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Prediction of Monthly Rainfall using Fuzzy Logic Tsukamoto in Medan Belawan

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Abstract

Rainfall prediction plays an important role in understanding the pattern of rainfall movement for daily life. This research aims to predict monthly rainfall in Medan Belawan using the Tsukamoto fuzzy logic method. Tsukamoto fuzzy logic is used to predict monthly rainfall in Medan Belawan. This method uses several steps, starting from data input, fuzzification, inference, to defuzzification to help predict rainfall. This research aims to apply Tsukamoto fuzzy logic to monthly rainfall prediction. Fuzzy logic has tolerance for imprecise data. This rainfall prediction uses 4 (four) input variables, namely air temperature, air humidity, air pressure and wind speed, and 1 (one) output variable, namely rainfall as a crips value which is the output generated for rainfall prediction. The data used is 12 monthly data from January 2023 to December 2023. The results show the accuracy of the fuzzy method of 57.75% using the MAPE calculation and show that the calculation of the Tsukamoto fuzzy method is sufficient or feasible to do.

Keywords: Prediction, Rainfall, Fuzzy Tsukamoto, Fuzzy Logic

1. Introduction

Prediction according to Jay Heizer et al is a combination of art and science that estimates future events or conditions using mathematical models or subjective estimates with past data (Ariani, 2022). According to Mukhlisin et, all in (Riza & Paputungan, 2022) prediction is also the result of projecting values into the future based on information from the past. This prediction helps in planning and decision making by predicting what will happen in a particular situation. Dependent on what you want to forecast, there are several information sources that can be used to make predictions.

Rain is water that falls to earth because water or air points in clouds exceed their capacity. Rainfall is the amount of rainwater that collects in a flat place, does not evaporate, does not seep, and does not flow (Prasetyo et al., 2018). According to the Central Bureau of Statistics, 1 (one) millimeter of rainfall means that in an area of one square meter on a flat place one millimeter of water or one liter of water is collected within a certain period of time. Rainfall in Indonesia is categorized into several categories such as light rain, medium rain, heavy rain and very heavy rain.

When the transitional season ends, the Medan area will experience a transition from the rainy season to the dry season, with unstable weather conditions most of the time. Unstable weather conditions can lead to extreme weather that commonly occurs, namely: Strong winds, high temperatures with short periods, and low-intensity rainfall that can cause global warming and drought. The increase in global temperature will affect the world's climate, changing the distribution of rain, wind direction and speed.

Global Warming is a term used to describe observed climate changes that are also caused by human activities, especially human activities that contribute to environmental degradation such as building underwater structures in coastal areas, indiscriminate disposal of factory waste and other activities. Global warming causes the Earth's surface temperature to rise and affects the climate and weather (ddhis et al., 2021). Global warming and climate change are currently making the temperature in North Sumatra increase, so it rarely rains around the coastal areas, especially in Medan Belawan.

In studying the phenomenon of rainfall, it can also be related to various sciences, one of which is fuzzy logic. Asklany, et al say fuzzy logic is a system built with clear definitions, workings and descriptions. Fuzzy logic methods can be used for weather prediction because fuzzy logic can solve problems that contain uncertainty, vagueness, and imprecision (Mahanani et al., 2015).

In fuzzy logic, there are three methods: Mamdani method, Tsukamoto method, and Sugeno method. In this research, the author uses the Tsukamoto method. The advantage of the Tsukamoto method is that it is intuitive and can work with qualitative, inaccurate, and ambiguous information (Widiyantoro et al., 2024). Based on this, the Tsukamoto method applies monotonous reasoning to each of its rules. The Tsukamoto method is logical and can provide results, even when working with incomplete, impossible to understand, or unclear data (Yulianto et al., 2023).

