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DETECTION SYSTEM FOR DETERMINISTIC EARTHQUAKE PREDICTION BASED ON RADON CONCENTRATION CHANGES IN INDONESIA

SUNARNO[1,*], HERLAMBANG L. FIRDAUS[1],
YAKUB F. LUCKYARNO[1], MEMORY M. WARUWU[2], RONY WIJAYA[3]

[1]Department of Nuclear Engineering and Engineering Physics, Faculty of Engineering,
Universitas Gadjah Mada, Jalan Grafika 2, Bulaksumur, Yogyakarta 55283, Indonesia
[2]Laboratory of Sensor and Telecontrol System, Faculty of Engineering,
Universitas Gadjah Mada, Jalan Grafika 2, Bulaksumur, Yogyakarta 55283, Indonesia
[3]Unit of Production House, Faculty of Medicine, Universitas Gadjah Mada,
Jalan Farmako, Senolowo, Sekip Utara, Yogyakarta 55281, Indonesia
*Corresponding Author: sunarno@ugm.ac.id

Abstract

Radon concentration changes are one of the natural anomalies that occur before an earthquake occurs. These events can be used as a medium to predict earthquakes. The detection system contains an ionization chamber, signal processor, system controller, data storage and electrical power supply. The detector placed on a chamber room to capture the accumulate radon emission is collected in the room. The detection system that has been developed is expected to be the first step to conduct studies on earthquake predictions. The detector system shows detection of the earthquake precursors anomaly which is radon concentration changes. To validate the results of this study, data that has been recorded on data storage media will be compared with secondary data from BMKG (Indonesian Meteorology, Climatology and Geophysics Agency). From June until August 2018, the radon concentration has a change of 0.1 pCi/l to 0.6 pCi/l respectively; the earthquake occurs within the next three days. This shows a fresh breeze in the earthquake prediction study field that the changes in radon concentration in Yogyakarta can be used as a medium to predict earthquakes. This report is in order to provide valuable information about the development system that can be used for earthquake prediction, although further studies and development of instrumentation systems from other earthquake precursor anomalies are needed.

Keywords: Earthquake, Detector system, Precursor, Prediction, Radon concentration.

1. Introduction

Earthquakes are one of the most unpredictable, most sudden, and therefore most destructive natural disasters. The quake is modulated of the spatial and temporal occurrence in the natural processes including changes in tectonic pressure, Earth's tides, land surface fluid migration, loading of ice and surface snow, heavy rainfall, demolition of sediments, changes in atmospheric pressure, and groundwater loss [1, 2]. The year 2015 alone saw several deadly earthquakes across the globe, motivating a streamlining of precursory studies [3, 4]. Shocks are the result of tectonic pressure surged and very difficult to predict because of the lack of the necessary statistical patterns to model events in the future. However, the level of uncertainty of the earthquakes is highly debated among seismology, with some publications are optimistic highlights the benefits and the need for ongoing research on earthquake precursor for improved prediction of the earthquake [5]. The confidence in the science of short-term earthquake prediction received a boost in 1975, when a warning was issued in Haicheng, China hours before a significant M 7.4 earthquake, saving many lives [6].

Previous studies believe that research on precursors or natural anomalies before earthquakes can be used to predict earthquakes in the future. A wide variety of natural phenomena that reportedly precedes at least some earthquakes, it's commonly known as an earthquake precursor. These natural anomalies include seismicity, magnetic field changes, groundwater level changes, gas emissions, temperature changes, surface deformations, and animal behavior. Some each of these phenomena has been deliberately observed before specific earthquakes, while others such observations have been serendipitous [6].

Earthquake prediction is different from earthquake forecasting, which can be defined as a probabilistic assessment of general earthquake hazards, including the frequency and magnitude of a massive earthquake. The earthquake can be said to be predictable if it is known when the time occurred, how significant the scale is, and where it is located. Further predictions can be distinguished from earthquake warning systems, which, after detecting earthquakes, provide a real-time warning to the surrounding area that might be affected [7]. Several parameters used to predict the earthquake are shown in Table 1.

