

Earthquake Date Prediction Based on The Fluctuation of Radon Gas Concentration Near Grundulu Fault

Prediksi Tanggal Gempa Bumi Berdasarkan Fluktuasi Konsentrasi Gas Radon di Sekitar Sesar Grundulu

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ABSTRACT

There were 5 to 26 destructive earthquakes from 2020 to 2022 in Indonesia. Earthquake prediction is unsuccessful and has not provided a reliable forecasting mechanism. At the same time, it is necessary to have an earthquake early warning system to reduce the risk of an accident. In Indonesia, radon gas has been studied to determine its relationship with earthquake events, but earthquake predictions have low sensitivity and accuracy values. In this study, the prediction of earthquake time was carried based on radon gas concentration fluctuations in the active Grundulu fault, which is located in Pacitan, East Java, Indonesia. The method is to collect radon gas concentration measurement data from telemonitoring stations near active faults. The data is then sent to the web server and processed based on the daily average. The daily average of radon gas concentrations and earthquake occurrences is tabulated by day. The daily average data for the concentration of radon gas that is processed is when an earthquake occurs between the Eurasian and Indo-Australian plates with a magnitude of more than M4.5. After that, the daily average radon gas concentrations were statistically processed to find the earthquake time prediction algorithm. The study's findings show that earthquakes above M4.5 that occur between the Eurasian and Indo-Australian plates can be predicted using statistical data processing from radon gas concentration measurements near the Grundulu fault, Pacitan, 1-4 days before the earthquake. The earthquake date prediction algorithm developed has a sensitivity and precision of 78.79% and 70.27 %. This achievement is better than previous research that predicts the time of earthquakes near the Opak Fault, Yogyakarta.

Kata kunci: Active Fault, Earthquake, Prediction, Radon, Telemonitoring

ABSTRAK

Terdapat 5 hingga 26 gempa bumi merusak dari tahun 2020 hingga 2022 di Indonesia. Prediksi gempa tidak berhasil dan belum memberikan mekanisme prediksi yang handal. Sementara itu, diperlukan adanya sistem peringatan dini gempa bumi untuk mengurangi risiko terjadinya bencana. Di Indonesia, gas radon telah dipelajari untuk mengetahui hubungannya dengan kejadian gempa bumi, tetapi prediksi gempa memiliki nilai sensitivitas dan akurasi yang rendah. Pada penelitian ini, prediksi tanggal gempa dilakukan berdasarkan fluktuasi konsentrasi gas radon di sesar aktif Grundulu yang terletak di Pacitan, Jawa Timur, Indonesia. Metode penelitian dilakukan dengan mengumpulkan data pengukuran konsentrasi gas radon dari stasiun tele-monitoring di dekat sesar aktif. Data tersebut kemudian dikirim ke server dan diproses berdasarkan rata-rata harian. Rata-rata harian konsentrasi gas radon dan kejadian gempa bumi ditabulasi berdasarkan hari. Data rata-rata harian konsentrasi gas radon yang diolah adalah saat terjadi gempa antara lempeng Eurasia dan Indo-Australia dengan magnitudo lebih dari M4,5. Setelah itu, rata-rata harian konsentrasi gas radon diolah secara statistik untuk menemukan algoritma prediksi tanggal gempa bumi. Hasil penelitian menunjukkan bahwa gempa di atas M4,5 yang terjadi di antara lempeng Eurasia dan Indo-Australia dapat diprediksi dengan menggunakan pengolahan data statistik dari pengukuran konsentrasi gas radon di dekat patahan Grundulu, Pacitan, 1-4 hari sebelum gempa dengan algoritma yang memiliki sensitivitas dan presisi sebesar 78,79% dan 70,27%.

Keywords: Gempa Bumi, Prediksi, Radon, Sesar Aktif, Telemonitoring

INTRODUCTION

Earthquake is one of the most destructive natural disasters (Hu *et al.*, 1996). From a geographical standpoint, Indonesia is situated within a region where multiple dynamic tectonic plates interact actively (Martha *et al.*, 2021). There are four tectonic plates in Indonesia, which make earthquakes usually happen in Indonesia, namely: the Eurasian Continental Plate moving southeast at a speed of about 0.4 cm/year, the Indo-Australian Ocean Plate moving northward at about 7 cm/year, the Pacific Ocean Plate moving westward at about 11 cm/year and the Philippine Sea Plate which is moving northwest at a speed of about 8 cm/year (Minster & Jordan, 1978). Based on the notes from the Geological Agency of Indonesia, there were 5 to 26 destructive earthquakes from 2020 to 2022 in Indonesia (Supartoyo, 2023). Destructive earthquakes have resulted in casualties, damage to buildings, environmental damage, and property loss (Supartoyo, 2023). Providing an earthquake early warning system is necessary to reduce the risk of earthquakes (Hu *et al.*, 1996). An Early Warning System (EWS) is necessary to furnish individuals with timely disaster information, enabling them to respond accurately (Sufri *et al.*, 2020). Earthquake prediction is unsuccessful and has not provided a reliable forecasting mechanism (Senthilkumar *et al.*, 2020).