Previous research conducted by (Muhandhis et al., 2021) by implementing the Tsukamoto fuzzy inference method to predict dasarian rainfall in Sumenep. It can be concluded that forecasting with Tsukamoto fuzzy can predict the beginning of the dry season, namely in Dasarian 3 in April 2020. The prediction of the beginning of the rainy season is Dasarian 2 in November 2020. With the results of rainfall forecasting with the Tsukamoto fuzzy inference method has good accuracy with a MAPE value of 10.64%. The differences between the two studies are that in previous studies the variables used were only rainfall and the variables were displayed with time series data from 2016-2019 with forecasting for 2020. This research developed a rainfall prediction model using Tsukamoto fuzzy logic with five different variables from previous research, where in this study the variables used were air temperature, air humidity, air pressure, wind speed and rainfall.

Researchers conduct prediction activities with various methods until they find the best approach. Fuzzy logic is one of the options whose methods can be used in predicting future events using one of its methods, namely the Tsukamoto method. Therefore, the use of Tsukamoto method fuzzy logic was chosen with the purpose of assisting in forecasting rainfall (Sholihah, 2022). This research aims to find out how the application of Tsukamoto fuzzy logic to the parameters of humidity, temperature, air pressure, and wind speed that occurred at the previous time in 2023 to estimate monthly rainfall in Medan Belawan.

2. Methods

The type of research used is applied research, the purpose of this research is to apply, test, and evaluate the capacity of a theory to solve actual problem. The approach used in this research is quantitative approach is a research methodology that ismeasured by numbers, from the data collection process to the process of analyzing and interpreting the results of the research. This research was conducted at the Maritime Meteorology Climatology and Geophysics Agency (BMKG) Belawan which is located on Jl. Raya Pelabuhan III, Bagan Deli, North Sumatra Province 20414. This research was conducted from July to completion.

2.1. Fuzzy logic

According to Jumaidi & Santika in (Rohman et al., 2024) Fuzzy Logic is one of the branches of Artificial Intelligence. The concept of Fuzzy Logic is a modification of set theory, where each member has a degree of membership that is continuous and can be valued between 0 and 1. Since the discovery of Fuzzy Logic by Lotfi A. Zadeh in 1965, Fuzzy Logic has been applied in various problems. Zadeh in 1965, Fuzzy Logic has been applied in various problems, including process control, classification and pattern matching, management and decision making, operational research, economics, and other fields. Since 1985, there has been rapid progress in the development of Fuzzy Logic, especially in the context of situations that are non-linear, not clearly defined, changing over time, and in very complex situations.

2.2. Fuzzy Tsukamoto

The Tsukamoto Fuzzy Method is one part of the Fuzzy Inference System which is used to draw a conclusion or help process vague data into certainty. To get the output, four steps are required (Citra et al., 2022).

1. Fuzzy Set Formation
   A fuzzy set is an array of values. Each value has a membership between 0 and 1, a value of 0 means not a member of the set, while a value greater than 0 is a member of the set.
2. Fuzzyfication
   In the Tsukamoto method Fuzzyfication is the process of converting non-fuzzy variables into fuzzy variables. The input value at this stage is entered into function that has been formed so as to produce a fuzzy input value. In this fuzzyfication process, a membership function using a shoulder curve as an input variable is used (Sholihah, 2022).
3. Fuzzy Inference
   The inference process is the process of making rules that will be used in the fuzzy system. Usually these rules will be denoted "IF-THEN" and the operator used between the input variables uses the 'and' operator, so the fuzzy rules used are as follows:
   $$IF\ x\ is\ A\ and\ y\ is\ B\ THEN\ z\ is\ C$$
4. Defuzzification

The Tsukamoto defuzzification method converts the fuzzy set into crisp numbers with the into crisp number with the weighted average calculation method (Weighted Avarage) with the following equation form:

$$Z = \frac{\sum \alpha i.zi}{\sum \alpha i} = 1,2,3, \ldots$$

Where:

Z = defuzzification value (output)

αi = predicate alpha at rule i

zi = inference output value at rule i

2.3. Forecasting Accuracy Measures

If you want to determine the accuracy of a model, you can use MSE and MAPE.