Table 1. Well-studied earthquake precursor

Precursors Anomaly	Example Reference
Seismicity	Asim et al. [8]
Magnetic Field	Balasis and Mandea [9]
Gas/aerosol emission	Guo and Wang [10]
Ionospheric	Sharma et al. [11]
Water level change	He et al. [12]
Air Temperature	Alvan et al. [13]
Land Surface Temperature	Bhardwaj et al. [5]
Surface Deformation	Borghi et al. [14]
Animal behavior	Grant et al. [15]

The first case that found the relationship of radon increase with earthquake occurred is in Kobe Earthquake 17 January 1995. Radon concentration in groundwater increased for several months before the 1995 southern Hyogo

Prefecture (Kobe). From the end of October 1994, the initial observation, until the end of December 1994, the concentration of radon increased about four times. On January 8, 9 days before the earthquake, radon concentrations reached a peak of more than 10 times at the start of the observation, before starting to decrease. This radon change tends to be an early phenomenon of earthquake disasters [16].

Radon gas is one of the noble gases that is radioactive, colorless, odorless, cannot be seen, and cannot be felt, so it cannot be detected by the senses. This radionuclide is a primordial natural radionuclide, the result of the daughter completely radium in the uranium series that has earth crust. Radon gas concentration is relatively high compared to natural radionuclides others. High concentrations of radon are found in soil and old-containing rocks, which contain granite, flakes (fragile rock fragments), phosphate and pitch-blende. Besides that, groundwater also influences the spread of Radon in the Environment. Because the air in the ground can dissolve radon if it penetrates crustal rock through rock cavities and radiation-containing soil.

In general, the amount of radon concentration in the environment is influenced by the situation, conditions and types of rock found in the soil layer. Some types of rocks that are higher than the average content of uranium, including; granite, phosphate sedimentary rocks, brightly colored volcanic rocks, shale rocks that contain a lot of organic material, and metamorphic rocks from the four previous rock types. Just as uranium is contained in every type of rock and soil, so is radon and radium, because it is a derivative of radioactive uranium decay. Each radium atom decays by ejecting out of its nucleus and producing alpha particles consisting of two neutrons and two protons. As soon as the alpha particles are released, newly formed radon atoms melt (recoil) in the opposite direction (like a high-powered rifle, when the bullet is fired). Alpha recoil is the most important factor that affects the release of radon from mineral grains. [17, 18].

Radon gas is released from the earth's surface into the air continuously, moves freely and enters the house by diffusion through soil pores, building materials, and water. Because radon is a gas, radon mobility is much higher than uranium and radium. Radon can more easily escape through rock cracks and pore space between soil grains. This convenience affects the level of radon levels that enter the house.

The speed of radon transfer through the soil is controlled by physical properties (moisture content, porosity, soil permeability) and meteorological factors (barometric pressure, wind, relative humidity, rainfall). Radon moves faster through permeable soil (which consists of sand and gravel), rather than through water-resistant soil (clay) [19].

In another case, Radon gas most often appears in volcanic areas that are still active, especially the crater or flank). Besides that subduction area is also an area that has high radon because it is a meeting between plates (continents and oceans). Both types and types of volcanoes for both the fore arch and the back arch will not affect the radon composition so the measurement of radon gas activity will produce the same value.

In general, the source of radon gas is far below the surface of the earth (magma) and through the crater pipe trying to go out to the surface. The speed and slowness of the gas will be affected by the gap around it. Aside from the nature of the gas itself. Before reaching the surface off through the soil/rock and flowing into the differences that exist such as faults and so on mixed with other gases. Of the various gases that emerge, radon is an isotope with a short half-life. Not all gases can directly reach the surface, but some are trapped in the cracks or pores of the rock. Judging from the concentration value, radon gas will be higher if it is located in the land/rock in with low porosity. The source of radon gas that is found deep in the rock layer will try to go out so that in line with the number of volcanic and tectonic earthquakes, gas counts can be known. Cracks and cracks are exciting phenomena in subduction and volcanic regions. Therefore, the amount of radon gas (gas anomaly) that characterizes the area has another value than the actual conditions. In line with the theory, if there is an increase in radon gas in an observation, especially in the fault zone, it will be accompanied by an increase in earthquakes that provide an opportunity for the release of surface radon gas. The example is shown in Fig. 1.

