Monitoring of earthquake precursors in Yogyakarta

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Abstract. Earthquake precursors continue to be developed by researchers to try to predict earthquakes, one of which is Radon. The monitoring of radon gas in the ground continues to be carried out in Yogyakarta and its surroundings as one of the earthquake mitigation efforts. This study aims to analyze the variation of radon gas and seismic activity as well as the emergence of local earthquake precursors that occurred in Yogyakarta and its surroundings. Radon gas monitoring is carried out in two locations, namely in the Pundong and Piyungan areas. Earthquake activity was recorded from the BMKG earthquake catalog. The radon anomaly study to determine the existence of earthquake precursors was carried out using the correlation method. Radon gas anomalies are determined when there is an increase in the Radon concentration graph. The results show that an increase in radon gas emissions is correlated with an increase in earthquakes' frequency. The correlation method's application indicates the presence of radon gas anomalies as a precursor to earthquakes around the Opak Fault. Further research is needed to see the correlation and consistency of radon gas anomalies with earthquake events around the Opak Fault.

1. Introduction
Understanding the earthquake precursor phenomenon, there are several standard methods for calculating earthquake return periods, calculating Radon, vp / vs, but precursors based on ionospheric disturbances are a relatively new field in current earth science promising success. Scientists around the world are now trying to learn an understanding of the physical and chemical processes before earthquakes occur. One such study is Radon, a radioactive gas that is odorless and colorless due to the decay of uranium stored in rocks with a half-life of about 3.8 days. Radon can be found in soil and rocks and can be found in various concentrations, both in soil, air, and water. Measurement of radon gas has several benefits, including an indication of buried uranium deposits, tracking the presence of moving air masses and groundwater as a result of dynamic geological faults, and can also be used to predict earthquakes [1].

The last few decades have developed attempts to study the relationship between radon gas and geodynamic processes. Radon is considered the most suitable for studying earthquake precursors than other gases because it is easy to detect. Efforts to improve monitoring and analysis of radon data continue, and methodologies and mathematical modeling are continuously being developed to strengthen the relationship between radon gas anomalies and geodynamic processes [2]. In Indonesia, monitoring of radon gas concentrations has been carried out around the Opak Fault, Yogyakarta, since...
2015, along with observing parameters of underground temperature, water level, air temperature, air pressure, and rainfall. The monitoring of radon gas concentrations has been carried out by placing radon sensors in boreholes in the ground at two locations, namely Pundong and Piyungan [3]. The measurement of radon gas in soil and groundwater is widely used throughout the world. The observations concluded that Radon could be used as an indicator of the earth's crust activity. Many studies have shown that radon gas anomalies are associated with seismic activity.

The first evidence showing a relationship between Radon and earthquake occurrence is observations of radon concentrations before the Tashkent earthquake [4]. These findings prompted other researchers to study the relationship between radon gas anomalies in soil and groundwater and earthquake events. Recent studies have shown that radon gas anomalies with more extended periods are positively correlated with future earthquake events of greater magnitude [5]. Statistical analysis also shows a relationship between radon gas variations and the release of earthquake energy. The concentration of radon gas in the soil also strongly correlates with the fault location [6]. Observations of radon gas in tectonically active areas in western Turkey show a linear correlation between the level of radon emissions and seismic activity in the study area [7].

This study aims to analyze the variation of radon gas and seismic activity around the Opak Fault in Yogyakarta and its surroundings and study the emergence of local earthquake activity precursors. Research on earthquake precursors around the Opak Fault is expected to be useful in raising awareness about earthquake disaster mitigation in the region.

2. Method

Monitoring of radon gas concentrations was carried out in two locations around the Opak Fault, precisely in the Pundong (110.343\(^{0}\) East Longitude, 7.956\(^{0}\) LS) and Piyungan (110.483\(^{0}\) East Longitude, 7.828\(^{0}\) LS) regions. During 2016 there was seismic activity around the Opak Fault. Earthquake activity around the Opak Fault was obtained from the BMKG earthquake data warehouse [8]. Figure 1 shows the seismicity of earthquakes around Yogyakarta. There were about 25 earthquakes throughout 2016 and the radon monitoring stations in Pundong and Piyungan, Yogyakarta.
Figure 1. Location of radon monitoring in Yogyakarta (green triangle), earthquake data around Yogyakarta 2016 (red circle) from the BMKG earthquake warehouse, base map is taken from GMT [8][9].

Figure 2. The radon gas monitoring system around Yogyakarta is installed simultaneously by observing the temperature below the earth's surface, water level, air temperature, pressure and rainfall [10].

The basic principle in obtaining radon data is to install a radon sensor in the ground by making an airtight borehole to measure the concentration of radon gas so that Radon does not escape into the air. From the sensor directly to the digitizer. Furthermore, the digitizer will store the data in memory. The data will be sent to the BMKG Research and Development Center in real-time using internet communication. This data is then monitored and analyzed see Figure 2 shows the radon gas monitoring system and other parameters air temperature, rainfall, and pressure at Pundong and Piyungan stations, Yogyakarta.

3. Results and discussion
The results of monitoring radon gas concentrations, rainfall at Pundong, Piyungan stations, and seismic activity around Yogyakarta in 2016 are shown in Figure 2. The variability of radon gas at Piyungan station during 2016 showed a relatively higher value than that at Pundong station. The concentration of radon gas at Piyungan station ranged from 0.1 - 35.652 Bq/L, while at Pundong station ranged from 0.1 - 34.354 Bq/L. The increase in radon gas concentration associated with the earthquake was 13 confirmations events and 10 events have not been confirmed for Piyungan station. In comparison, 9 events have been confirmed and 19 events have not been confirmed shown in Figure 3 and 4.

Radon data at the two stations increased simultaneously from May 2016 to the end of September 2016. The increase in radon gas concentration at the two stations correlated with the increase in the frequency of earthquakes around the Opak Fault. Radon data at Piyungan station also increased several times from early May to September 2016, while at Pundong station, there was an increase in early August to September 2016. Earthquakes detected the most massive increase in radon data at Piyungan station at sea with a magnitude of 3.5 dates 9 September 2016. Even though the distance is quite far, the
magnitude also affects Radon's variation, which reaches 35,652 Bq/L. This observation of radon gas is in line with previous research, which stated an increase in the concentration of radon gas before a major earthquake [11][12].

Figure 3. Correlation of Radon Concentration with the 2016 Earthquake at the Radon Piyungan Observation Station, earthquake data around Yogyakarta 2016 (red circle) from the BMKG earthquake warehouse, base map is taken from GMT [8][9].
Figure 4. Correlation of Radon Concentration with the 2016 Earthquake at the Radon Pundong Observation Station, earthquake data around Yogyakarta 2016 (red circle) from the BMKG earthquake warehouse, base map is taken from GMT [8][9].

4. Conclusion
The correlation method's application indicates the presence of radon gas anomalies as a precursor to earthquakes around the Opak Fault. Further research is needed to see the correlation and consistency of monitoring results of radon gas anomalies with earthquake events around the Opak Fault.

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