Mamdani Fuzzy Inference System using Three Parameters for Flood Disaster Forecasting in Bandung region

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Abstract. This study aims to investigate the flood events forecast by applying the Mamdani fuzzy inference system and rule-based reasoning. For input and output linguistic variable of the model based on three parameters such as population density, altitude, as well the rainfall. Each variable has three to four membership functions. The data used come from the Statistic Bureau of Indonesia, National Disaster Management Authority, and Meteorology and Climatology Center of Indonesia for 2014 to present. A different model for each region was constructed depending on available data sets. We determine based our model on forty-eight fuzzy IF-THEN rules and fuzzy reasoning. The output variable which has three membership function takes from 220 to 402 as representative flooding level warning such as normal, alert, and danger. The results of the study have high agreements with recorded data in on site with increases the output values toward the real-time flood event. Therefore, if that area will be used for living, this will have risks that flood always is a threat to those areas.

1. Introduction
The flood is the most frequent disaster in Indonesia. At least there are 8,498 flood events in period 1980-2017 and overall was happened in Java Island. Which Java is the island with the largest population, it means that if a flood happens in Java will cause many disadvantages, people lose their homes, lost their crops, missed school education, even through they lost their life [1].

Disaster management officials in Indonesia report that one person has died and thousands of homes were damaged by flash floods in the city of Bandung. National Disaster Management Authority knows as BNPB informed that 77 mm of rain fell in the town in just 1,5 hours around midday[2][3]. Areas of the city were inundated with flood water between 120 cm and 200 cm deep in parts [2][3]. In the same month, a part of Gorontalo, Indonesia also occurred flood, at least 1,500 homes damaged, and around 4,500 people were forced to evacuate their homes [3][4]. In December 2016, part of West Nusa Tenggara Province, Indonesia, were hit by two floods in the space of days, forcing over 100,000 people from their homes. BNPB informed that thousands of homes were damaged and streets were left under flood water from 1 meter to 3 meters deep. In 26th January 2017 flood was occurred in North Sulawesi, Indonesia [3][5].

This flood affected 11 villages in Gorontalo Utara forcing more than 100 people to evacuate and damaging over 700 homes, some schools and agricultural land [3][6]. In 3rd March 2017, at least six
people have been killed, two seriously injured and thousands displaced due to floods in Indonesia’s West Sumatra Province. The flood also caused power and communications outages, and over one hundred electrical sub-stations were shut down. It means that this province almost 15,000 homes were left without electricity [3] [7].

The theory of Fuzzy Logic [8,9] was first raised by the mathematician Lotfi A. Zadeh in 1965. This theory is a result of the insufficiency of Boolean Algebra to many problems of the real world. As most of the information, in reality, is imprecise, and one of the humans’ greatest abilities is to process imprecise efficiently and “fuzzy” information. The Oxford English Dictionary determined the word Fuzzy be defined as blurred, indistinct, imprecisely defined, confused or vague. Fuzzy systems are knowledge-based or rule-based systems. The heart of a fuzzy system is a knowledge base consisting of the so-called fuzzy IF-THEN rules. A fuzzy IF-THEN rule is an IF-THEN statement [10] in which continuous membership functions characterize some words.

2. Method
The data used in building our model comes from the Statistic Bureau of Indonesia, National Disaster Management Authority, and Meteorology and Climatology Center of Indonesia for 2014 to present. First, we separate the input variables with their corresponding present flood data, then separated set of data for the training process. After building the model, we selected the flood event causes to study the vulnerability of the models as seen in Figure 1.

2.1 Data Sets
The population density, large area, and rainfall in this study were obtained from three regions in West Java province randomly selected for example Bojongloa Kaler, Gedebage, and Cibiru. Data gathered from those regions were used to develop the fuzzy model, and the result is validating the model flood vulnerability event as shown in Table 1.
Table 1. Data sets of Mamdani fuzzy.

| District of West Java Province | Input Variables |
|-------------------------------|-----------------|
| Bojongloa Kaler               | Population Density | Altitude Area | Rainfall |
|                               | 39817            | 694           | 198.8    |
| Gedebage                      | 3732             | 666           | 198.8    |
| Cibiru                         | 11086            | 706           | 198.8    |

2.2 Fuzzy Sets and Membership Function

For each input and output variables, a fuzzy set is conducted by dividing its universe of discourse into some sub-regions and named as a linguistic variable. A linguistic variable is a variable whose values expressed in words or sentences in a natural language, and membership function (MF) suitable to defined the linguistic variable.

