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Forecasting Rainfall in Padang Panjang City Using Fuzzy Time Series Cheng

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Abstract. Rainfall is essential in many areas of life, including agriculture, water resource management, and disaster mitigation. Padang Panjang is one of the cities with high rainfall. Rainfall varies throughout the year, affecting agriculture and people's livelihoods. Therefore, accurate rainfall estimation is required to support effective planning and management. This study aims to forecast the amount of rainfall in Padang Panjang City from January 2020 to November 2024 using the fuzzy time series method of the Cheng model. The data is on the monthly rainfall amount from January 2020 to November 2024, obtained from the BMKG Padang Pariaman Climatology Station. The stages in the fuzzy time series Cheng model are forming the universe set, forming intervals, fuzzifying the data, analyzing Fuzzy Logical Relationship (FLR) and Fuzzy Logical Relationship Group (FLRG), determining the weight of the relationship, forecasting, and measuring the accuracy of predicting using Mean Absolute Percentage Error (MAPE). The forecasting results were validated using MAPE, with a value of 41%, which indicates that the model is feasible. The forecasting results for the following three periods are December 2024 high rainfall, January 2025 medium rainfall, and February 2025 high rainfall. This research shows that the fuzzy time series method of the Cheng model can be used as an alternative means of forecasting time series data.

Keywords: Rainfall, Fuzzy Time Series Cheng, Forecasting, MAPE.

1 Introduction

Indonesia is an archipelago in a tropical climate and is vulnerable to climate change. This results in erratic changes in rainfall intensity due to climate change [1]. Information about rainfall is essential, especially in the agricultural sector. In the farm sector, rainfall information is used to determine the type of crop to be planted according to the rainfall intensity, and to predict the beginning of the planting season in the planting calendar to minimize the risk of planting [1]. Rainfall patterns will shift the start of both the wet and dry seasons. Drought due to the longer dry season will threaten land productivity [2].

Padang Panjang City is a city with high rainfall [3]. The geographical and climatic conditions of Padang Panjang City are unique, as it is located in the highlands and surrounded by mountains. Favorable geographical conditions, such as fertile soil and a suitable climate, make this city ideal for various agricultural commodities. There are approximately 2,009 agricultural business households operating businesses in the farming sector in Padang Panjang City [4]. These fluctuating rainfall conditions directly impact the farm sector in Padang Panjang City. Agriculture is highly dependent on rainfall patterns for irrigation and crop growth.

The most widely used method is classical time series analysis, such as ARIMA, SARIMA, and Moving Average. Classical time series analysis requires several assumptions to be met [5]. Currently, several types of forecasting methods do not require these assumptions, one of which is the fuzzy time series method [6]. Forecasting is an activity that predicts future events based on historical patterns [7]. Forecasting is the art and science of estimating future events [8].

Fuzzy time series is a new concept in artificial intelligence that is used for forecasting problems where the historical data is formed in linguistic values and produces more accurate forecasts [9]. Fuzzy Time Series (FTS) is a forecasting method that uses fuzzy principles as its basis. Forecasting systems with fuzzy time series capture patterns from past data and then use them to project future data [10]. Fuzzy time series are used to forecast data and agricultural production, an area's climate, or especially rainfall [11]. Rainfall intensity is the

amount of rainfall in a specific unit of time, which is usually expressed in mm/hour, mm/day, mm/year, and others [12].

There are several models that apply fuzzy time series methods, including Chen's model, Cheng's model, and others. Each method provides different steps in forecasting a value [13]. In [14], forecasting using the Cheng method, which uses adaptive forecasting, has a smaller forecasting error size than the Chen method, with an MAPE value is 0.970%. This research is fundamental because accurate rainfall forecasting can help the people of Padang Panjang City deal with the impacts of climate change, strengthen food security, and optimize water resource management. In addition, the results of this research can support better infrastructure development planning and disaster risk mitigation, such as floods and landslides.

2 Theoritical Basic

2.1 Fuzzy Time Series

Song and Chissom introduced the basic concept of FTS in 1993, where fuzzy time series values are represented in fuzzy sets. According to Song, the following is the definition of fuzzy time series [15].