1. MSE (*Mean Square Error*) MSE is the average of the squared difference between the predicted value and the observed value (Sholihah, 2022). Mean Squared Error, is a metric used to assess the accuracy of a forecast. The more precise the forecasting, the smaller the MSE value should be. The following is the form of the equation:

$$MSE = \frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y}_i)^2$$

Where:

MSE = Mean Squared Error

n = amount of data

y = actual value

$\hat{y}$ = predicted value

2. MAPE (*Mean Absolute Percent Error*)

Mean Absolute Percent Error or abbreviated (MAPE) is a method used to calculate the average percentage absolute error in a forecasting measurement (Fuadi, 2023). The resulting error is how the difference between the predicted result and the value to be predicted. The form of the equation is as follows:

$$MAPE = \frac{1}{n} \sum_{i=1}^{n} \frac{(|yi - \hat{y}i|)}{y(i)} \times 100\%$$

Description:

MAPE = average percent absolute error

n = amount of data

yi = actual value of the index

$\hat{y}i$ = predicted value of the index

In MAPE there is a range of values that can be used as a reference in measurement. The MAPE value ranges are:

a. <10% The prediction model is categorized as very good
b. 10-20% The prediction model is categorized as good
c. 20-50% The prediction model is categorized as decent / sufficient
d. >50% The prediction model is categorized as bad

3. Result and Discussion

In this study, the variables used by researchers are input and output variables. The input variables consist of: temperature air temperature, humidity, air pressure and wind speed. And the output variable is rainfall. The data used in this study were 12 months starting from January 2023 to December 2023. The following data obtained can be seen in the table 1.

Table 1. Research Variables

Month (years)	Suhu Udara	Kelembaban Udara	Tekanan Udara	Kecepatan Angin	Curah Hujan
January	27.1	80	1010,4	4,1	5
Februari (2023)	27.7	78	1010,2	3,9	2
Maret (2023)	27.8	79	1010,5	4	8
April (2023)	28.8	77	1009,3	3,8	1,2
Mei (2023)	29.1	77	1009,7	4,2	3,8
Juni (2023)	28.9	79	1009,3	4,2	4,9
Juli (2023)	28.8	79	1009,7	4,3	4,3
Agustus (2023)	28.2	81	1010,6	4,4	7,6
September (2023)	28.3	80	1010	4	4,7
Oktober (2023)	28.1	81	1011,6	3,4	5,2
November (2023)	27.9	82	1010,5	3,7	9,3
Desember (2023)	27.7	84	1010,6	3,6	12

3.1. Fuzzyfikasi

The first stage carried out in this research is fuzzification. The purpose of this fuzzification is to convert explicit input data into fuzzy. In this study, air temperature, air humidity, air pressure, and wind speed are used as input variables while rainfall is the output variable to form a fuzzy set. The universe of speech obtained from each variable is determined by finding the lowest and highest values derived from the input and output variables. Can be seen in table 2 below:

Table 2. Conversation Universe for Each Fuzzy Variable

Function	Variable	Semesta Pembicaraan

input	Suhu Udara	27,1 – 29,
	Kelembapan Udara	77 – 84
Input	Tekanan Udara	1009,3 – 1011,6
	Kecepatan Angin	3,4 – 4,4
Output	Curah Hujan	1,2 – 12

