				2008-2010	−137.354	0.000
				2009-2010*	−331.189	1.000
NURD	62.236	3	0.000	2007-2008	−171.048	0.000
				2007-2009*	−27.317	1.000
				2007-2010*	56.217	0.439
				2008-2009	143.732	0.000
				2008-2010	227.226	0.000
				2009-2010	83.534	0.032
KZIL	66.448	3	0.000	2007-2008*	7.246	1.000
				2007-2009	215.379	0.000
				2007-2010	112.208	0.002
				2008-2009	208.133	0.000
				2008-2010	104.962	0.003
				2009-2010	−103.171	0.003
OSMA	20.578	3	0.000	2007-2008	138.834	0.000
				2007-2009	100.183	0.008
				2007-2010	92.293	0.020
				2008-2009*	−38.651	1.000
				2008-2010*	−46.541	0.721
				2009-2010*	−7.890	1.000
PALU	246.291	3	0.000	2007-2008	245.906	0.000
				2007-2009	246.136	0.000
				2007-2010	491.389	0.000
				2008-2009*	0.229	1.000
				2008-2010	245.483	0.000
				2009-2010	245.253	0.000
PTRG	168.218	3	0.000	2007-2008	363.587	0.000
				2007-2009	349.865	0.000
				2007-2010	233.932	0.000
				2008-2009*	−13.721	1.000
				2008-2010	−129.654	0.000
				2009-2010	−115.933	0.001
SURG	405.753	3	0.000	2007-2008	357.518	0.000
				2007-2009	−229.010	0.000
				2007-2010	140.556	0.000
				2008-2009	−586.528	0.000
				2008-2010	−216.962	0.000
				2009-2010	369.566	0.000

The Kruskal Wallis test was conducted to check whether stations exhibited differences compared to each other in years throughout the time of interest. The results are shown in Table 3.

According to the ^{222}Rn concentration results measured at the stations, no significant difference was observed between the stations in 2007, 2008, 2009 and 2010 (p value <0.05). In Figure 2, binary comparisons of ^{222}Rn concentrations measured in different years are presented. Relationships observed between stations for 2007 are given in Table 4.

Table 3 Kruskal-Wallis test for soil ^{222}Rn data by years

Year	**2007**	**2008**	**2009**	**2010**
Kruskal-Wallis H	3015.05	2669.14	2423.45	2440.64
df	12.00	12.00	13.00	11.00
p Value	0.00	0.00	0.00	0.00