Earthquake investigation activities continue to be carried out to identify the characteristics of the earthquake source so that the map of earthquake-prone areas, earthquake distribution maps, and characteristics of active faults can be updated. Earthquake precursors have been monitored around the world. There are radon gas concentrations, groundwater level, temperature, humidity, animal behavior, seismicity, electromagnetic, *etc* (Kundu *et al.*, 2015).

The variations in groundwater radon (Rn) caused by seismic and tectonic activity are seen as significant triggers for monitoring potential major earthquakes that might occur soon (Alam *et al.*, 2020). Zmazek (2005) distinguishes radon gas

anomalies caused by environmental parameters from those caused solely by seismic activity; the following methods were used: (i) deviation of radon concentration from the seasonal average, (ii) correlation between time gradients of radon concentration and barometric pressure, and (iii) regression trees within a machine learning program. Standard deviation ($\pm 2\sigma$) is far less successful in forecasting anomalies induced by the seismic event than a connection between time gradients of radon concentration and barometric pressure and regression trees within a machine learning algorithm. (Zmazek *et al.*, 2005).

One month prior to the earthquake, Josip Planinac's teams monitored soil radon gas concentrations for a year. However, there was an aberration in the monitoring. Due to its high sensitivity, radioactivity, and deep origin, radon gas in soil and groundwater can be one of the possible antecedents of earthquakes (Cigolini *et al.*, 2009; Jaishi *et al.*, 2014). Jae Wook Kim investigates the relationship between earthquakes and indoor radon concentrations at a building in the ground floor of the Energy Engineering Hall of Dongguk University in Gyeongju, Korea between February 2016 and January 2017. The measurements were made with a RAD 7 detector based on the US Environmental Protection Agency measurement protocol. Each measurement was continuously made every 30 minutes over the measurement period every month. There are similar spike-like patterns between the indoor radon concentration distributions and earthquakes. A sudden increase in the peak indoor radon concentration 1-4 days before an earthquake, gradual decrease before the earthquake, and sudden drop on the day of the earthquake if the interval between successive earthquakes was moderately longer. (Kim *et al.*, 2018).

Hickman *et al.* state that the strain field varies when the stress in the Earth's crust increases; the development of new cracks and passageways under the tectonic stress alters gas transport and causes a rise in volatiles from the deep layers to the surface (Hickman *et al.*, 1995). While in 1997, according to Fleischer, changes in the

stress-strain environment and the shifting of rock masses inside the Earth's crust are likely to significantly impact radon levels on Earth's surface (Fleischer, 1997).

Banna reviews the Application of Artificial Intelligence in Predicting Earthquakes (Banna *et al.*, 2020). The literature review shows that the earthquake prediction model accurately predicted magnitude between 3 and 5 (Banna *et al.*, 2020). Hajikhodaverdikhan *et al.* in 2018 predict earthquake using machine learning based on the earthquake magnitude and meteorological data (temperature, average wind speed, and precipitation) in Tabriz, northwest Iran. The result show that the earthquake prediction is within a month, magnitude below M4.4 and the prediction area is wide (Hajikhodaverdikhan *et al.*, 2018). Banna *et al.* used seismic indicators, earthquake precursors, seismographs, and data from the satellite to predict an earthquake using rule-based, shallow machine learning, deep machine learning. The research result show there is too long date and time prediction (20 days to 5 months) with no prediction above M5 (Banna *et al.*, 2020). In Indonesia, radon gas concentration, groundwater level, and meteorological parameters are monitored to identify the relationship between precursors and earthquakes (Firdaus *et al.*, 2020; Martha *et al.*, 2021; Oka Pratama, 2021; Sunardi, 2018). Based on the United States Geological Survey, the ideal earthquake prediction consists of date, time, magnitude, and location (United State Geological Survey, 2015).