Each fuzzy set has a domain whose values are contained in the universe of speech. The domain is obtained from the lowest data in the lower quartile (Q1), medium (Q2), and upper quartile (Q3), as well as the highest data in the input variable. Before looking for quartile values, first sort each variable data from lowest to highest. After sorting, continue by calculating the quartile value of each variable to get the domain contained in the universe of discussion (Fuadi, 2023).
Find the quartile values (Q1, Q2, and Q3) for the air temperature variable as follows:
To find the lower quartile value for the air temperature variable as follows:

$$Q_1 = \frac{x\left(\frac{12}{4}\right) + x\left(\frac{12}{4}+1\right)}{2}$$

$$\leftrightarrow Q_1 = \frac{x3 + x4}{2}$$

$$\leftrightarrow Q_1 = \frac{27,7 + 27,8}{2}$$

$$\leftrightarrow Q_1 = 27,8$$

Then, to find the middle quartile formula used in the study as follows:

$$Q_2 = \frac{x\left(\frac{12}{2}\right) + x\left(\frac{12}{2}+1\right)}{2}$$

$$\leftrightarrow Q_2 = \frac{x6 + x7}{2}$$

$$\leftrightarrow Q_2 = \frac{28,1 + 28,2}{2}$$

$$\leftrightarrow Q_2 = 28,2$$

Then to find the upper quartile value on the air temperature variable as follows:

$$Q_3 = \frac{x\left(\frac{3.12}{4}\right) + x\left(\frac{3.12}{4}+1\right)}{2}$$

$$\leftrightarrow Q_3 = \frac{x9 + x10}{2}$$

$$\leftrightarrow Q_3 = \frac{28,8 + 28,8}{2}$$

$$\leftrightarrow Q_3 = 28,8$$

From the results above, the quartile values for the air temperature variable are $Q1$ = 27,8; $Q2$ = 28,2 and $Q3$ = 28,8.

This can be done for the remaining variables with the same steps, then each value for Q1, Q2 and Q3 will be obtained. For the air humidity variable, Q1 = 78.5; Q2 = 79.5 and Q3 = 81. Then for the air pressure variable, the value of Q1 = 1009.7; Q2 = 1010.3 and Q3 = 1010.6. Then for the wind speed variable, the value of Q1 = 3.8; Q2 = 4 and Q3 = 4.2. Finally, for the rainfall variable, Q1 = 3.8; Q2 = 4.95 and Q3 = 7.8.

In the following table are the results of quartiles and rainfall criteria that have been calculated to be formed into the domain of each fuzzy set.

3.2. Formation of Fuzzy Set

Each variable's category level is explained via fuzzy sets. After that, a membership function is generated between this fuzzy variable that defines the domain in the fuzzy set into a degree of membership, ranging in 0 to 1 [0 1].

Function	Variable	Fuzzy set	Semesta Pembicaraan	Domain
	Suhu Udara	Dingin	27,1 – 29,1	27,1 – 28,2
		Sedang		27,8 – 28,8
		Panas		28,2 – 29,1
	Kelembapan Udara	Rendah	77 – 84	77 – 79,5
Input		Sedang		78,5 – 81
		Tinggi		79,5 – 84
	Tekanan Udara	Rendah	1009,3 – 1011,6	1009,3 – 1010,3
		Sedang		1009,7 – 1010,6
		Tinggi		1010,3 – 1011,6
	Kecepatan Angin	Lambat	3,4 – 4,4	3,4 – 4
		Cepat		3,8 – 7,8
Output	Curah Hujan	Cerah	1,2 – 12	1,2 – 4,95
		Berawan		3,8 – 7,8
		Hujan		4,95 - 12

Table 3. Fuzzy set and domain

3.2.1. The air temperature fuzzy set

The air temperature input variable has three category levels: cold, medium and hot. The next membership function for the air temperature variable can be formulated as follows:

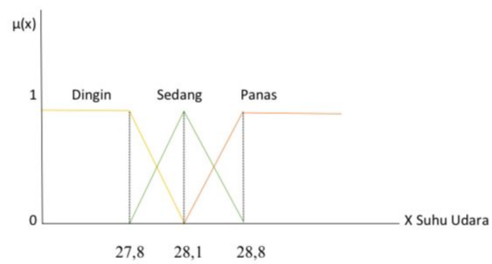

Figure 1. Graph Air Temperature

Cold temperature membership function

$$\mu dingin[x]=\begin{cases}1\ ;x\le 28,8\\ \dfrac{(x-28,2)}{(28,8-28,2)};28,2\le x\le 28,8\\ 0;x\ge 28,2\end{cases}$$