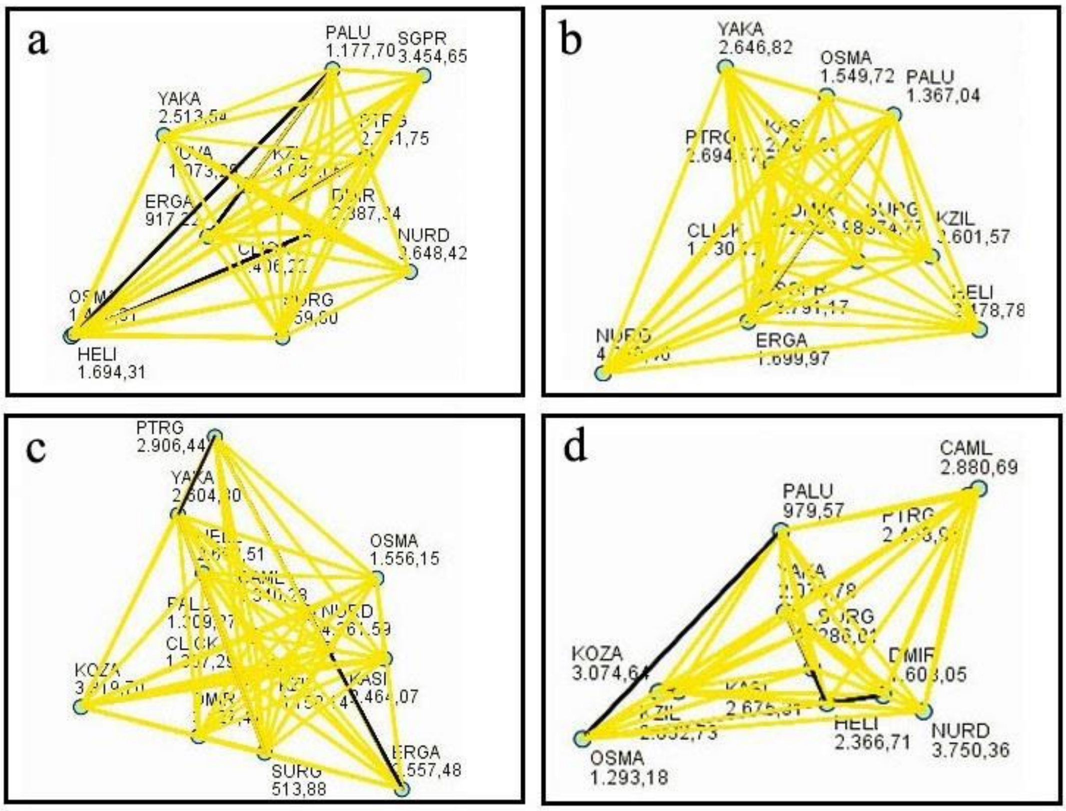

Figure 2 Binary comparisons of ^{222}Rn data measured at stations in

(a) 2007 **(b)** 2008 **(c)** 2009 **(d)** 2010

Table 4 Relationships observed between stations for 2007 (* indicates no relationship)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1				*		*		*			*				*	
2						*		*			*					
3						*				*						
4	*					*									*	
5						*			*			*				
6	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
7						*										
8	*	*				*					*					
9					*	*										
10			*			*										
11	*	*				*		*								
12					*	*										*
13						*										
14						*										
15	*			*		*										
16						*						*				

Binary comparisons of ^{222}Rn gas measured at stations in 2008 are given in Figure 2 (b). It shows that there was a significant difference between the SURG station and every other station. There was a significant difference between the ERGA station and other stations except for the PALU, OSMA and CLIK stations. There was a significant difference between the PALU station and other stations except for the OSMA and ERGA stations. There was a significant difference between the CLIK station and other stations except for the ERGA and OSMA stations. There was a significant difference between the OSMA station and other stations except for the ERGA, PALU and CLIK stations. There was a significant difference between the DMIR station and other stations except for the KASI and HELI stations. There was a significant difference between the KASI station and other stations except for the DMIR, HELI, YAKA and PTRG stations. There was a significant difference between the HELI station and other stations except for the DMIR, KASI, YAKA and PTRG stations. There was a significant difference between the PTRG station and other stations except for the KASI, HELI and YAKA stations. Finally, there was a significant difference between the SGPR station and other stations except for the KZIL station.

Binary comparisons of ^{222}Rn gas measured at stations in 2009 are given in Figure 2 (c). According to this figure, there was a significant difference between the SURG station and every other station. There was a significant difference between the ERGA station and other stations except for the KASI, YAKA, HELI and PTRG stations. A significant difference was observed between the PALU station and other stations except for the CLIK and OSMA stations. There was a significant difference between the CLIK station and other stations except for the PALU and OSMA stations. There was a significant difference between the OSMA station and other stations except for the PALU and CLIK stations. There was a significant difference between the DMIR station and other stations except for the PTRG, KZIL and CAML stations. There was a significant difference between the KASI station and other stations except for the ERGA, HELI and YAKA stations. There was a significant difference between the YAKA station and other stations except for the ERGA, KASI, HELI and PTRG stations. There was a significant difference between the HELI station and other stations except for the ERGA, KASI, YAKA and PTRG stations. There was a significant difference between the PTRG station and other stations except for the ERGA, YAKA, HELI, DMIR and KZIL stations. There was a significant difference between the KZIL station and other stations except for the DMIR, PTRG and CAML stations. In Table 5, calculations of binary correlations for the stations are given as follows:

Table 5 Binary correlation coefficients of the stations in the study area relative to each other