Definition 1. Suppose $Y(t) \in R\ (t = 0, 1, 2, 3, \dots)$ is a time series. If A_i is a fuzzy set on $Y(t)$ and $F(t) = \{A_1, A_2, A_3, \dots\}$, then $F(t)$ is called fuzzy time series on $Y(t)$.

The fuzzy logical relationship is the relationship between $F(t) = A_j$ and $F(t-1) = A_I$ which can be expressed by $A_I \rightarrow A_j$. The following definition related to FLR [16].

Definition 2. Suppose $F(t) = A_j$ is caused by $F(t-1) = A_I$, then fuzzy logical relationship (FLR) is defined as the relationship between $F(t)$ and $F(t-1)$ which can be expressed by $A_I \rightarrow A_j$. If there are two FLRs have the same fuzzy set $(A_I \rightarrow A_{j1}, A_I \rightarrow A_{j2})$ which is expressed by $A_I \rightarrow A_{j1}, A_{j2}, \dots$, it is called FLRG.

The main difference between fuzzy time series and conventional time series is in the values used for forecasting. The fuzzy time series uses a fuzzy set of real numbers over a specified universe [17].

2.2 Fuzzy Time Series Cheng

In determining the interval, Cheng's method slightly differs in forming a Fuzzy Logical Relationship (FLR) based on the order and recurrence of the same FLR to include all relationships with weights. Forecasting can be modified by using adaptive forecasting [18].

The stages in forecasting time series data with the Cheng model are as follows:

a. Determine the universe set (U) of the actual data:

$$U = [d_{min} - d_1, d_{max} + d_2] \quad (1)$$

where d_{min} is the smallest data and d_{max} is the largest data. D_1 and d_2 are positive numbers randomly determined by the researcher to facilitate the division of intervals.

b. Determining the width of the interval using the frequency distribution, with the following steps:
   1) Determine the range with the following formula:

$$R = d_{max} - d_{min} \quad (2)$$

   2) Determine the number of class intervals using the Sturges Equation.
   The formula is as follows:

$$K = 1 + 3.322 \times \log(n) \quad (3)$$

   3) Determine the width of the interval. The formula is as follows :

$$I = \frac{\text{range (R)}}{\text{the number of class intervals (K)}} \quad (4)$$

   4) Find the middle value. The formula is as follows :

$$m_i = \frac{\text{(upper limit + lower limit)}}{2} \quad (5)$$

   where i is the number of fuzzy sets.

c. The fuzzy set is formed by looking at the number of different frequencies, then the first highest frequency is divided into *h* equal intervals. Next, the second highest frequency is divided into *h* - 1

equal intervals, and the interval at the third highest frequency is divided into *h* - 2 equal intervals. This is done until the interval with the frequency is no longer divisible.

d. Defining fuzzy sets and fuzzifying the actual observed data. Suppose $A_1, A_2, \dots, A_p$ are fuzzy sets that has a linguistic value of a linguistic variable, the definition of the fuzzy sets $A_1, A_2, \dots, A_p$ on U :

$$\begin{aligned} A_1 &= \frac{1}{u_1} + \frac{0.5}{u_2} + \frac{0}{u_3} + \cdots + \frac{0}{u_p} \\ A_2 &= \frac{0.5}{u_1} + \frac{1}{u_2} + \frac{0.5}{u_3} + \cdots + \frac{0}{u_p} \\ A_3 &= \frac{0}{u_1} + \frac{0.5}{u_2} + \frac{1}{u_3} + \cdots + \frac{0}{u_p} \\ &\vdots \\ A_p &= \frac{0}{u_1} + \frac{0}{u_2} + \frac{0}{u_3} + \cdots + \frac{0.5}{u_{p-1}} + \frac{1}{u_p} \end{aligned} \tag{6}$$

where $u_I\ (i = 1, 2, .., p)$ are elements of the universe sets (U)and the number symbolized "/" represents the degree of memberships of $\mu_{A_i}(u_I)$ terhadap $A_I\ (i = 1, 2, .., p)$ where the value are 0, 0.5 or 1.