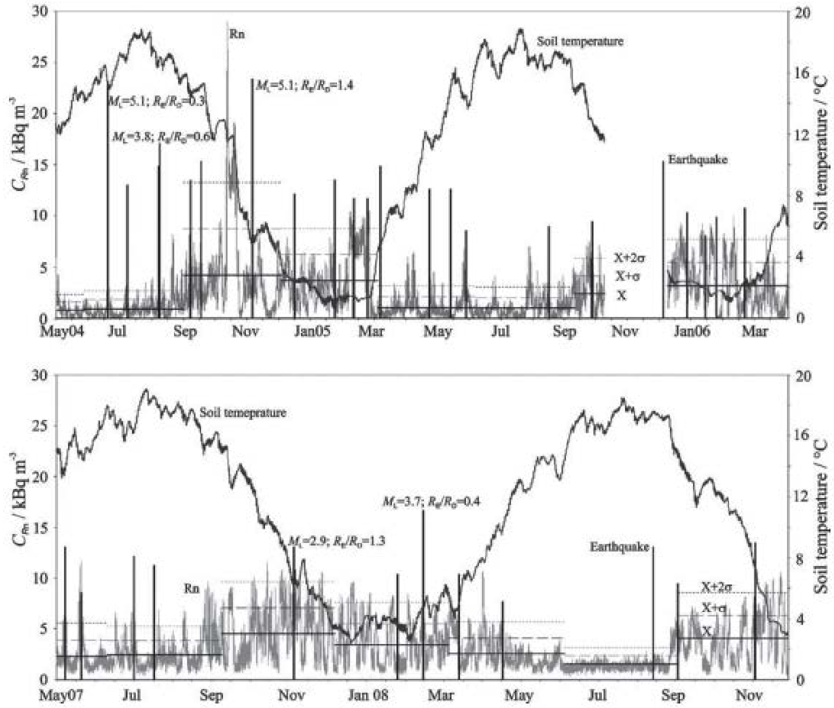

Fig. 1. Time series of hourly radon concentration in soil gas at Cazzaso (Friuli) [20].

Along with the growth of the times, the level of public trust in earthquake predictions is getting lower. That is because stakeholders in the government always spread information that earthquakes cannot be predicted. But besides that, there are still many researchers who are very optimistic about earthquake predictions. Some of them believe that earthquakes can be predicted based on history in the past, Others think that natural behavior before an earthquake can be observed for earthquake predictions. Signals that can be found before earthquakes which indicate a high probability of location, time, and magnitude of future events are the most widely used predictive methods depending on the concept of diagnostic precursors. The research for diagnostic precursors has not yet got a successful short-term prediction scheme [21].

The previous research has found that the earthquake occurred 2 to 50 days before the quake. It detects the different earthquake precursor anomaly that is groundwater level change in the same region that is the Yogyakarta-Indonesia region [22, 23]. This paper discusses the novelty of efforts to predict earthquakes based on natural anomalies, i.e., radon concentration changes which appear a few moments to initiate an earthquake event.

2. Method of Experiments

The radon concentration monitoring system was placed at a chamber room consisting of the ionization chamber, and signal processing. The block diagram of the detector system is shown in Fig. 2.

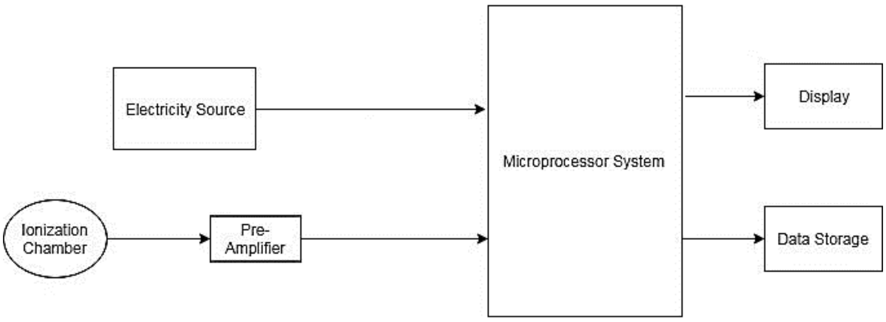

Fig. 2. Block Diagram of the radon monitoring system.

