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Application of Fuzzy Tsukamoto Method to Rainfall Prediction in Sleman Regency

Rizky Diar Panuntun[-1*)], Arief Hermawan[-2]

Faculty of Science & Technology
Universitas Tekonologi Yogyakarta, Yogyakarta, Indonesia
rizki.diar01@gmail.com[-1*)], ariefdb@uty.ac.id[-2]

(*) Corresponding Author

Abstract

The context of this research is that erratic rainfall can disrupt community activities, especially for traders who want to make sales. In addition, information about rainfall is also needed by farmers in determining planting patterns in order to get maximum yields. The purpose of this research is to be able to help farmers predict rainfall to get maximum crop yields. One method to be able to predict rainfall is Fuzzy Logic. This research will use the Tsukamoto Fuzzy method. In the research conducted this time, the author conducted monthly rainfall forecasting in Sleman Regency. Rainfall data in Sleman Regency from 2015 to 2022 will be used in this research. This research succeeded in getting a MAPE value of 49.31%. The result of this research is the highest monthly rainfall prediction in November, with a rainfall of 713.78 mm. At the same time, the lowest occurred in August, which amounted to 36.47 mm. This research only gets a MAPE value of 49.31%. So, it can be concluded that the Tsukamoto fuzzy method cannot predict rainfall well.

Keywords: Fuzzy Logic; Prediction; Rainfall; Sleman Regency; Tsukamoto

Abstrak

Latar belakang dari penelitian ini adalah curah hujan yang tidak menentu dapat mengganggu aktivitas masyarakat, terutama bagi para pedagang yang ingin melakukan penjualan. Selain itu, informasi mengenai curah hujan juga dibutuhkan oleh para petani dalam menentukan pola tanam agar mendapatkan hasil panen yang maksimal. Tujuan dari dilakukannya penelitian ini yaitu agar dapat membantu para petani dalam memprediksi curah hujan untuk mendapatkan hasil panen yang maksimal. Salah satu metode untuk dapat memprediksi curah hujan adalah Fuzzy Logic. Penelitian ini akan menggunakan metode Fuzzy Tsukamoto. Dalam penelitian yang dilakukan kali ini, penulis melakukan peramalan curah hujan bulanan di Kabupaten Sleman. Data curah hujan di Kabupaten Sleman dari tahun 2015 hingga 2022 akan digunakan dalam penelitian ini. Penelitian ini berhasil mendapatkan nilai MAPE sebesar 49,31%. Hasil dari penelitian ini adalah prediksi curah hujan bulanan tertinggi pada bulan November dengan curah hujan sebesar 713,78 mm. Sedangkan untuk yang terendah terjadi di bulan Agustus yaitu sebesar 36,47 mm. Penelitian ini hanya mendapatkan nilai MAPE sebesar 49,31%. Sehingga dapat disimpulkan bahwa metode fuzzy tsukamoto tidak dapat memprediksi curah hujan dengan baik.

Kata kunci: Logika Fuzzy; Prediksi; Curah Hujan; Kabupaten Sleman; Tsukamoto

INTRODUCTION

Meteorological parameters include lightning, wind speed and direction, humidity and air temperature, and rainfall (Sunardi, Yudhana, & Muflih, 2020). Of these parameters, the most influential parameter is rainfall. Of these parameters, the most influential parameter is rainfall (Adib Azka, Aditya Sugianto, Kurniawan Silitonga, & Redha Nugraheni, 2018). The amount of rain that falls to the surface in a particular area and period is referred to as rainfall (Winarno, Harianto, & Santoso Trio, 2019). Rainfall has a vital role for every community, especially farmers. This is because agricultural yields are highly dependent on the level of rainfall. In determining cropping patterns, farmers need weather information so that crop yields can be maximized (Mahendra Putra & Anjar Rani, 2020).

Indonesia's diverse conditions, such as latitude, altitude, distribution of land and water landscapes, wind patterns (trade winds and monsoons), and high mountains, make Indonesia have different rainfall characteristics in various

regions and vary from time to time. These diverse characteristics in space and time make rainfall fluctuate. One of the regions in Indonesia where rainfall fluctuates is Sleman Regency. The following is a graph of rainfall that occurred in Sleman Regency from 2021 to 2022.