e. Create a FLR table based on actual data. FLR can be denoted by $A_i \rightarrow A_j$, where A_I is current state and A_j is next state.

f. Determine the weights of FLR relationships into a Fuzzy Logical Relationship Group (FLRG) by including all relationships and assigning weights based on the same order and recurrence. FLR that have the same current state (A_i) are combined into one group in the form of a weighting matrix. The resulting weight values are then transferred into a weight matrix written as follows:

$$W = \begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1p} \\ w_{21} & w_{22} & \cdots & w_{1p} \\ \vdots & \vdots & w_{ij} & \vdots \\ w_{p1} & w_{p2} & \cdots & w_{pp} \end{bmatrix} \tag{7}$$

Where W is weight matrix and w_{ij} is weight matrix at row i column j with $i = 1,2, \dots, p\ ; j = 1,2, \dots, p$

g. Then transfer the FLRG weights into a standardized weight matrix (W^*) with the following equation :

$$W^* = \begin{bmatrix} w_{11}^* & w_{12}^* & \cdots & w_{1p}^* \\ w_{21}^* & w_{22}^* & \cdots & w_{1p}^* \\ \vdots & \vdots & w_{ij}^* & \vdots \\ w_{p1}^* & w_{p2}^* & \cdots & w_{pp}^* \end{bmatrix} \tag{8}$$

Where W^* is a standardized weight matrix with

$$w_{ij}^* = \frac{w_{ij}}{\sum_{j=1}^{p} w_{ij}} \tag{9}$$

h. Determining the defuzzification of forecasting values. To generate forecasting values, the standardized weight matrix (W^*) is multiplied by the mean value (m_i). The forecasting result can be calculated using the following formula :

$$F_i = w_{i1}^*(m_1) + w_{i2}^*(m_2) + \cdots + w_{ip}^*(m_p) \tag{10}$$

Where F_I is forecasting result and w_{ip}^* is standardized weight matrix

If the fuzzification result of a period i are A_I and A_I haven't FLR in FLRG with the condition $A_I \rightarrow \emptyset$, where the maximum value of the membership degree at u_I, then the forecasting value (F_I) are the middle value of u_I , or defined by m_I [19].

2.3 Forecasting Accuracy

The accuracy of the forecasting results can be calculated using the Mean Absolute Percentage Error (MAPE) with the formula:

$$MAPE = \frac{\sum_{t=1}^{n} \left| \frac{X_t - F_t}{X_t} \right|}{n} \times 100\% \tag{11}$$

Generally, the significance of a good MAPE value is seen from the percent of model feasibility by looking at the MAPE value interval [20].

Table 1. Forecasting Accuracy on MAPE

MAPE	Significance
< 10%	Excellent forecasting
10% − 20%	Good forecasting
20% − 50%	Feasible forecasting
> 50%	Poor forecasting