There is an earthquake prediction algorithm based on the radon gas fluctuation in Bantul, Yogyakarta, Indonesia, one to three days before the earthquake with a magnitude more than M4.5. The radon gas concentration monitor for nine months produced the correctness of the prediction is 51.52% and accuracy of 66.67% (Pratama *et al.*, 2021). It needs to increase the algorithm's correctness and accuracy. As a result, the designed algorithm predicts more earthquakes. This research aims to get the earthquake prediction algorithm based on the fluctuation of radon gas concentration in Pacitan, East Java-Indonesia station.

RESEARCH METHODOLOGY

In this section, the methodology employed to address the research objectives is comprehensively elucidated.

Based on the literature review, the author will determine the requirements for the system to conduct the research, which are: (1). Radon concentration telemonitoring systems are placed near the active fault of the region or province because the fault area is susceptible to seismic activity; (2). The radon gas concentration telemonitoring system is placed in the basement of the building; (3). The telemonitoring system uses a chamber room because radon has a short lifetime (3.8 days).

The radon gas concentration telemonitoring system is confined in the chamber to accumulate radon gas. (2012)

The radon gas telemonitoring system should measure every 10 minutes to negate emissions from Actinium ($T_{1/2} = 3.92$ s) and Thoron ($T_{1/2} = 54.5$ s) (Cember & Johnson, 2009).

The radon gas concentration telemonitoring system was placed at a maximum of 4.142 cm from the ground opening to effectively measure radon gas emission radiation. (Cember & Johnson, 2009).

The earthquake early warning system based on the radon gas fluctuation telemonitoring system is shown in Figure 1. The radon gas telemonitoring system consists of a radon gas transducer, electric supply, microcontroller system, internet, web server, and data storage. Radon Eye is used as the radon gas transducer. The telemonitoring system is designed to provide continuous monitoring through a web server that can be accessed from anywhere and anytime if there is an internet connection. The electricity source provides power to the internet module and microcontroller. The transducer is used to measure the concentration of radon gas. Data from the transducer is transferred to the microcontroller system and then sent via the internet to the server data storage every minutes continuously. The data can be seen in the dash-

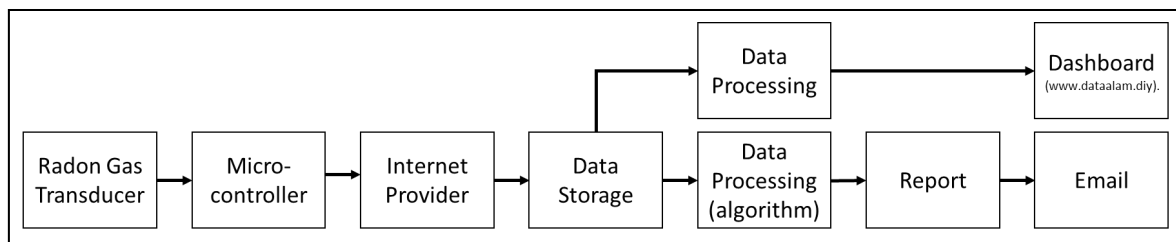


Figure 1. Earthquake early warning system design based on radon gas concentration.

board on www.dataalamdiy.com. The radon gas concentration telemonitoring system's prediction algorithm will send the result daily to the email.

The radon gas concentration telemonitoring system is located in Pacitan, East Java at -8.1848489, 111.1161185, close to the active fault, Grundulu Fault (shown in Figure 2) with stratigraphy of Alluvium (Cobble, pebble, sand, silt, clay, and mud) (Google, 2023; Samudra et al., 2012). The radon gas telemonitoring data would be confirmed using seismic data from the BMKG (Badan Meteorologi, Klimatologi, dan Geofisika) and Postdam Geofon - GFZ German Research Centre for Geosciences. The data will be checked weekly in order to perform an interval test to verify the dependability of the instrumentation equipment.