Figure 1. Graph of Rainfall in Sleman Regency

Fluctuating rainfall has a significant impact on society, especially farmers. High rainfall can cause waterlogging and flooding, which is very detrimental to crops. Meanwhile, low rainfall causes the soil to dry out and reduces crop yields. Fluctuating rainfall also makes water management more difficult. Farmers often rely on irrigation as a source of water for their crops. Excess water due to excessive rain or lack of water due to drought can disrupt irrigation scheduling and water resource management. In addition, farmers also become confused in choosing which crops to select due to fluctuating rainfall. This is because the crops suitable for planting during high and low rainfall are different. Crops that are planted during high rainfall include rice, bananas and cassava. Meanwhile, crops that are usually planted during low rainfall are peanuts, kidney beans, and sugar cane. Therefore, a way is needed in order to predict rainfall in the future.

Based on these problems, the problem formulation in this research is that fluctuating rainfall is difficult to predict, so a system is needed that can predict rainfall in the future. One method for rainfall forecasting is Fuzzy Logic. Logic that has indeterminate, fuzzy, ambiguous, and grey values is called Fuzzy Logic. Fuzzy logic is a line of values where each value has a degree of membership (Rindengan & Langi, 2019). This method has been used in rainfall forecasting in Batu City with Fuzzy Tsukamoto (Wahyuni & Ahda, 2018). From this study, a relatively small RMSE value was obtained, namely in the Junggo area at 9.196, in the Pujon area at 9.407, in the Tinjomulyo area at 8.798, and the Ngujung area at 8.825. The Fuzzy Tsukamoto method has also been used in forecasting dasarian rainfall in one of the cities in East Java, namely Sumenep (Muhandhis, Ritonga, & Murdani, 2021). This research produces good accuracy with a MAPE value of 10.64%. Tsukamoto Fuzzy Logic has also been applied in forecasting rainfall in Central Kalimantan, namely East Kotawaringin Regency (Sholihah, 2022). This research resulted in an MSE value of 3.15375. In addition, other fuzzy methods, such as fuzzy time series, have been used in forecasting rainfall in the Jombang Regency area (Suhartanto, Nuryana, & Mujianto, 2021). This research produces an average MAPE value of 0.90. Fuzzy Mamdani has also been used in a weather forecasting system that uses the Lasiana Meteorological, Climatological, and Geophysical Agency as a case study (Wele, Rumlaklak, & Boru, 2020). This research obtained the highest accuracy rate of 65.20%. Based on this research, the Fuzzy Logic method can be applied to perform rainfall forecasting.

One of the methods developed from extending fuzzy logic is the Tsukamoto method, in which each rule consequence in this method must be described as a fuzzy set with a membership function (Setiawan, Yanto, & Yasdomi, 2018). The fuzzy Tsukamoto Method will be applied in this study to forecast rainfall that occurs in Sleman. Regency. This research uses monthly rainfall data from 2015 to 2022. The structure of this article is research methods, results and discussion, and conclusions and suggestions. The method chapter explains the method that will be used in this research. Furthermore, the results and discussion chapter explains the results of the tests performed and explains how the test results were analyzed. The conclusion chapter explains how to draw conclusions based on the test results in this study and suggests them to future researchers.

RESEARCH METHODS

The method in this research is data collection, fuzzification, inference, defuzzification, system implementation, and evaluation. Figure 2 below is the method in this research.

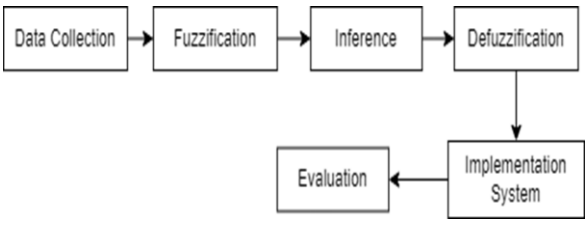


Figure 2. Research method

Data Collection

The first stage is data collection. Rainfall data from 2015 to 2022 in Sleman Regency will be used in this research. This data is obtained from the website of the Regional Development Planning Agency (BAPPEDA) of Yogyakarta Province. Data from 2015 to 2021 will be used in making fuzzy rules, while data in 2022 will be used as benchmark forecasting data. Table 1 below is a sample of data in this study.

