Karangetang Mount Early Warning System using Inference Fuzzy Logic

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Abstract. Mount Karangetang, located on Siau Island, SITARO Archipelago Regency, is one of Indonesia's 127 active volcanoes, making it the nation most susceptible to volcanic eruptions. In 2015, an eruption resulted in the displacement of as many as 465 residents, the destruction of four homes, and the loss of gardens, animals, and property. In February of 2023, Mount Karangetang's volcanic activity increased once more. This project seeks to aid the local Regional Disaster Management Agency in implementing preventative measures or evacuating residents; an early warning system for Mount Karangetang's eruption will be created. Temperature and seismicity information will be collected through sensors deployed throughout the facility. In the meantime, the distance data is measured based on the real size of the residential location, and the height of the heated clouds is received from the observation post. The current study focuses on the development of a fuzzy logic model with four input variables and a single output variable with three levels: alert, alarm, and alert. Depending on the status of the alert, the system can also emit repeated sirens for a specified length. In this study, 81 rules are utilized to determine the status of a warning.

1 Introduction

Based on data from The Center for Volcanology and Geological Disaster Mitigation in Indonesia (PVMBG) estimates that there are 127 active volcanoes in Indonesia, however the organization only monitors 69 of them for 24 hours. The monitoring was done because the mountain has historical record of eruptions dating back to the year 1600 [1]. Mount Karangetang, located in Sitaro Regency, North Sulawesi, is a particularly active volcano due to the fact that its rest phase only lasts for two to three months, and then its eruptive activity will begin to increase. Since 1672, there have been 62 ordinary eruptions to explosive eruptions, which have resulted in number of casualties and material losses [1]. The latest eruption activity of Mount Karangetang's was documented on February 8th, 2023. Because the level of mountain activity has reached level III (Alert), on March 14, 2023 the Head of the Karangetang Volcano Observation Post, Yudia P. Tatipang, warned the the public and tourists not to approach, undertake activities, or climb within a radius of 1.5 km [2][3].

East Siau District is an area categorized by the SITARO Regional Disaster Management Agency (BPBD) as prone to volcanic eruption because it is located under the foot of the mountain. According to a report by the National Disaster Mitigation Agency, in 2015, the volcanic activity of Mount Karangetang caused as many as 465 people to be forced to find new homes, and four homes in Bebali Village were destroyed [4].

In earlier research, employing sensors (TGS2602), (DHT11), and (TGS2602), a successful early warning system was constructed to monitor the activities of Mount Kelud (MPU6050). These sensors collect data regarding seismicity, the concentrations of SO2 and CO2 gas, and the rise in air temperature. The information will be evaluated with fuzzy logic, and the expected outcome is a warning status [5]. Ichwanda et al. also developed an early detection method that uses fuzzy logic (2020). The amount of SO2 gas and CO2 gas present, in addition to the seismic activity and temperature of the area, were the variables that were used as inputs. The technology can forecast volcanic eruptions based on four different categories, which are normal, caution, warning, and evacuate [6]. Beltran et al. (2021) have researched that the Philippines government can employ to implement early warning management of natural catastrophes such as typhoons, earthquakes, and volcanic eruptions in communities using short messaging service [7].

The purpose of this study is to provide the local government of Sitaro Regency, particularly East Siau District, with assistance in evacuating the citizens of the area if there is an increase in the volcanic activity of Mount Karangetang. This will help to reduce the amount of material damage caused by the incident. The author will determine the status of Mount Karangetang by applying the fuzzy logic method. There are four variables used as input: the distance from the residential area, the height of the hot clouds, the temperature around the place, and the intensity of the seismicity. The output is volcano’s warning status. The warning management for residents is done using

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sirens, and each siren has three different time periods. The status can be determined based on the duration of siren.

This article is divided into five sections. In the first section, will be discusses the background of the research and its goal. In the related work section will discuss the current research topic with another previous research. In section 3, will be a description of the methodology of the research. The results, as well as the discussions from section 4, are presented in section 5, which also contains the conclusion to this work.

2 Related Works

Studies have been done on several fuzzy logic-based systems in the past. Yuwono (2019), using fuzzy logic developed decision support system to identify the status of flood disasters [8]. The study determines the flood status based on the water level and the amount of rain. IoT will be used to broadcast the status to the general audience. Simon also did some research on early warning systems for a different subject (2020). The research hopes to assist the government in providing the people with the information they need to promptly avoid the radius affected by the volcanic explosion. The Arduino microcontroller was used in the development of the system, and the data processing results will be transmitted through the ThingSpeak web server before being distributed through the smartphones of each individual user [9]. A volcano early warning system utilizing Internet of Things also investigated by Amaliya et al. (2018). The goal of the project is to develop an Internet-of-things-based system that is capable of monitoring volcanic activity. The rise in magma activity is measured using the parameters of temperature and humidity that change because of the increase. At the same time, the concentrations of CO2 and SO2 in the surrounding atmosphere are utilized to determine how deep the magma conduit goes. The DHT11 sensor, TGS2602 sensor, MGS811 sensor, and ADXL345 sensor are the ones that are utilized for the purpose of supporting data collecting. An Arduino microcontroller is used to process each piece of data that is acquired [10]. An earthquake early warning system based on fuzzy logic and the IoT was proposed by Trisnadinata (2019). The results of this study are intended to serve as a warning to the public on the impending arrival of an earthquake. Horizontal and vertical wave vibrations provide the basis for the measurements used in quake detection [11]. The Internet of Things (IoT) is used by the system so that it can automatically and continually read data. Ripepe et al. (2018) were successful in developing an early warning system that uses infrasound. The system was put through a total of one thousand experiments before it could validate and categorize the status of an earthquake with an average speed of 10-15 seconds. After a volcanic eruption, the end goal of this research is to develop a method that requires less involvement from humans in the process of reducing the effects of natural disasters. The possibility of a volcanic eruption can be communicated to the government through infrasound technology. This infrasound can travel up to 500 kilometers [12].