Radon gas concentration measurement data is downloaded via the data storage web server. The data stored on the server dashboard is the time and measurement value of radon gas concentrations. The measurement values for radon

gas concentrations are calculated based on their daily averages and then tabulated together with earthquakes happen between the Eurasian and Indo-Australian plates with magnitudes greater than M4,5. The daily average data when an earthquake occurs is then grouped, and an algorithm for average daily fluctuations in radon gas concentrations is searched by comparing the daily averages when an earthquake occurs. Then, from the existing comparisons, the most correct comparisons were chosen and checked against the daily average data of radon gas concentrations and earthquake events that had been grouped per day to determine the minimum requirements. The comparison indicates the fluctuation of radon gas concentration before the earthquake happen. Then, the earthquake date prediction algorithm tests the data collection (Figure 3). The earthquake date prediction algorithm is used when it has a sensitivity and precision of more than or equal to 70%, it must be rearranging the earthquake date prediction

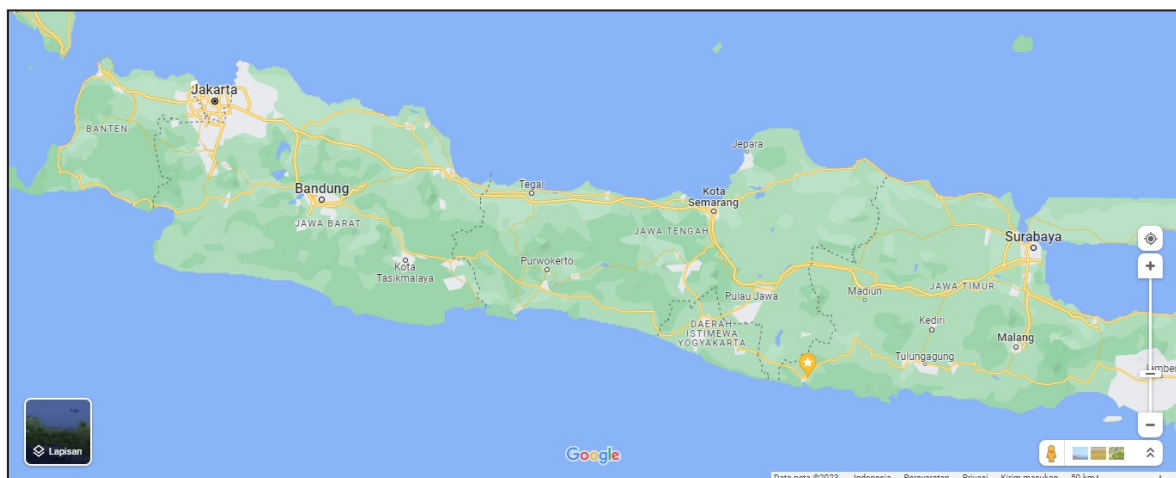


Figure 2. Location of radon gas telemonitoring station in Pacitan, East Java, Indonesia. (Google, 2023)

algorithm if the sensitivity and precision of lower than 70%.

In this research, confusion matrices use to tabulated and calculate the sensitivity and precision of the earthquake date prediction algorithm. Confusion matrices shown in Table 1.

Confusion matrices are calculated using the predictions of a model on a data set. Note that the entries inside of a confusion matrix are counts:

Table 1. Confusion Matrix

	Earthquake	No Earthquake
Prediction ON (1)	True Positive (TP)	False Positive (FP)
Prediction OFF (0)	False Negative (FN)	True Negative (TN)

(1). True Positive: the number of predictions ON, followed by an earthquake; (2). True Negative: the number of predictions OFF, not followed by an earthquake; (3). False Positive: the number of predictions ON, not followed by an earthquake; (4). False Negative: the number of predictions OFF, followed by an earthquake
Confusion matrix can be used to calculate the sensitivity and precision. The sensitivity determines as:

$$\text{Sensitivity} = \frac{TP}{(TP + FN)} \times 100\% \dots\dots\dots (1)$$

The precision determines as:

$$\text{Precision} = \frac{TP}{(TP + FP)} \times 100\% \dots\dots\dots (2)$$

In this study there was no data collection of radon gas concentrations in different stratigraphy.

RESEARCH AND DISCUSSION

Measurements of radon gas concentrations were carried out from the beginning of January 2022 to January 2023 by radon telemonitoring station near Grundulu active fault in Pacitan, East Java, Indonesia collected every minutes.

After analyzing 51 of 74 earthquakes (70%) with magnitudes greater than M4.5 that occurred between the Eurasian and Indo-Australian plates, researchers developed an algorithm for predicting earthquake time based on radon gas concentrations daily average. Table 2 described the earthquake prediction algorithm based on radon gas concentrations.

If the algorithm is met, the system will notify users via telegram and email that an earthquake with a magnitude greater than M4.5 is predicted to occur within the next 1-4 days between the Eurasian and Indo-Australian plates. The earthquakes that the algorithm can predict can be seen in Table 3.