2.4 Research Methods

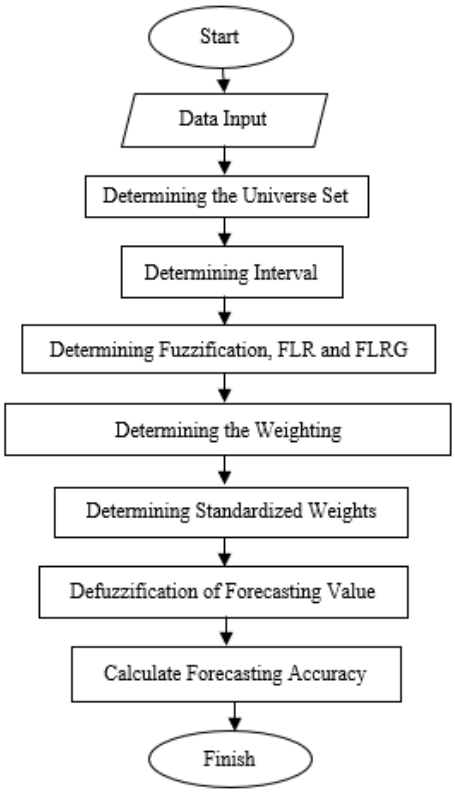

Fig 1. Flowchart of Fuzzy Time Series Cheng

The data analysis steps in this study are to input data on the amount of rainfall in Padang Panjang City from January 2020 to November 2024. The formation of the universe set (U) for the universe set is denoted by U, where U is historical data. Then determine the minimum and maximum data. Then Interval Formation for the number of interval classes using the Sturges formula. Then Fuzzification Formation, Fuzzy logic Relations (FLR), and Fuzzy Logic Relations Group (FLRG). Assigning weights to fuzzy logic relation groups and forming a standardized weighting matrix. Determine the defuzzification of forecasting values. The weighting matrix is multiplied by the middle value in each fuzzy set to get the forecasting value. Finally, calculating the value of the data forecasting accuracy measure in Cheng's fuzzy time series method, using the MAPE error measure. The smaller the resulting error value, the more accurate the forecasting value obtained.

3 Results and Discussion

3.1 Actual Data

The data to be analyzed in this study is data on the amount of rainfall in Padang Panjang City from January 2020 to November 2024, taken from the West Sumatra Meteorology, Climatology and Geophysics Agency (BMKG) Padang Pariaman Climatology Station can be seen in Figure 2.

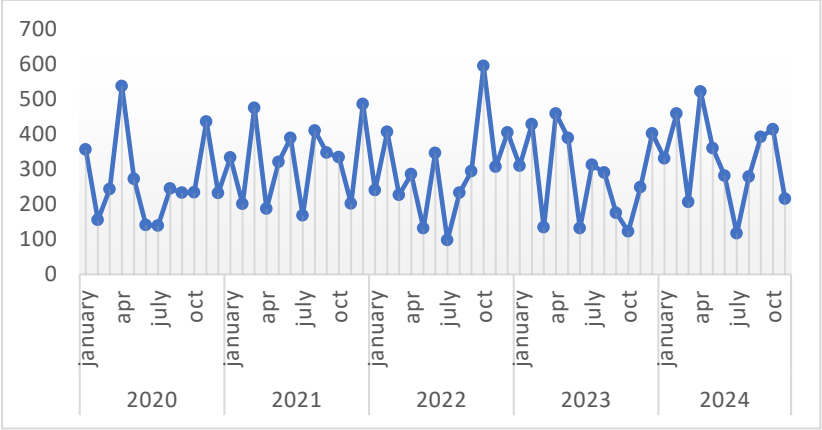

Fig 2. Actual Rainfall Amount Data of Padang Panjang City

3.2 Data Analysis

The following are the steps for forecasting rainfall in Padang Panjang City using Cheng's fuzzy time series.

1. Determining the Universe Set

   The values of d_1 and d_2 are positive numbers randomly determined by the researcher to facilitate the division of intervals, so that the values of $d_1 = 12$ and $d_2 = 30$ are determined, so that the universe set (U) is obtained according to equation (1) as follows:

$$U = [d_{min} - d_1; d_{max} + d_2]$$
$$= [98 - 12;\ 595 + 30]$$
$$= [86; 625]$$

Table 2. Rainfall Interval

Intervals (u_i)	Lower Limit	Upper Limit	Middle Value (m_i)
u_1	98	163	124.5
u_2	163	240	201.5
u_3	240	317	278.5
u_4	317	394	355.5
u_5	394	471	432.5
u_6	471	548	509.5
u_7	548	625	586.5

2. Determining Interval

   In determining the width of the interval, first determine the data range according to equation (2) as follows :

$$R = d_{max} - d_{min}$$
$$= 625 - 86$$
$$= 539$$

Next, determine the number of class intervals using the Sturges equation (3) as follows:

$$K = 1 + 3{,}322 \times \log(n)$$
$$= 1 + 3{,}322 \log 60$$
$$= 6.9 \approx 7$$

Based on equation (4), the following interval width is obtained:

$$I = \frac{R}{K}$$
$$= \frac{539}{7}$$
$$= 77$$

So the universe set (U) consists of 7 intervals with the same interval width of 77, so it can be seen in Table 2.