Medium temperature membership function

$$\mu sedang[x]=\begin{cases}0\ ;x\le 27,8\ atau\ x\ge 28,8\\ \dfrac{(x-27,8)}{(28,2-27,8)};27,8\le x\le 28,2\\ \dfrac{(28,8-x)}{(28,8-28,2)};28,2\le x\le 28,8\end{cases}$$

Hot temperature membership function

$$\mu panas[x]=\begin{cases}1\ ;x\ge 28,8\\ \dfrac{(x-28,2)}{(28,8-28,2)};28,2\le x\le 28,8\\ 0;x\le 28,2\end{cases}$$

3.2.2. The air humidity fuzzy set

The air humidity input variable has category levels, namely low, medium and high. The air humidity variable can then be represented using a curve graph.

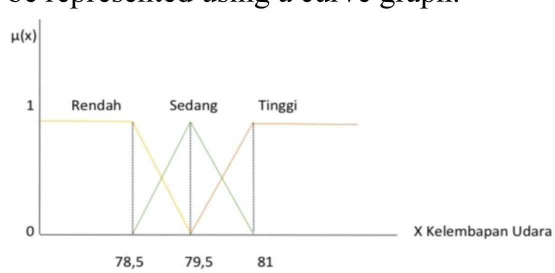

Figure 2. Graph Air Humidity

Low air humidity membership function

$$\mu rendah[x]=\begin{cases}1\ ;x\le 78,5\\ \dfrac{(79,5-x)}{(79,5-78,5)};78,5\le x\le 79,5\\ 0;x\ge 79,5\end{cases}$$

Medium air humidity membership function

$$\mu sedang[x]=\begin{cases}0\ ;x\le 78,5\ atau\ x\ge 81\\ \dfrac{(x-78,5)}{(79,5-78,5)};78,5\le x\le 79,5\\ \dfrac{(81-x)}{(81-79,5)};79,5\le x\le 81\end{cases}$$

High air humidity membership function

$$\mu tinggi[x]=\begin{cases}1\ ;x\ge 81\\ \dfrac{(x-79,5)}{(81-79,5)};79,5\le x\le 81\\ 0;x\le 79,5\end{cases}$$

3.2.3. The air pressure fuzzy set

The air pressure input variable has a category level of low, medium and high. The air pressure variable can then be represented using a curve graph.

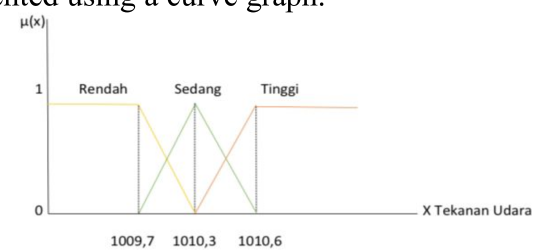

Figure 3. Graph Air Pressure

Low air pressure membership function

$$\mu rendah[x]=\begin{cases}1\ ;x\le 1009,7\\ \dfrac{(1010,3-x)}{(1010,3-1009,5)};1009,7\le x\le 1010,3\\ 0;x\ge 1010,3\end{cases}$$

Medium air pressure membership function

$$\mu sedang[x]=\begin{cases} 0 \ ; x \le 1009,7 \ atau \ x \ge 1010,6 \\ \dfrac{(x-1009,7)}{(1010,3-1009,7)} ; 1009,7 \le x \le 1010,3 \\ \dfrac{(1010,6-x)}{(1010,6-1010,3)} ; 1010,3 \le x \le 1010,6 \end{cases}$$

High air pressure membership function

$$\mu tinggi[x]=\begin{cases} 1 \ ; x \ge 1010,6 \\ \dfrac{(x-1010,3)}{(1010,6-1010,3)} ; 1010,3 \le x \le 1010,6 \\ 0 ; x \le 1010,3 \end{cases}$$

3.2.4. Fuzzy set of wind speed

The wind speed input variable has a category level of slow and fast.