Based on the analysis of the earthquake prediction time algorithm, there are 52 predictions followed by the earthquakes, 22 predictions without an earthquake in 1-4 days after, and 14 earthquakes without prediction before. Based on that calculation, the sensitivity of the prediction algorithm is 78.79%, and the precision is 70.27%. The earthquake prediction with a magnitude above M4.5 happens 1-4 days after the algorithm completes with the prediction area between the Eurasia and Indo-Australia plates. The greatest magnitude of earthquakes that happen between the Eurasia and Indo-Australia plates is M6.8. The average earthquake magnitude is M5.1, with a standard deviation of 0.5. Whilst the day average Earthquake occurrence after the algorithm was fulfilled. This algorithm for predicting the time of earthquake occurrence from the telemonitoring station in Pacitan has better sensitivity and precision than previous studies. (Pratama *et al.*, 2021).

The earthquake prediction system based on radon gas concentration fluctuation may change at another site due to differences in stratigraphy and permeability of subterranean rock formation, which affect the radon gas transport to the Earth's surface. Earthquake prediction needs further study by telemonitoring combination with other earthquake precursors (groundwater level, temperature, humidity, seismicity, total electron content, etc.) to fulfill the ideal parameter of earthquake prediction (date and time,

Table 2. Earthquake prediction time algorithm

Statistical Parameter	Algorithm requirement	Prediction time
DA(n-14) < DA(n-7) DA(n-14) < DA(n-3) DA(n-14) > D(n-7) DA(n-14) < D(n-6) DA(n-7) < DA(n-3) DA(n-7) > DA(n-7) DA(n-7) < DA(n-4) DA(n-3) > D(n-7) D(n-7) < D(n-6) D(n-7) < D(n-5) D(n-7) < D(n-4) D(n-7) < D(n-3)	Earthquake prediction algorithm ON when at least 9 out of 12 comparisons are true.	1-4 days after the prediction algorithm ON

Table 3. Predicted earthquakes

No	Date	Mag-nitude	Locations	Earthquakes accident after the algorithm fulfilled	True Positive	False Negative	False Positive
1	1/25/2022	4.6	Lospalos, Timor Leste	4	1		
2	1/31/2022	5.2	Laut Sawu, Rote Ndao, Nusa Tenggara Timur	-		1	
3	2/4/2022	5.5	Banten, Indonesia	2	1		
4	2/10/2022	4.6	Pagar Alam, Bengkulu	1	1		
5	2/11/2022						1
6	2/17/2022	5.1	Banjar, West Java	2	1		
7	2/21/2022	5.8	Ruteng, NTT	3	1		
8	2/25/2022	6.2	Pasaman Barat, Sumatra	1	1		
9	2/28/2022	4.8	Bayah, West Java	1	1		
10	3/1/2022	5.3	Aceh Barat, Aceh	1	1		
11	3/2/2022	-	-	-			1
12	3/22/2022	4.7	Barat Laut Labuhan Bajo, NTT	-		1	
13	3/25/2022	4.8	Jimbaran, Bali	3	1		
14	3/27/2022	4.5	Lebak, West Java	4	1		
15	3/30/2022	5	Tanggamus, Lampung	3	1		
16	4/1/2022	5.1	Bayah, Banten	2	1		
17	4/1/2022	-	-	-			1
18	4/6/2022	5.6	Kota Sabang, Aceh	2	1		
19	4/10/2022	5.2	Kota Sabang, Aceh	3	1		
20	4/10/2022	-	-	-			1
21	4/12/2022	-	-	-			1
22	4/17/2022	5.1	Kodi-Sumba Barat Daya-NTT	3	1		
23	4/23/2022	4.6	Kencong, Jatim Indonesia	1	1		
24	4/26/2022	4.8	Tenggara Kab-Sukabumi-West Java	3	1		
25	4/30/2022	4.8	Lembar, NTT	4	1		
26	5/1/2022	4.6	Bandar Lampung, Indonesia	4	1		
27	5/1/2022	-	-	-			1
28	5/4/2022	-	-	-			1

Table 3. continued ...