The radon monitoring system contains the ionization chamber as a detector, signal conditioning, signal processing, system display, and electrical power supply. The specification of the radon monitoring system will be shown in Table 2.

Table 2. Radon monitoring system specification.

Item	Specification
Electricity Input	18VDC 200mA
Sensor	Ionization Chamber
Sensor Voltage	250VDC
Full-scale reading	0.0 – 999.9 pCi/l
System Display	Seven Segment
Accuracy	± 20% pCi/l
Data Storage	32 Gb

The radon monitoring system has an algorithm path to explain the working principle from the detector. The algorithm path will be shown in Fig. 3.

Moreover, the radon monitoring system placed in a chamber room. It put on 50 centimeters above the floor of the chamber room. This system uses the ionization chamber as a gas detector, and it cannot distinguish the type of radiation source. To reducing the other radiation besides radon, the chamber room is used. Besides that, radon can accumulate in the chamber room. To validate the results of this study, data that has been stored on storage media will be compared with secondary data from BMKG (Indonesian Meteorology, Climatology, and Geophysics Agency), and the data retrieval process also intends to perform an interval test to see the reliability of the instrumentation system. Field data acquisition is completed on a range time June-August 2018.

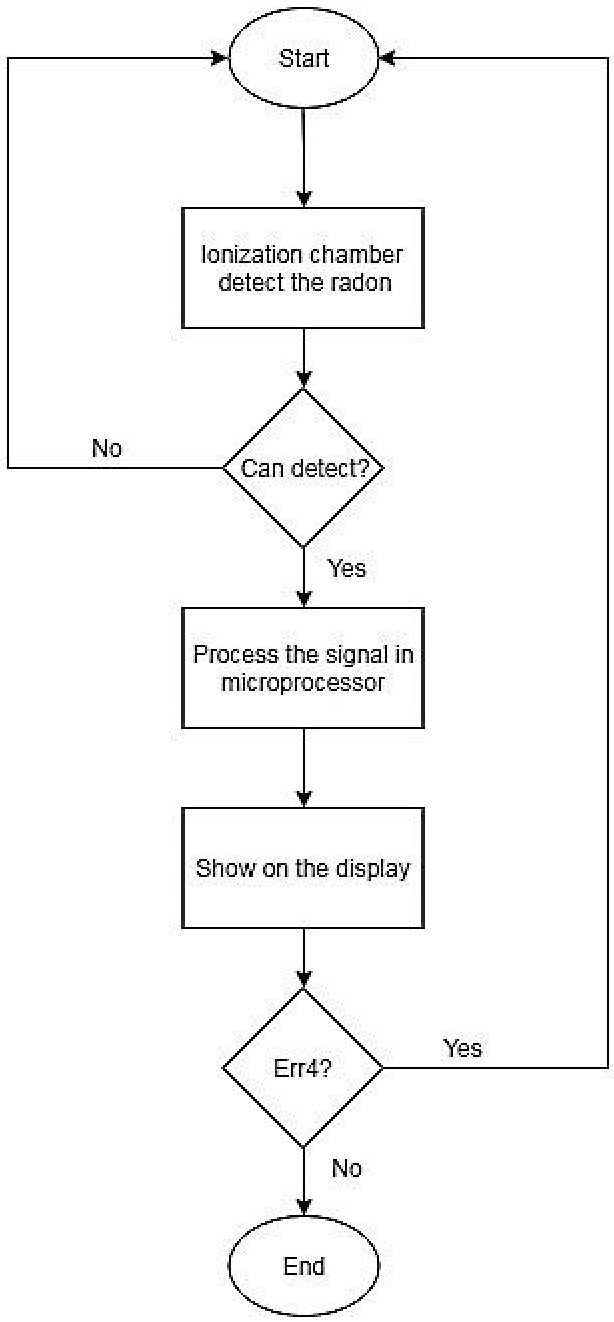

Fig. 3. Algorithm of the radon monitoring system.