	CLIK	**DMIR**	**ERGA**	**HELI**	**KZIL**	**NURD**	**OSMA**	**PALU**	**PTRG**	**SGPR**	**SURG**	**YAKA**
CLIK	1	−0.388	−0.312	0.375	0.114	0.118	0.162	0.063	−0.129	0.065	−0.234	−0.010
DMIR	−0.388	1	0.327	0.102	0.095	0.210	0.360	0.555	0.321	0.409	0.403	0.496
ERGA	−0.312	0.327	1	0.365	0.046	0.243	0.317	0.244	−0.008	0.358	0.325	0.318
HELI	0.375	0.102	0.365	1	0.273	0.570	0.515	0.406	0.061	0.407	−0.107	0.575
KZIL	0.114	0.095*	0.046	0.273	1	0.555	0.489	0.463	0.309	0.342	−0.090	0.514
NURD	0.118	0.210	0.243	0.570	0.555	1	0.531	0.536	0.188	0.472	−0.226	0.659
OSMA	0.162	0.360	0.317	0.515	0.489	0.531	1	0.555	0.264	0.703	0.118	0.707
PALU	0.063	0.555	0.244	0.406	0.463	0.536	0.555	1	0.285	0.477	0.148	0.693
PTRG	−0.129	0.321	−0.008	0.061	0.309	0.188	0.264	0.285	1	0.313	0.252	0.315
SGPR	0.065	0.409	0.358	0.407	0.342	0.472	0.703	0.477	0.313	1	0.154	0.575
SURG	−0.234	0.403	0.325	−0.107	−0.090	−0.226	0.118	0.148	0.252	0.154	1	−0.063
YAKA	−0.010	0.496	0.318	0.575	0.514	0.659	0.707	0.693	0.315	0.575	−0.063	1

Binary comparisons of ^{222}Rn gas measured at stations in 2010 are given in Figure 2 (d). This figure indicated that there was a significant difference between the SURG station and every other station. There was a significant difference between the PALU station and other stations except for the OSMA station. There was a significant difference between the OSMA station and other stations except for the PALU and DMIR stations. There was a significant difference between the DMIR station and other stations except for the OSMA station. There was a significant difference between the KASI station and other stations except for the HELI, KZIL, PTRG and CAML stations. There was a significant difference between the YAKA station and other stations except for the HELI station. There was a significant difference between the HELI station and other stations except for the KASI, YAKA and PTRG stations. There was a significant difference between the PTRG station and other stations except for the KASI and HELI stations. There was a significant difference between the KZIL station and other stations except for the KASI, KOZA and CAML stations. There was a significant difference between the CAML station and other stations except for the KASI, KZIL and KOZA stations.

4. DISCUSSION

Considering Table 4 with the information given in Figure 2 (a), where the relations between the stations are given, the most interesting finding was that even though there was no significant difference from other stations in 2007 in terms of ^{222}Rn gas emission data, there was a significant difference in 2008, 2009 and 2010. If the map of the region is thoroughly examined, it will be noticed that Station 6 in almost in the middle of the other stations. Considering this fact and the geographical location of the region, it is normal that there is no significant difference, but when the fault lines in the region are taken into consideration, the significant difference is normal. The fault line where Station 6 is located and the fault lines passing through the nearby stations are different. Since the fault motion that triggered the release of ^{222}Rn gas in 2007 had no effect, no difference was observed with other stations in terms of ^{222}Rn gas emission. However, ^{222}Rn gas emission showed differences in 2008, 2009 and 2010 due to the mobility of the fault lines in different directions. This finding proves that the emission of ^{222}Rn gas is highly affected by the mobility of these fault lines.

Station 7 and Station 6 are located very close to each other. However, Station 7 is located on both fault lines. Therefore, a significant difference is observed in terms of the emission of ^{222}Rn gas at Station 7 in other years except 2007. In 2008 and 2009, there was no significant difference between Station 7, and Stations 2 and 12. Although the geographical properties are different from each other, no significant difference was observed in ^{222}Rn gas emission due to the mobility of the fault line on which they are located. This situation puts the Gulf region, which includes Hatay, in a very risky situation in terms of fault line mobility.

Although the locations of stations 1, 2, 3 and 5 are all close to each other and on the same fault line, a significant difference was observed in terms of ^{222}Rn gas emissions. The reason for this is that there are many fault lines located to the east of Station 1 and in the region, including Bingöl, with different fault ruptures. Moreover, there may be some fault lines that have not yet been detected.

No significant difference was observed between Station 1 and Station 11 in terms of ^{222}Rn gas emission in 2007, 2008, 2009 and 2010. It is a striking result that there was no difference between these two stations although the geographical properties are quite different, according to the map. The fault line on both stations affects ^{222}Rn gas emission at the same degree. This situation reveals that the area of the gulf where Station 11 is located is the riskiest region in terms of earthquakes. This region is affected by almost all of the mobility of the Eastern Anatolian fault ruptures. Considering the correlation coefficients given in Table 5, the correlation coefficient of Station 1 and Station 11 is 0.555, one of the highest correlations in the table.