3 Methodology

Figure 1 is a block layout of an early warning system for the eruption of Mount Karangetang. Sensors collect soil temperature and vibration data, which is then transferred to a microcontroller. While the data on the resident's distance from the place is calculated based on the actual distance, the data on the height of the heat cloud is derived from the monitoring station. The fuzzy logic model is utilized to process all the collected data, and the output presented on the monitor screen includes the state of the eruption and the attached siren's sound. However, current research focuses on the development of a fuzzy logic model as a tool for determining the volcano's alert status.

![Figure 1. Block Diagram](https://example.com/block-diagram.png)

Table 1. Input and Output Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fuzzy sets</th>
<th>Universal set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (In kilometer)</td>
<td>Near [0-40]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Far away [30-70]</td>
<td></td>
</tr>
<tr>
<td>Hot clouds (In meter)</td>
<td>Low [0-2800]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Middle [2500-3500]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>High [3300-4000]</td>
<td></td>
</tr>
<tr>
<td>Temperature (In Celsius)</td>
<td>Normal [0-38]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hot [35-60]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hottest [50-75]</td>
<td></td>
</tr>
<tr>
<td>Seismicity (Richter scale)</td>
<td>Light [0-4.5]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strong [4.0-6.0]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Major [5.5-8.0]</td>
<td></td>
</tr>
<tr>
<td>Warning Status (According to</td>
<td>Caution (Waspadal)</td>
<td></td>
</tr>
<tr>
<td>Indonesian Government)</td>
<td>Warning [30-60]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evacuate (Awas)</td>
<td>[60-85]</td>
</tr>
</tbody>
</table>

- **Membership function**

All input variables employ the trapezium and triangle membership functions, but the output variable employs the triangle membership function. Trapezium membership function has clarity of fuzzy set and has two most likely values. Meanwhile triangle membership function, which
has only one most likely value, is appropriate for use in the output variable [13]. In equations 1 through 6, the formula for expressing an example of the input variable distance membership function and the output variable warning status membership function can be found.

\[
\mu_{\text{Near}}(x) = \begin{cases} 
1 & x \leq 20 \\
\frac{1}{2} - \frac{x - 20}{40 - 20} & 20 \leq x \leq 40 \\
0 & x \geq 40 
\end{cases}
\] (1)

\[
\mu_{\text{Far}}(x) = \begin{cases} 
30 & x \leq 0 \\
\frac{1}{2} \left( \frac{30 - x}{30/50 - 30} \right) & 0 \leq x \leq 70 \\
\frac{1}{2} \left( \frac{70 - x}{70/50 - 70} \right) & x \geq 70 
\end{cases}
\] (2)

\[
\mu_{\text{Far away}}(x) = \begin{cases} 
0 & x \leq 60/90 - 60 \\
\frac{1}{2} & 60 \leq x \leq 80 \\
1 & x \geq 80 
\end{cases}
\] (3)

Fig. 3. Membership Function Output Variable: Warning Status

- Inference rules

A total of 81 rules, obtained based on four input variables and one output variable. In this inference rule section, there are two stages, namely Implication & Aggregation which is a process for calculating the \(IF\) part and Composition for calculating the \(THEN\) part. This research employs the And (min) operator implication to demonstrate how Mamdani inference operates. These data are utilized to examine problem-solving. The distance is 30 kilometers, the height of the heated clouds is 2700 meters, the temperature is 55 degrees Celsius, and the seismicity is 4.5 on the Richter scale. The following findings are derived from the results of the implication function using the eight generated rules but only two rules are fitted as rule aggregation.

\[
[R14] \text{If the distance is near and the height of the hot cloud is middle and the temperature is hot and the seismicity is strong, then warning status is caution} \\
\alpha_3 = \min(\mu_{\text{Near}} \cup \mu_{\text{Middle}} \cup \mu_{\text{Hot}} \cup \mu_{\text{Strong}}) = \min(0.5, 0.4, 0.4, 0.6) = 0.4
\]

\[
[R17] \text{If the distance is near and the height of the hot cloud is middle and the temperature is hottest and the seismicity is strong, then warning status is Warning} \\
\alpha_4 = \min(\mu_{\text{Near}} \cup \mu_{\text{Middle}} \cup \mu_{\text{Hottest}} \cup \mu_{\text{Strong}}) = \min(0.5, 0.4, 0.2, 0.6) = 0.2
\]