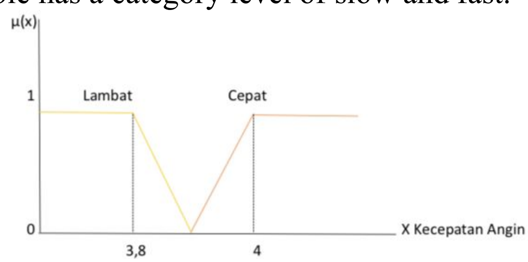

Figure 4. Graph Wind Speed

Slow wind speed variable membership function

$$\mu lambat[x]=\begin{cases} 1 \ ; x \le 3,8 \\ \dfrac{(4-x)}{(4-3,8)} ; 3,8 \le x \le 4 \\ 0 ; x \ge 4 \end{cases}$$

Fast wind speed variable membership function

$$\mu cepat[x]=\begin{cases} 0 \ ; x \le 3,8 \\ \dfrac{(x-3,8)}{(4-3,8)} ; 3,8 \le x \le 4 \\ 1 ; x \ge 4 \end{cases}$$

3.2.5. Rainfall fuzzy set

The rainfall variable has category levels of sunny (low), cloudy (medium) and rainy (high).

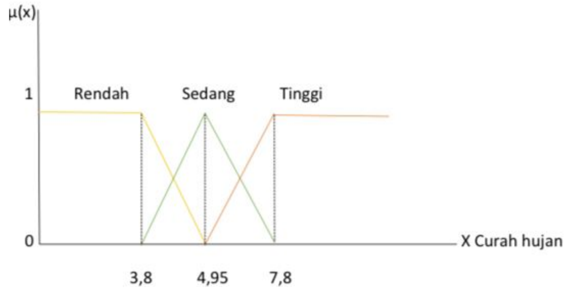

Figure 5. Graph Rainfall

Here is the membership function of low rainfall category

$$\mu rendah[x]=\begin{cases}1\ ; x\le 3,8\\ \dfrac{(4,95-x)}{(4,95-3,8)}; 3,8\le x\le 4,95\\ 0; x\ge 4,95\end{cases}$$

The following is the membership function of the medium rainfall category

$$\mu sedang[x]=\begin{cases}0\ ; x\le 3,8\ atau\ x\ge 7,8\\ \dfrac{(x-3,8)}{(4,95-3,8)}; 3,8\le x\le 4,95\\ \dfrac{(7,8-x)}{(7,8-4,95)}; 4,95\le x\le 7,8\end{cases}$$

Here is the membership function for high rainfall category

$$\mu tinggi[x]=\begin{cases}1\ ; x\ge 7,8\\ \dfrac{(x-4,95)}{(7,8-4,95)}; 4,95\le x\le 7,8\\ 0; x\le 4,95\end{cases}$$

3.3. Calculating The Fuzzy Membership Degree

Membership degrees will be calculated using formulas for each membership function as previously created and based on the average values of temperature, humidity, air pressure and wind speed in January 2023. The details of data can be seen in Table 1.

a) Finding the degree of humidity membership.
   It is known that the value of the air humidity variable to be used is 80%.
   μKLrendah (80) = 0.

$$\mu KLsedang(80)=\frac{81-80}{81-79,5}=0,6$$

$$\mu KLtinggi(80) = \frac{80 - 79,5}{81 - 79,5} = 0,33$$

b) Looking for the degree of membership of air temperature.
It is known that the value of the air temperature variable to be used is 27.1 ° C.
μSUdingin (27,1) = 1.
μSUsedang (27,1) = 0.
μSUpanas (27,1) = 0.

c) Finding membership degree of air pressure.
It is known that the value of the air pressure variable to be used is 1010.4 (mb).
μTUrendah (1010,4) = 0.

$$\mu TUsedang[1010,4] = \frac{1010,6 - 1010,4}{1010,6 - 1010,3} = 0,67$$

$$\mu TUtinggi[1010,4] = \frac{1010,4 - 1010,3}{1010,6 - 1010,3} = 0,33$$

d) Looking for the degree of membership of wind speed
It is known that the value of the wind speed variable to be used is 4m/s.
μKAlambat (4,1) = 0.
μKAcepat (4,1) = 1.