3. Determining Fuzzy Sets
The fuzzy set (A_i) is determined as many intervals as have been obtained, where there are 7 interval classes as shown in Fig 3.

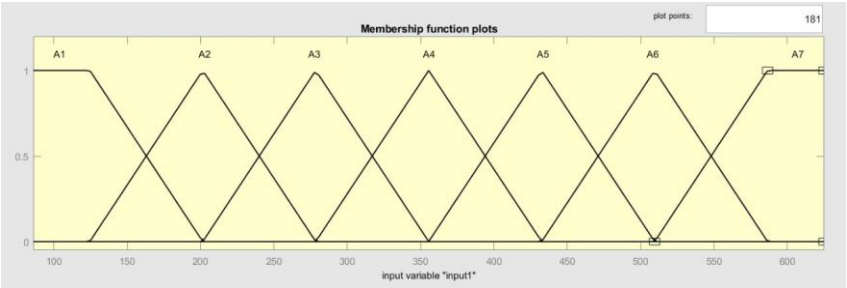

Fig 3. Fuzzy Membership Representation Curve

A total of 59 rainfall amount data are fuzzified using membership degrees, as shown in Figure 3. The membership degree values can be seen in Table 3.

Table 3. Fuzzy Membership Degree of Total Rainfall

Period	Data	A_1	A_2	...	A_6	A_7
January 2020	357	0	0	⋮	0	0
February 2020	156	0,59	0,41	⋮	0	0
March 2020	243	0	0,54	⋮	0	0
April 2020	536	0	0	⋮	0,37	0,37
⋮	⋮	⋮	⋮	⋮	⋮	⋮
August 2024	279	0	0	⋮	0	0
September 2024	393	0	0	⋮	0	0
October 2024	414	0	0	⋮	0	0
November 2024	216	0	0,19	⋮	0	0

For the definition of seven fuzzy sets $A_1, A_2, \ldots, A_7$ as linguistic variables in the set universe U. Fuzzy sets are defined as follows:

Table 4. Fuzzy Sets and Linguistic Values

Fuzzy sets	Linguistic Values
A_1	Very low rainfall
A_2	Low rainfall
A_3	Intermediate rainfall
A_4	Fairly high rainfall
A_5	Moderately high rainfall
A_6	High rainfall
A_7	Very high rainfall

4. Determining Fuzzification
The following are the results of fuzzifying rainfall amount data from January 2020 to November 2024, which are denoted in linguistic variables in Table 5.
5. Determining Fuzzy Logic Relationship and Fuzzy Logic Relationship Group
Suppose that for the January 2020 rainfall amount data, the fuzzification is A_4, then in the next month, February 2020, the fuzzification is A_1 so that the FLR between January 2020 and February 2020 is $A_4 \rightarrow A_1$. Based on the same rules, the FLR for the rainfall data of Padang Panjang City from February 2020 to November 2024 is determined, which is presented in Table 6.

Table 5. Fuzzification of Rainfall Amount Data

Period	Rainfall Total (mm)	Fuzzification
January 2020	357	A_4
February 2020	156	A_1
March 2020	243	A_3
April 2020	536	A_6
⋮	⋮	⋮
August 2024	279	A_3
September 2024	393	A_4
October 2024	414	A_5
November 2024	216	A_2

Table 6. FLR Cheng's FTS Rainfall Data

Period	Fuzzification	FLR
January 2020	A_4	$CS \rightarrow NS$
February 2020	A_1	$A_4 \rightarrow A_1$
March 2020	A_3	$A_1 \rightarrow A_3$
April 2020	A_6	$A_3 \rightarrow A_6$
⋮	⋮	⋮
August 2024	A_3	$A_1 \rightarrow A_3$
September 2024	A_4	$A_3 \rightarrow A_4$
October 2024	A_5	$A_4 \rightarrow A_5$
November 2024	A_2	$A_5 \rightarrow A_2$