From the results of the implication function above, the max method is used to perform rule composition.

\[
\alpha_3 = 0.4 \text{ (Caution)} \\
0.4 = \frac{x - 30}{45 - 30} x = \frac{2.4 - x}{15} = 2.4(15) = 36 \text{ or}
\]

\[
\alpha_4 = 0.2 \text{ (Warning)} \\
0.2 = \frac{x - 60}{72.5 - 60} x = \frac{1}{12.5} x = \frac{1}{5} + \frac{24}{5} x = 5(12.5) = 62.5 \text{ or}
\]

Defuzzification is the final step to convert fuzzy set results from inference rules to real numbers. The results of this defuzzification will be used to determine control of the fuzzy logic. The defuzzification method utilized in this study is the centroid of the area (COA). This method will find the center of the composition rules from inference rules. Equation 7 is the rule composition formula for the defuzzification procedure.

\[
\mu_{\text{5f}}(x) = \begin{cases} 
0 & x \leq 0 \text{ or } x \geq 85 \\
\frac{x - 30/45}{30} & 30 \leq x \leq 36 \\
\frac{1}{2} & 36 \leq x \leq 54 \\
\frac{1}{2} \left( \frac{60 - x}{60/60 - 60} \right) & 54 \leq x \leq 60 \\
\frac{1}{2} \left( \frac{60}{60/72.5 - 60} \right) & 60 \leq x \leq 62.5 \\
\frac{1}{2} \left( \frac{85 - x/85 - 80}{85/85 - 72.5} \right) & 82.5 \leq x \leq 85
\end{cases}
\] (7)

The results of calculating the sum of all areas (\(A_i\)) of the membership function with COA (\(X_i\)) can be seen in table 2. Meanwhile, the defuzzification results from COA are shown in Figure 4.
Table 2. The Calculation of $A_i \times X_i$

<table>
<thead>
<tr>
<th>$A_i$</th>
<th>$X_i$</th>
<th>$A_i \times X_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>34</td>
<td>40.8</td>
</tr>
<tr>
<td>7.2</td>
<td>45</td>
<td>324</td>
</tr>
<tr>
<td>1.2</td>
<td>56</td>
<td>67.2</td>
</tr>
<tr>
<td>0.25</td>
<td>61.66</td>
<td>15.415</td>
</tr>
<tr>
<td>4</td>
<td>72.5</td>
<td>290</td>
</tr>
<tr>
<td>0.25</td>
<td>83.33</td>
<td>20.83</td>
</tr>
</tbody>
</table>

\[
X' = \frac{(A_1 \times X_1) + (A_2 \times X_2) + \cdots + (A_6 \times X_6)}{(A_1 + A_2 + \cdots + A_6)} = \frac{758.25}{14.1} = 53.77
\]

Fig. 4. Defuzzification using COA

The number 53.77 indicates that the status of a warning is warning (Siaga)

4 Result and Discussion

This section examines the decision-making for the eruption status of Mount Karangetang using 33 training data. The training data was obtained from PVMBG from 1990 - 2023. Meanwhile, two test data sets were used based on factual data from January - February 2023. Each test data consisted of 10 data. Training data and test data are processed using the Matlab 2020 program. Figure 5 shows the steps for using the application.

Main page user interface the Mount Karangetang Early Warning System can be seen in Figure 6.
The authors perform human calculations using the same data to validate the system output results. The results are the same between manual calculations and system output, namely warning status (siaga). Figure 7 illustrates the output system.

When the status is a caution (Waspada), the siren will activate along with the warning status and repeat every minute. When the status is a warning (Siaga), the siren will repeat every 45 seconds, when it is evacuated (Awas), it will repeat every 30 seconds. The emergency siren will sound for a total of two minutes.

The system will display an error notice if it gets data that does not fulfill the requirements, as shown in Figure 8. An evaluation of system accuracy is used to determine the built model’s performance measure. The accuracy of the Mount Karangetang Early Warning System Using Inference Logic is calculated based on two datasets. First, dataset 1 used 10 testing data, obtained an accuracy of 100%. This result is obtained from the calculation (True data/total dataset 1) * 100 = 10/10 * 100 = 100%. Dataset 2 also used 10 data, obtained an accuracy of 80%. There are two errors because the input used is a fraction number. It can be concluded that the average accuracy of the system is (100 + 80)/2 = 90%

5 Conclusion

This article presents the development of an early warning system for Mount Karangetang that makes use of fuzzy logic. A report on the current level of danger posed by Mount Karangetang could be generated by the system. The sound of the siren could be interpreted by the municipal authority as a signal to take preventative action or to evacuate the residents. It is required to add certain sensors to this early detection system so that data may be acquired in real-time to advance the study that is being done on it.

References


8. M. Wafid, *Increased Activity Level of Mt. Karangetang from Warning Level to Evacuate Level (Peningkatan tingkat aktivitas G. Karangetang dari Level II (WASPADA) ke Level III (SIAGA))*, Magma Indonesia Jakarta, (2023)