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REFERENCES

[1] Durrani, S., A., Ilić, R., 1997. Radon Measurements by Etched Track Detectors, World Scientific, Singapore.

[2] Papachristodoulou, C., Stamoulis, K. & Ioannides, K., 2020. Temporal Variation of Soil Gas Radon Associated with Seismic Activity: A Case Study in NW Greece. Pure Appl. Geophys. 177, 821–836. https://doi.org/10.1007/s00024-019-02339-5

[3] Esan, D.T., Sridhar, M.K.C., Obed, R. et al., 2020. Determination of Residential Soil Gas Radon Risk Indices over the Lithological Units of a Southwestern Nigeria University. Sci Rep 10, 7368. https://doi.org/10.1038/s41598-020-64217-8

[4] Morales-Simfors, N., Wyss, R., A., Bundschuh, J., 2020. Recent progress in radon-based monitoring as seismic and volcanic precursor: A critical review, Critical Reviews in Environmental Science and Technology, 50:10, 979-1012, DOI: 10.1080/10643389.2019.1642833

[5] Kulali, F., Akkurt, I., Özgür, N., 2017. The effect of meteorological parameters on radon concentration in soil gas, Acta Physica Polonica A, 132 (3), pp. 999-1001.

[6] Baldev R. Arora, Arvind Kumar, Vivek Walia, Tsanyao Frank Yang, Ching-Chou Fu, Tsung-Kwei Liu, Kuo-Liang Wen, Cheng-Hong Chen, 2017. Assesment of the response of the meteorological/hydrological parameters on the soil gas radon emission at Hsinchu, northern Taiwan: A prerequisite to identify earthquake precursors, Journal of Asian Earth Sciences, Volume 149, Pages 49-63, ISSN 1367-9120, https://doi.org/10.1016/j.jseaes.2017.06.033.

[7] Ćujić, M., Janković Mandić, L., Petrović, J. et al., 2020. Radon-222: environmental behavior and impact to (human and non-human) biota. International Journal of Biometeorology. https://doi.org/10.1007/s00484-020-01860-w

[8] Okabe, S., 1956. Time Variation of the Atmospheric Radon Content Near the Ground Surface with Relation to Some Geophysical Phenomena. *Memoirs of the College of Science, Kyoto Imperial University, Series A*, 28, 99-115.

[9] King, C.Y., 1986. Gas Geochemistry Applied to Earthquake prediction: An Overview, *Journal of Geophysical Research*, 91, 12269–12281.

[10] King, C.Y., Luo, G., 1990. Variations of Electric Resistance and H_2 and Rn Emissions of Concrete Blocks Under Increasing Uniaxial Compression, *Pure and Applied Geophysics*, 134, 45–56.

[11] King, C. Y., King, B. S., Evans, W. C., 1995, Spatial Radon Anomalies on Active Faults in California, *Applied Geochemistry*, 11, 497-510.

[12] Ghosh, D., Deb, A., Sengupta, R., 2009. Anomalous radon emission as precursor of earthquake, Journal of Applied Geophysics, 69, pp. 67-81,

[13] Zmazek, B., Vaupotič, J., Živčić, M., Premru, U., Kobal, I., 2020. Radon monitoring for earthquake prediction in Slovenia, Fiz B, 9, pp. 111-118, 0048-9697, https://doi.org/10.1016/j.scitotenv.2020.137857.

[14] Riggio, A., SAntulin, M., 2015. Earthquake forecasting: a review of radon as seismic precursor, Bollettino di Geofisica Teorica ed Applicata, Vol. 56, n. 2, pp. 95-114.

[15] Piersanti, A., Cannelli, V., Galli, G., 2015. Long term continuous radon monitoringin a seismically active area, Annals of Geophysics, 58, 4.

[16] Chen, Z., Li, Y., Liu, Z. et al., 2018. Radon emission from soil gases in the active fault zones in the Capital of China and its environmental effects. Sci Rep 8, 16772. https://doi.org/10.1038/s41598-018-35262-1

[17] Atabey, E., 2000. Deprem, *Maden Teknik ve Arama Genel Müdürlüğü*, 34, Ankara.

[18] Arpat, E, Şaroğlu, F., 1972. The East Anatolian Fault System; Thoughts on its Development . Bulletin of the Mineral Research and Exploration , 78 (78) , 1-12 .