MF is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. In this study, three input such as population density, large area, and rainfall were used to determine the flood events. The output variables split into three linguistic variables named as normal, alert, and danger. The form of MFs model based on trapezoidal.

2.3 Population Density

The condition of this variable based on the population density in some area consists of four types: no population, low population, high population, and overpopulation. Figure 2 shows the trapezoidal membership function of the population density of West Java province.

Where;
NP = No Population; LP = Low Population; HP = High Population; OP = Over Population

2.4 Altitude Area

The condition of this variable based on the altitude in some area consists of three types: low, moderate, and high altitude. In Figure 3 shows the trapezoidal membership function of altitude area in West Java province.
2.5 Rainfall

The condition of this variable based on the rainfall in some area consists of four types: low, moderate, high, and extremely of rainfall. In Figure 4 shows the trapezoidal membership function of rainfall in West Java province.

![Figure 4. The trapezoidal membership function of rainfall.](image)

Where; L = Low, M = Moderate, and H = High

The result of the flood vulnerability consists of three states: normal, alert, or danger as seen in Figure 5.

![Figure 5. The trapezoidal membership function of flood vulnerability.](image)

The decision making of flood vulnerability in Mandani Fuzzy employ five methods namely Centroid, Large of Maximum (LOM), Mean of Maximum (MOM), Smallest of Maximum (SOM), and Bisector. In Figure 6 shows the details of the rules editor for each of the input and output variables.
3. Results and Discussion

3.1 Centroid Method

Table 2 shows the result of Mamdani Fuzzy forecasting uses the Centroid method for three districts in West Java Province. Through in the table, the state of all districts is a danger.

| District of West Java Province | Population Density | Altitude | Rainfall | Flood vulnerability | State |
|--------------------------------|--------------------|----------|----------|---------------------|-------|
| Bojongloa Kaler                | 39817              | 694      | 198.8    | 394                 | Danger|
| Gedebage                       | 3732               | 666      | 198.8    | 393                 | Danger|
| Cibiru                         | 11086              | 706      | 198.8    | 394                 | Danger|

3.2 Mean of Maximum Method (MOM)

The result of Mamdani Fuzzy forecasting uses MOM method for three districts in West Java Province can be seen in Table 3. Through in table, the state of all districts is danger which placed the mean of the flood vulnerability value for danger state according to the membership function.

| District of West Java Province | Population of Density | Altitude Area | Rainfall | Flood vulnerability | State |
|--------------------------------|-----------------------|---------------|----------|---------------------|-------|
| Bojongloa Kaler                | 39817                 | 694           | 198.8    | 402                 | Danger|
| Gedebage                       | 3732                  | 666           | 198.8    | 398                 | Danger|
| Cibiru                         | 11086                 | 706           | 198.8    | 402                 | Danger|
3.3 Analysis of Mamdani Fuzzy Forecasting

The analysis of Mamdani fuzzy result takes one district namely Bojongloa Kaler which has population density 39,817 people/km², the altitude area 694 amsl. This district also has rainfall intensity in wet season 198.8 mm. How to assess the flood vulnerability in Bojongloa Kaler district?

3.3.1 The first step: determine a fuzzy set

The Population density variables defined in four fuzzy sets namely very low, low, high, and very high. The membership degree for population density shown in the equations (1), (2), (3), and (4). So that obtained membership degrees for population density 39,817 people/km² that are \( \mu_{PDP}\) = 0 , \( \mu_{LDP}\) = 0 , \( \mu_{HDP}\) = 0.0367 , \( \mu_{VDP}\) = 0.963 . Which mean that the population density in this district is high population with membership degree of 3.67% and over population with membership degree of 96.3%.

The altitude area variables defined in three fuzzy sets namely low, middle, and high. The membership degree for the altitude of the area in equations (5), (6), and (7). So that obtained membership degree for the altitude area variable 694 amsl are \( \mu_{L}\) = 0 , \( \mu_{M}\) = 0.069 , \( \mu_{H}\) = 0.96. Which mean that the altitude area is middle altitude area with a membership degree of 6.9% and high-altitude area with membership degree of 96.6%.