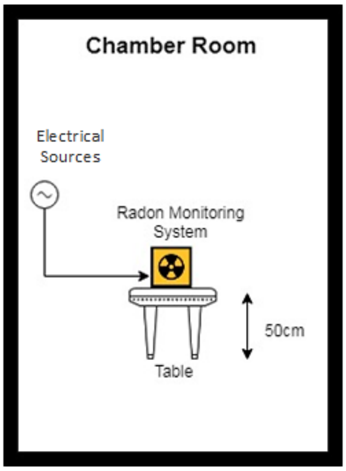

Fig. 4. Schematic diagram of the radon concentration monitoring system in the chamber room.

The system which placed on the chamber room was supported with electrical sources from PLN (Indonesian National Electricity Agency) electricity, it was explained in Fig. 4. The radon monitoring system put on the table in the chamber room. The data will be stored on data storage (SD Card), and then it will be analysed later. The chamber room location is on the propellant room Department of Nuclear Engineering and Engineering Physics Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta Region, Indonesia that is shown in Fig. 5.

Fig. 5. Implementation of the radon monitoring system.

3. Results and Discussions

The detection of radon concentration changes is performed from June 8, 2018, until August 7, 2018. The yield of the detection is compared with the occurred earthquake-event in the same range of time. The earthquake event data took from the secondary data sources, i.e., BMKG (Indonesian Meteorology, Climatology, and Geophysics Agency). The relationship between radon concentration changes and the earthquake event occurs will be shown in Fig. 6.

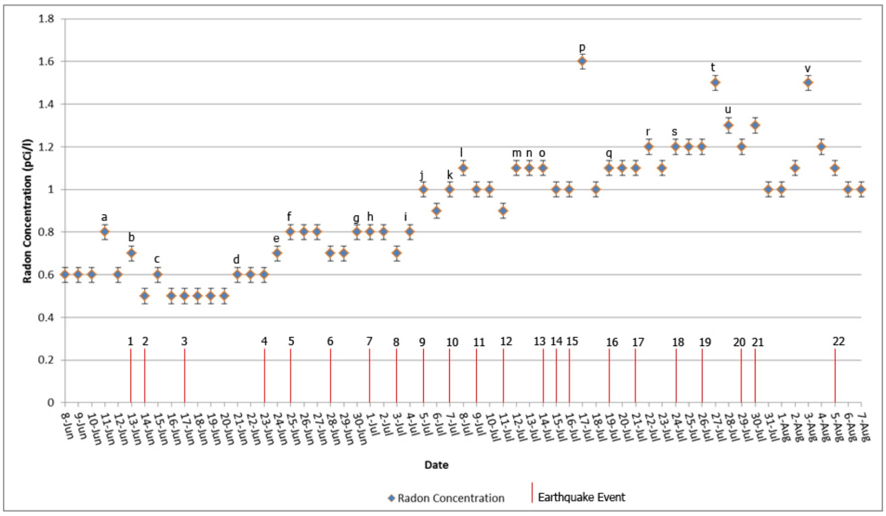

Fig. 6. Detection of radon concentration changes from June 8, 2018 – August 7, 2018.

The radon monitoring system captures radon anomalies in the chamber room in a period. Radon activities have a pattern that can be observed before the earthquake event occurred, it means that code a has a relationship against code 1, then code b with code 2, till the code v against code 22, as shown in Fig. 6. The pattern obtained in this research is that radon concentration will always increase in two days before the earthquake event. It can be proven by the primary data (live data acquisition) and the secondary data (earthquake event data from BMKG).

In this research, radon concentration detection can figure out the relationship between radon concentration change in the chamber room against an earthquake event that occurred. The change occurred two days before the earthquake event, it around 0.1 pCi/l to 0.6 pCi/l. The most significant change occurred two days before the earthquake event in Malang on July 19, 2018. This pattern also shows, if the earthquake has a considerable magnitude and the location more near to the position of the detector, so the radon concentration will explain the much significant changes. The relationship between the earthquake events that occurred in the range of time against the radon concentration changes shown in Fig. 6 will clearly explain in Table 3.