The next step is to determine the FLRG based on the FLR results obtained in Table 6. FLRG is formed by counting the number of possible FLRs that are the same and then weighted according to the number of occurrences. The following is the FLRG for the rainfall amount data of Padang Panjang City:

Table 7. Fuzzy Logic Relationship (FLRG)

No	FLRG	
	Current State	Next State
1	A_1	$\rightarrow A_1, A_2, 5(A_3), A_4, A_5$
2	A_2	$\rightarrow A_1, A_2, 2(A_3), 2(A_4), 2(A_5), 3(A_6)$
3	A_3	$\rightarrow 3(A_1), 2(A_2), A_3, A_4, 4(A_5), A_6, A_7$
4	A_4	$\rightarrow 3(A_1), 3(A_2), A_3, 2(A_4), 2(A_5)$
5	A_5	$\rightarrow A_1, 4(A_2), A_3, 3(A_4)$
6	A_6	$\rightarrow A_2, 2(A_3), A_4$
7	A_7	$\rightarrow A_3$

6. Determining the weighting

The weighting matrix for 7 intervals is obtained as follows:

$$W = \begin{bmatrix} 1 & 1 & 5 & 1 & 1 & 0 & 0 \\ 1 & 1 & 2 & 2 & 2 & 3 & 0 \\ 3 & 2 & 1 & 1 & 4 & 1 & 1 \\ 3 & 3 & 1 & 2 & 2 & 0 & 0 \\ 1 & 4 & 1 & 3 & 0 & 0 & 0 \\ 0 & 1 & 2 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

In the matrix, the highest weighting is $w_{13} = 5$, meaning that there is a change in rainfall from very low rainfall to medium rainfall 5 times. Next, the standardized weight matrix (W^*) will be determined using equation (8). Suppose for w_{11}, calculated using the formula in equation (9) as follows:

$$w_{11}^* = \frac{w_{11}}{\sum_{j=1}^{7} w_{ij}} = \frac{1}{1+1+5+1+1+0+0} = \frac{1}{9} = 0.1$$

The standardized weight matrix for each fuzzy sets can be obtained as follows :

$$W^* = \begin{bmatrix} 0.11 & 0.11 & 0.56 & 0.11 & 0.11 & 0 & 0 \\ 0.09 & 0.09 & 0.18 & 0.18 & 0.18 & 0.27 & 0 \\ 0.23 & 0.15 & 0.08 & 0.08 & 0.31 & 0.08 & 0.08 \\ 0.27 & 0.27 & 0.09 & 0.18 & 0.18 & 0 & 0 \\ 0.11 & 0.44 & 0.11 & 0.33 & 0 & 0 & 0 \\ 0 & 0.25 & 0.5 & 0.25 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

7. Calculating the Defuzzification of Forecasting Values
To calculate the defuzzification of forecasting values using equation (10), where to produce forecasts by multiplying the standardized weight matrix(W^*) by the middle value (m_i). The results of forecasting defuzzification can be seen in Table 8.

Table 8. Defuzzication Results

Group	FLRG	Forecast Value
A_1	$A_1 \rightarrow A_1, A_2, 5(A_3), A_4, A_5$	279
A_2	$A_2 \rightarrow A_1, A_2, 2(A_3), 2(A_4), 2(A_5), 3(A_6)$	363
A_3	$A_3 \rightarrow 3(A_1), 2(A_2), A_3, A_4, 4(A_5), A_6, A_7$	326
A_4	$A_4 \rightarrow 3(A_1), 3(A_2), A_3, 2(A_4), 2(A_5)$	258
A_5	$A_5 \rightarrow A_1, 4(A_2), A_3, 3(A_4)$	253
A_6	$A_6 \rightarrow A_2, 2(A_3), A_4$	279
A_7	$A_7 \rightarrow A_3$	279

After determining the defuzzification process, the next step is to perform rainfall forecasting in Padang Panjang City for the period January 2020 to November 2024. The results of rainfall forecasting in Padang Panjang City can be seen in Table 9.