The rainfall variables defined in four fuzzy sets namely light, moderate, heavy, and very heavy. The membership degree for rainfall described in equations (8), (9), (10), and (11). So that obtained level of membership degree for rainfall variable 198.8 mm that are \( \mu_{FL}\) = 0 , \( \mu_{FM}\) = 0 , \( \mu_{FH}\) = 0.06 , \( \mu_{VHF}\) = 0.94. Which mean that the rainfall in this area is heavy with membership degree of 6% and very heavy rain with membership degree of 94%.

3.3.2 The second steps: Rule evaluation

The implication function used is this algorithm which MIN function, that is by taking the minimum membership degree of the input variables as the output variable. So, obtained rules as follows:

- [R1] if Population Density is HP and AltitudeArea is M and Rainfall is H so that Vulnerability Flood is Danger

\[ \alpha - \text{predictate}_1 = \mu_{HP} \cap \mu_{M} \cap \mu_{H} = \min(\mu_{HP}(39817), \mu_{M}(694), \mu_{H}(198.8)) = \min(0.0367; 0.069; 0.06) = 0.0367 \]

- [R2] if Population Density is HP and AltitudeArea is M and Rainfall is EX so that Vulnerability Flood is Danger

\[ \alpha - \text{predictate}_2 = \mu_{HP} \cap \mu_{M} \cap \mu_{EX} = \min(\mu_{HP}(39817), \mu_{M}(694), \mu_{EX}(198.8)) = \min(0.0367; 0.069; 0.94) = 0.0367 \]

3.3.3 The third steps: Aggregations of the rule output

The aggregations of the rules output are the overall of conclusion by taking maximum membership degree of each consequences implications function and aggregating of all the end of each rule, so that fuzzy solution area obtained as follows:

\[ \mu_{yp}(y) = \max(\mu_{yp}(y)) = \max(0.0367; 0.06; 0.069; 0.94) = 0.94 \]

Rule of intersection node is if \( \mu_{yp} = 0.94 \), therefore the value of \( y \) can be determined as follow:
\[
\begin{align*}
\frac{x - 374}{28} &= 0.94 \\
(x - 374) &= 28(0.94) \\
x &= 374 + 28(0.94) = 400.32
\end{align*}
\]

Thereby obtained the area solution of membership function as follow:

\[
\mu_{VF} = \{0.94; 400.32 \leq x \leq 402\}
\]

3.3.4 The fourth steps: defuzzification

Defuzzification is the converting process of the fuzzy set to become a crisp set. The inputs of the defuzzification process are fuzzy sets, while the output is the number of those fuzzy domain set. The defuzzification used in determining the flood vulnerabilities is centroid, MOM, LOM, SOM, and Bisector.

a. Centroid

\[
X = \frac{\int_{400.32}^{402} x dx}{\int_{400.32}^{402} dx} = \frac{\frac{1}{2} x^2|_{400.32}^{402} - \frac{1}{2} x^2|_{0}^{400.32}}{402 - 400.32} = \frac{673.95}{1.68} = 401.16
\]

The value of the flood vulnerability is 311 and represent the danger category.

b. LOM Method

Take the greatest \(z\) value of the maximum membership degree value (\(\mu(z)\)). The membership degree can be seen in the Table 4.

| Rule | \(\mu(z)\) | \(Z\) |
|------|----------|------|
| 1    | 0.94     | 400.32 |
| 2    | 0.94     | 402   |

From Table 4 that obtained the value of LOM is 402. Hence, according to calculation, the flood vulnerability in Bojongloa district is a danger category (Figure 7).
According to the result of Mamdani Fuzzy forecasting in Matlab and analysis employ mathematic equation shown the same state of flood vulnerability is a danger shown in figure 7. Nevertheless, it has little difference in value between Mamdani fuzzy forecasting in Matlab and mathematical calculations to the equation for all method in Mamdani Fuzzy with a percentage of no more than 2.03% of different. [12]

Similarity research was conducted by [13] introduced the model to predict streamflow an hour after flood event occurred. They also compared the result using fuzzy exemplar-based inference system with backpropagation neural network to show that fuzzy model performs better than the neural network. A method based on fuzzy arithmetic to estimate the possible range of flow rates and water level based on possible rainfall events by forcing and uncertainty model [12].

In this research developing a system that can predict such regions which depending on several variables causes flood events so that more precisely.

4. Conclusion
The result of this research is the fuzzy inference system apply Mamdani algorithm in Matlab has been successful for forecasting the flood to inform the state in a region in West Java Province and present high accuracy to decided the forecasting state in a region.

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