The radon concentration monitoring system placed in the chamber room, because the radon appears from the earth can be accumulated in the enclosed space. Radon increase several days before the earthquake event occurred due to the rocks stress under the lithosphere that happened on seismic activity. This is like a sponge dipped in water and then squeezed. Radon in the rocks is like the water that comes out through the squeezed sponge pores, and the squeezing force is the seismicity activity on the lithosphere. The monitoring system can capture the radon concentration increases with 0.1 to 0.6 pCi/l several days before the earthquake event occurred. To validating the systems work, data that get from the radon monitoring system compared against the secondary data from BMKG.

Table 3. The relationship between radon concentration changes and earthquake events.

Radon Changes		Earthquake Occurred			
No.	**Concentration (pCi/l)**	**No.**	**magnitude**	**location**	**occurred after the changes**
a	0.2	1	5.6 RS	Mentawai	2 Days
b	0.1	2	5.1 RS	Mentawai	1 Days
c	0.1	3	4.2 RS	Bantul	2 Days
d	0.1	4	5.0 RS	Indramayu	2 Days
e	0.1	5	5.0 RS	Mentawai	1 Days
f	0.1	6	5.2 RS	Seram	3 Days
g	0.1	7	4.3 RS	Tasikmalaya	1 Days
h	0.1	8	5.9 RS	Bali	2 Days
i	0.1	9	5.8 RS	Gunung Kidul	1 Days
j	0.2	10	4.6 RS	Lebak	2 Days
k	0.1	11	5.2 RS	Lampung	2 Days
l	0.1	12	5.5 RS	Pesisir Barat	3 Days
m	0.2	13	5.1 RS	Bengkulu	2 Days
n	0.2	14	4.8 RS	Lebak	2 Days
o	0.2	15	4.7 RS	Garut	2 Days
p	0.5	16	5.8 RS	Malang	2 Days
q	0.1	17	5.5 RS	Padang	2 Days
r	0.1	18	5.0 RS	Sumbawa Barat	2 Days
s	0.1	19	5.0 RS	Bengkulu	2 Days
t	0.3	20	6.4 RS	Lombok	2 Days
u	0.1	21	5.3 RS	Nias	2 Days
v	0.4	22	7.0 RS	Lombok	2 Days

Not all earthquakes that occur in the Indonesian region can give the impact on radon concentration changes, as an example in the case of earthquakes and tsunamis that occurred in Palu and Donggala, Central Sulawesi on September 28, 2018, did not provide a change effect on radon detectors that installed in Java. That means radon concentration changes as earthquake precursors are significantly affected by the hypocenter, epicenter, magnitude and distance of the earthquake point against the radon detector location.

The relationship of radon concentration changes against M 6.3 Situbondo earthquake is shown in Fig. 7. This indicates that radon concentration increased three days before the earthquake occurred. On October 7, 2018, radon detected by the radon monitoring system was 0.8 pCi/l, and then radon increased by 0.3 pCi/l to 1.1 pCi/l on October 8, 2018. The day after increased, the radon decreased returns to the equilibrium point in the chamber room. And then, the earthquake event occurs three days after the radon anomalies.