3.4. Fuzzy Rule Formation

After being reflected into the fuzzy set, the next process will be carried out. Formation of fuzzy rules on each variable. This process aims to form fuzzy rules as a form of expressing the relationship between input and output variables. For α-predicate can be determined by finding the smallest value (min).

Table 4. Fuzzy Rules

Rule	Suhu Udara	Kelembaban Udara	Tekanan Udara	Kecepatan Angin	Curah Hujan
R1	Dingin	Rendah	Rendah	Lambat	Cerah
R2	Dingin	Rendah	Rendah	Cepat	Berawan
R3	Dingin	Rendah	Sedang	Lambat	Cerah
R4	Dingin	Rendah	Sedang	Cepat	Cerah
R5	Dingin	Rendah	Tinggi	Lambat	Berawan
R6	Dingin	Rendah	Tinggi	Cepat	Hujan
R7	Dingin	Sedang	Rendah	Lambat	Cerah
R8	Dingin	Sedang	Rendah	Cepat	Hujan
⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮
R50	Panas	Tinggi	Rendah	Cepat	Berawan
R51	Panas	Tinggi	Sedang	Lambat	Hujan
R52	Panas	Tinggi	Sedang	Cepat	HUjan

R53	Panas	Tinggi	Tinggi	Lambat	Hujan
R54	Panas	Tinggi	Tinggi	Cepat	Hujan

After being reflexed into a fuzzy set, 4 fuzzy rules are formed, they are:
[R10] IF Suhu Cool AND Kelembapan Medium AND Tekanan Udara Medium AND Kecepatan Angin Fast THEN Curah Hujan Cloudy.

$\alpha - predikat = \mu dingin \cap \mu sedang \cap \mu sedang \cap \mu cepat$

= min (1: 0,67; 0,67; 1) = 0,67

$$\mu\text{CUberawan} = \frac{x - 3,8}{4,95 - 3,8}$$

$$\mu(z) = \frac{z10 - 3,8}{4,95 - 3,8}$$

$$0,67 = \frac{z10 - 3,8}{1,15}$$

$$z10 = 4,57$$

[R12] IF Suhu Cool AND Kelembapan Medium AND Tekanan Udara High AND Kecepatan Angin Fast THEN Curah Hujan Cloudy.

$\alpha - predikat = \mu dingin \cap \mu sedang \cap \mu tinggi \cap \mu cepat$

= min (1: 0,67; 0,33; 1) = 0,33

$$\mu\text{CUberawan} = \frac{x - 3,8}{4,95 - 3,8}$$

$$\mu(z) = \frac{z12 - 3,8}{4,95 - 3,8}$$

$$0,33 = \frac{z12 - 3,8}{1,15}$$

$$z12 = 4,18$$

[R16] IF Suhu Cool AND Kelembapan High AND Tekanan Udara Medium AND Kecepatan Angin Fast THEN Curah Hujan Rain.

$\alpha - predikat = \mu dingin \cap \mu tinggi \cap \mu sedang \cap \mu cepat$

= min (1: 0,33; 0,67; 1) = 0,33

$$\mu\text{CUberawan} = \frac{x - 4,95}{7,8 - 4,95}$$

$$\mu(z) = \frac{z16 - 4,95}{7,8 - 4,95}$$

$$0,33 = \frac{z10 - 3,8}{2,85}$$

$$z16 = 5,59$$

[R18] IF Suhu Cool AND Kelembapan High AND Tekanan Udara High AND Kecepatan Angin Fast THEN Curah Hujan Rain.