No	Date	Magnitude	Locations	Earthquakes accident after the algorithm fulfilled	True Positive	False Negative	False Positive
29	5/9/2022	4.9	Kupang. NTT	3	1		
30	5/12/2022	5	SSW of Banda Aceh. Indonesia	-		1	
31	5/13/2022	-	-	-			1
32	5/25/2022	6.2	Lahomi. North Sumatra	2	1		
33	5/25/2022	-	-	-			1
34	5/31/2022	5.4	Selatan Bangkunt. Pesisir Barat. Lampung			1	
35	5/31/2022	-	-	-			1
36	6/6/2022	5.1	Domp. NTB	1	1		
37	6/6/2022	-	-	-			1
38	6/12/2022	5.3	Tenggara Pacitan. East Java	2	1		
39	6/18/2022	5.4	Kaur. Bengkulu	1	1		
40	6/22/2022	4.7	Northern Sumatra	4	1		
41	6/24/2022	5	Padang. Sumatra	2	1		
42	6/28/2022	5	Naisano Dua Kupang. NTT	4	1		
43	7/3/2022	4.6	North Komodo Island	4	1		
44	7/6/2022	5.3	Barat laut Enggano Bengkulu			1	
45	7/9/2022	5.4	Lumajang. East Java	2	1		
46	7/9/2022	-	-	-			1
47	7/17/2022	5.5	Barat Daya Pacitan	-		1	
48	7/20/2022	5.8	South Sumatra	2	1		
49	7/23/2022	5.4	Maumere	2	1		
50	7/27/2022	4.5	Domp. Sumbawa Region	2	1		
51	7/27/2022	-	-	-			1
52	8/2/2022	4.9	Tapanuli Tengah. Sumatera Utara	1	1		
53	8/3/2022	5.1	Timor Tengahut- NTT	2	1		
54	8/5/2022	5.1	Sumur. Banten	2	1		
55	8/7/2022	5.1	Seluma-Bengkulu	2	1		
56	8/13/2022	5.2	Karera. East Sumba. NTT	2	1		
57	8/15/2022	5.3	Jepara. Central Java	4	1		
58	8/17/2022	5.5	Timor Leste. Laut Banda	2	1		
59	8/22/2022	5.8	Tenggara Kuta Selatan Bali	-		1	
60	8/25/2022	5	Sengkulu. South Sumatra	-		1	
61	8/28/2022	4.6	South East Java	3	1		
62	8/29/2022	6	Nias. Sumatra Selatan	4	1		
63	9/5/2022	5.1	Bengkulu	4	1		
64	9/8/2022	5.3	Gunung Kidul. Yogyakarta	2	1		
65	9/11/2022	6.1	Southern Sumatra	3	1		
66	9/16/2022	-	-	-			1
67	9/21/2022	5	Mentawai. Sumatra barat	-		1	
68	9/24/2022	6.4	Aceh Sumatra Utara	-		1	
69	9/27/2022	-	-	-			1

Table 3. continued ...

No	Date	Magnitude	Locations	Earthquakes accident after the algorithm fulfilled	True Positive	False Negative	False Positive
70	10/1/2022	-	-	-			1
71	10/9/2022	5.5	Bayah, Banten	4	1		
72	10/12/2022	-	-	-			1
73	10/15/2022	-	-	-			1
74	10/21/2022	4.8	South Sumatra	4	1		
75	10/28/2022	-	-	-			1
76	11/4/2022	-	-	-			1
77	11/6/2022	-	-	-			1
78	11/11/2022	5	Jember, East Java	2	1		
79	11/14/2022	5.4	Barat Daya Cilacap	-	1		
80	11/16/2022	5.6	Enggano, Bengkulu	-		1	
81	11/18/2022	6.8	Enggano, Bengkulu	1	1		
82	11/24/2022	5.1	Mukomuko Bengkulu	-		1	
83	12/13/2022	5.2	Karangasem Bali	4	1		
84	12/17/2022	5.1	Sumur-Banten	-		1	
85	12/19/2022	-	-	-			1
86	12/25/2022	5.3	Tenggara Cilacap-Jateng	-		1	
87	12/30/2022	5.2	Tenggara Enggano-Bengkulu	3	1		
88	1/2/2023	4.9	North Sumatra	4	1		
89	1/17/2023	4.8	Selatan Jawa Timur	1			
				Total	52	14	22
				Precision	70.27		
				Sensitivity	78.79		
				F-Measure	74.29		

magnitude, and location) by other methods to help society reduce disaster risk.

CONCLUSION

By analyzing statistical data on the average daily concentration of radon gas measured close to an active fault (Grundulu-Pacitan, East Java), an algorithm for earthquake date prediction with magnitude greater than the M4.5 earthquake between the Eurasian and Indo-Australia plates can be created with the sensitivity 78.79%, and the precision is 70.27%, with a date prediction of 1-4 days after the prediction algorithm is satisfied.

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