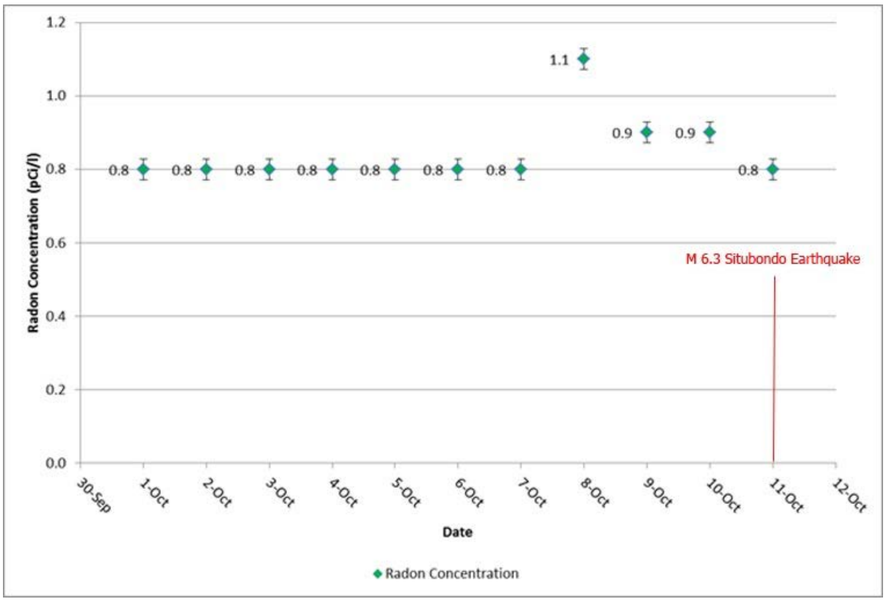

Fig. 7. The correlation of Situbondo earthquake against radon concentration changes.

4. Conclusions

This research informs that the radon concentration changes as an earthquake precursor anomaly can be detected using the detector system which placed on Yogyakarta Region - Indonesia. The detection system designed in this report is expected to improve the knowledge and technology for earthquake prediction deduced from the anomalies at Yogyakarta Region - Indonesia.

The yield of the detection system test at the Yogyakarta region indicates that the radon concentration changes recorded on the system have a relationship with the occurred earthquake. On the range time, the radon concentration has a change of 0.1 pCi/l to 0.6 pCi/l respectively, and then the quake occurs within the next one till three days.

This study found that when there is a change in the radon concentration monitoring system in a certain period of time, an earthquake will occur sometime later. Hypocenter, epicenter, magnitude and the distance of the earthquake point against the radon detector location is very important to be a highlight in the earthquake prediction deduced on radon concentration changes. To make radon concentration changes as a natural anomaly for predicting earthquakes, furthermore development must be done in database systems and system reliability. This report aims to give much valuable information from developing a system that can be used for earthquake prediction.

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Abbreviations

AC	Alternating Current
BMKG	Indonesian Meteorology, Climatology, and Geophysics Agency
DC	Direct Current
PLN	Indonesian National Electricity Agency
M	Magnitude
RS	Richter Scale

References

1. Kundu, B.; Vissa, N.K.; and Gahalaut, V.K. (2015). Influence of anthropogenic groundwater unloading in Indo-Gangetic plains on the 25 April 2015 Mw 7.8 Gorkha, Nepal earthquake. *Geophysical Research Letters*, 42(24), 10.607-10.613.
2. Foulger, G.R.; Wilson, M.P.; Gluyas, J.G.; Julian, B.R.; and Davies, R.J. (2017). Global review of human-induced earthquakes. *Earth-Science Reviews*, 178, 438–514.
3. Holzer, T.L.; and Savage, J.C. (2013). Global Earthquake Fatalities and Population. *Earthquake Spectra*, 29(1), 155-175.
4. Mansouri Daneshvar, M.R.; and Freund, F.T. (2017). Remote Sensing of Atmospheric and Ionospheric Signals Prior to the Mw 8.3 Illapel Earthquake, Chile 2015. *Pure and Applied Geophysics*, 157-191.
5. Bhardwaj, A.; Singh, S.; Sam, L.; Joshi, P.K.; Martín-Torres, F.J.; and Kumar, R. (2017). A review on remotely sensed land surface temperature anomaly as an earthquake precursor. *International Journal of Applied Earth Observation and Geoinformation*, 63, 158-166.
6. Cicerone, R.D.; Ebel, J.E.; and Britton, J. (2009). A systematic compilation of earthquake precursors. *Tectonophysics*, 476(3-4), 371-396.
7. Hjorleifsdottir, V.; Flores, K.; singh, S.K.; Iglesias, A.; Castillo, J.; Vallee, M.; and Ji, C. (2017). Characteristics of Large Earthquakes Occurring on the Shallowest Portion of the Mexican Subduction Megathrust. *American Geophysical Union, Fall Meeting 2017*.
8. Asim, K.M.; Idris, A.; Iqbal, T.; and Martínez-Álvarez, F. (2018). Seismic indicators based earthquake predictor system using Genetic Programming and AdaBoost classification. *Soil Dynamics and Earthquake Engineering*, 111, 1-7.
9. Balasis, G.; and Mandea, M. (2007). Can electromagnetic disturbances related to the recent great earthquakes be detected by satellite magnetometers?. *Tectonophysics*, 431(1-4), 173-195.
10. Guo, G.; and Wang, B. (2008). Cloud anomaly before Iran earthquake. *International Journal of Remote Sensing*, 29(7), 1921-1928.
11. Sharma, G.; Champati Ray, P.K.; Mohanty, S.; and Kannaujiya, S. (2017). Ionospheric TEC modelling for earthquakes precursors from GNSS data. *Quaternary International*, 462, 65-74.
12. He, A.; Fan, X.; Zhao, G.; Liu, Y.; Singh, R.P.; and Hu, Y. (2017). Co-seismic response of water level in the Jingle well (China) associated with the Gorkha Nepal (Mw 7.8) earthquake. *Tectonophysics*, 714, 82-89.