Table 9. Cheng's FTS Rainfall Forecast Results

Period	Actual Data	Fuzzification	Forecasting Results
January 2020	357	A_4	NA
February 2020	156	A_1	258
March 2020	243	A_3	279
April 2020	536	A_6	326
⋮	⋮	⋮	⋮
August 2024	279	A_3	279
September 2024	393	A_4	326
October 2024	414	A_5	258
November 2024	216	A_2	253

From Table 9, it can be seen that the forecasting result for January 2020 is “NA” or Not Available, which means that there is no forecasting value for the January 2020 period because there is no actual data in the previous month. In November 2024, the fuzzification is A_2 so that the forecasting result for the next month, December 2024, is 363. The following is a comparison between the actual data on the amount of rainfall in Padang Panjang City and the forecast results for the amount of rainfall in Padang Panjang City.

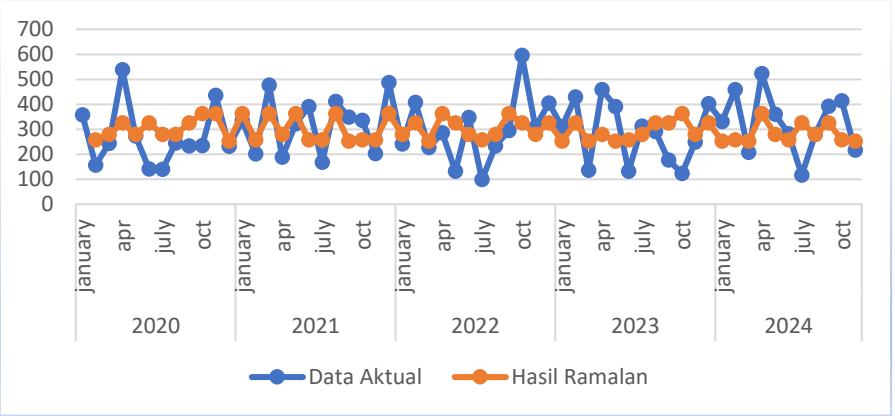

Fig 4. Data Plot of Actual and Forecast Data Comparison

The results of rainfall forecasting in Padang Panjang City using Cheng's fuzzy time series model for the following three periods, namely December 2024, January 2025, and February 2025, can be seen in Table 10.

Table 10. Forecasting the Next Period

Period	Rainfall Forecasting
Desember 2024	High rainfall
January 2025	Intermediate rainfall
February 2025	High rainfall

8. Forecasting Accuracy

In research, for the accuracy of rainfall forecasting in Padang Panjang City, using the MAPE. MAPE is used to see the percentage error in the forecasting results obtained. Based on Equation (11), the MAPE value can be calculated as follows:

$$\text{MAPE} = \frac{\sum_{t=1}^{n} \left| \frac{X_t - F_t}{X_t} \right|}{n} \times 100\%$$

$$= \frac{65 + 15 + 39 + \cdots + 17 + 38 + 17}{58} \times 100\%$$

$$= 41\%$$

From the calculation results using the MAPE obtained, the prediction error value using Cheng's fuzzy time series in rainfall forecasting in Padang Panjang City is 41%. Table 1 shows that this forecasting includes feasible forecasting. The high MAPE value in rainfall forecasting in this study can be caused by several factors, including minimal actual values in most of the data, thus increasing the percentage error. In addition, rainfall has fluctuating and extreme characteristics that are difficult to predict with simple statistical models, and the possibility of outlier values that have not been handled optimally.

4 Conclusion

Based on the results and discussion on the analysis of the amount of rainfall in Padang Panjang City for the period January 2020 to November 2024 that has been carried out, the conclusion that can be obtained in this study is the result of rainfall forecasting in Padang Panjang City using Cheng's fuzzy time series model for the period December 2024 is 363 mm, meaning that rainfall in December is high rainfall, January 2025 is 258 mm, meaning medium rainfall, and February 2024 is 326 mm, meaning that rainfall in February is high. Then, for the results of the accuracy of rainfall forecasting in Padang Panjang City, based on the MAPE value obtained of 41%, this forecasting is categorized as feasible to use.

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