$\alpha - predikat = \mu dingin \cap \mu tinggi \cap \mu tinggi \cap \mu cepat$

$= \min(1{:}\ 0{,}33;\ 0{,}33;\ 1) = 0{,}33$

$\mu \text{CUhujan} = \dfrac{x - 4{,}95}{7{,}8 - 4{,}95}$

$\mu(z) = \dfrac{z18 - 4{,}95}{7{,}8 - 4{,}95}$

$0{,}33 = \dfrac{z18 - 4{,}95}{2{,}85}$

$z18 = 5{,}89$

3.5.Defuzzyfikasi

After calculating all fuzzy rules and getting the results of each rule, the next stage to be carried out is defuzzification, at this stage defuzzification which changes the fuzzy output results obtained from the inference engines into firm or crisp values. To get the output results of the Tsukamoto method. Then to get the defuzzification value, the centered average equation is used as follows:

$$\Leftrightarrow Z = \frac{\sum_{i=1}^{n} \alpha i.x_1}{\sum_{i=1}^{n} \alpha i}$$

$$\Leftrightarrow Z = \frac{(0{,}67 \times 4{,}57) + (0{,}33 \times 4{,}18) + (0{,}33 \times 5{,}89) + (0{,}33 \times 5{,}89)}{0{,}67 + 0{,}33 + 0{,}33 + 0{,}33}$$

$Z = 5$

For the next month is used in the same way to obtain rainfall prediction results, so that the following is obtained:

Table 5. Fuzzy Tsukamoto Calculation Results and Actual Data

Month	Actual Data Curah Hujan	Variable Linguistik	Result Fuzzy Tsukamoto	Variable Linguistik
January	5	Berawan	5	Berawan
February	2	Cerah	4.37	Cerah
March	8	Hujan	4.98	Hujan
April	1.2	Cerah	3.8	Berawan
May	3.8	Berawan	3.8	Berawan
June	4.9	Berawan	4.38	Berawan
July	3.8	Berawan	4.38	Berawan
August	7.6	Hujan	6.38	Hujan
September	4.7	Berawan	5.22	Hujan
October	5.2	Hujan	4.91	Berawan
November	9.3	Hujan	5.69	Hujan
December	12	Hujan	7.8	Hujan

3.6. MAPE Analysis

The following are the results of tests carried out using the Tsukamoto fuzzy logic method. In this test, the results of the error calculation on the model are estimated using MAPE (Mean Absolute Percentage Error), which serves to measure the extent of the difference between the value predicted by the model and the actual value. The MAPE value found is as follows:

$$MAPE = \sum_{i=1}^{n} \left| \frac{y_i - \hat{y}_i}{y_i} \right| \times 100\%$$

$$= \frac{5,07}{12} \times 100\%$$

$$= 42,25\%$$

From the app's error rate, we can find out the accuracy of the app below:

Accuracy = 100% - 42,25% = 57,75 %

The results of MAPE in the calculation of rainfall predictions from January 2023 to December 2023 using the Tsukamoto fuzzy method are 42,25%. This shows that the MAPE value is in the range of 20-50%, which means it has a category that is feasible or sufficient. From the MAPE value, the accuracy of this fuzzy calculation is 57,75%. Accuracy = 100% - 42,25% = 57,75 %.

4. Conclusion

Based on this research, it can be concluded that the analysis that has been carried out with the Tsukamoto fuzzy logic method on the variables of air temperature, air humidity, air pressure and wind speed to predict rainfall by producing a MAPE value of 42.25% shows that this MAPE value is in the range of 20-50% where this category indicates that rainfall prediction with Tsukamoto fuzzy logic has sufficient and feasible results. This study has limitations in terms of the amount of data and variables, so future research can focus on collecting more complete data and can use other fuzzy methods such as Mamdani or Sugeno and compare these methods in order to obtain the most appropriate fuzzy method for forecasting rainfall.

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