13. Alvan, H.V.; Mansor, S.; Omar, H.; and Azad, F.H. (2014). Precursory signals associated with the 2010 M8.8 Bio-Bio earthquake (Chile) and the 2010 M7.2 Baja California earthquake (Mexico). *Arabian Journal of Geosciences*, 7(11), 4889-4897.
14. Borghi, A.; Aoudia, A.; Riva, R.E.M.; and Barzaghi, R. (2009). GPS monitoring and earthquake prediction: A success story towards a useful integration. *Tectonophysics*, 465, 177-189.
15. Grant, R.A.; Raulin, J.P.; and Freund, F.T. (2015). Changes in animal activity prior to a major (M = 7) earthquake in the Peruvian Andes. *Physics and Chemistry of the Earth, Parts A/B/C*, 85, 69-77.
16. Igarashi, G.; Saeki, S.; Takahata, N.; Sumikawa, K.; Tasaka, S.; Sasaki, Y.; and Sano, Y. (1995). Radon Anomaly: A Possible Precursor of the 1978 Izu-Oshima-kinkai Earthquake. *Science*, 207(4433), 882-883.
17. Kim, J.W.; Joo, H.Y.; Kim, R.; and Moon, J.H. (2018). Investigation of the relationship between earthquakes and indoor radon concentrations at a building in Gyeongju, Korea. *Nuclear Engineering and Technology*, 50(3), 512-518.
18. Deb, A.; Gazi, M.; Ghosh, J.; Chowdhury, S.; and Barman, C. (2018). Monitoring of soil radon by SSNTD in Eastern India in search of possible earthquake precursor. *Journal of Environmental Radioactivity*, 184, 63-70.
19. Tomer, A. (2016). Radon as a Earthquake Precursor: A Review. *International Journal of Science, Engineering and Technology*, 4(6), 815-822.
20. Riggio, A.; and Santulin, M. (2015). Earthquake forecasting: a review of radon as seismic precursor. *Bolletino di Geofisica Teorica ed Applicata*, 56(2).
21. Jordan, T.; Jordan, T.H.; Chen, Y.-T.; Gasparini, P.; Madariaga, R.; Main, I.; and Zschau, J. (2011). Operational Eartquake Forecasting. State of Knowledge and Guidelines for Utilization. *Annals of Geophysics*, 54(4).
22. Sunarno, S.; Waruwu, M.M.; and Wijaya, R. (2016). Development of the real time telemonitoring system for earthquake prediction deduced from fluctuations in groundwater levels at Yogyakarta region-Indonesia. *Journal of Theoretical and Applied Information Technology*, 83(1), 95-99.
23. Firdaus, H.L.; Sunarno, S.; Waruwu, M.M.; and Wijaya, R. (2018). Development of the Groundwater Level Changes Detector for Earthquake Prediction at Yogyakarta Region – Indonesia. *Proceeding of 1st International Conference on Industrial Electrical and Electronics (ICIEE).* Anyer-Indonesia.