Table 1. Sleman District Rainfall Data

Month	2019	2020	2021	2022
January	457	327	334	255
February	337	317	264	251
March	560	812	316	422
April	413	374	230	339
May	22	254	123	208
June	0	77	272	280
July	1	1	16	97
August	1	26	12	53
September	0	44	170	100
October	0	238	173	560
November	164	342	472	480
December	390	460	356	413

Fuzzification

Fuzzification is the process of converting system inputs that have strict values into linguistic variables using membership functions stored in the fuzzy knowledge base (Surbakti, Rahayu, Pa, & Ginting, 2020). In this fuzzification stage, the value mapping of the input values is carried out into a fuzzy set. Crisp value data is converted into a membership function. The calculations in this process are based on the boundaries of the membership function. In this study, the fuzzy set has three linguistic values, namely, low, medium, and high. Researchers determine these three values because farmers can adjust what crops to plant with the level of rainfall. There are eight variables to be modeled in this study, namely data in 2022 (Zi), data in 2021 (Zi-1), data in 2020 (Zi-2), data in 2019 (Zi-3), and so on. The graph of the fuzzy set based on rainfall is shown in the following graph.

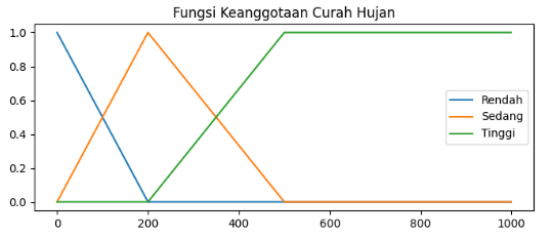


Figure 3. Fuzzy Set Graph Based on Rainfall

Based on Figure 3, the fuzzy set membership functions for all variables are as follows.

The low-value membership degree is as follows.

$$\mu_{Low}(x) = \begin{cases} 1; x \leq 0 \\ \frac{200-x}{200-0}; 0 < x \leq 200 \\ 0; x > 200 \end{cases} \quad \text{..... (1)}$$

The membership degree for the medium level is as follows.

$$\mu_{Medium}(x) = \begin{cases} 0; x \leq 0 \\ \frac{x-0}{200-0}; 0 < x \leq 200 \\ \frac{500-x}{500-200}; 200 < x \leq 500 \\ 0; x > 500 \end{cases} \quad \text{..... (2)}$$

The high-value membership degree is as follows.

$$\mu_{High}(x) = \begin{cases} 0; x < 200 \\ \frac{x-200}{500-200}; 200 < x \leq 500 \\ 1; x \geq 500 \end{cases} \quad \text{..... (3)}$$

Inference

The next stage is inference. The inference process is an implication process using the MIN and MAX operators. In this research, the implication process will use the MIN operator to create a rule base (Rullah & Prebianto, 2020). Then, based on the previous rule, in this stage, the calculation of the degree of membership is carried out. After knowing the value of the membership degree, look for the value of a predicate. This a-predicate value is the minimum value of the membership degree. The fuzzy rules in this study are 2187, which are presented in Table 2.

Table 2. Fuzzy Rules

No	Zi-1	Zi-2	Zi-3	Zi-4	Zi-5	Zi-6	Zi-7	Zi
1	Low	Low	Low	Low	Low	Low	Low	Low
2	Low	Low	Low	Low	Low	Low	Medium	Low
3	Low	Low	Low	Low	Low	Low	High	Low
4	Low	Low	Low	Low	Low	Medium	Low	Low
5	Low	Low	Low	Low	Low	Medium	Medium	Low
6	Low	Low	Low	Low	Low	Medium	High	Low
7	Low	Low	Low	Low	Low	High	Low	Low
8	Low	Low	Low	Low	Low	High	Medium	Low
...	...	...	...	...	...	...	...	...
2185	High	High	High	High	High	High	Low	High
2186	High	High	High	High	High	High	Medium	High
2187	High	High	High	High	High	High	High	High

Defuzzification

The defuzzification process is the process of changing the fuzzy quantity represented in the form of a fuzzy output set with its membership

function in order to obtain a firm value form (Shaum et al., 2023). In this stage, calculations using the Tsukamoto method are carried out to produce the value of rainfall prediction results. The following is the equation used in the defuzzification process.

$$Z = \frac{\sum(\alpha-\text{predict i} \times Z_i)}{\sum \alpha-\text{predict i}} \quad \text{.....(4)}$$

Description:
Z = defuzzification result
Zi = crisp value of inference result
α-predict = minimum value of membership degree
i = number of fuzzy rules

Implementation System

At this stage, the system implementation will be made, and a web-based system will be made. There are several tools used to help make the system in this research, namely HTML, CSS, Python, and Flask.

Evaluation

After forecasting rainfall data in 2022, an evaluation process is carried out by calculating the MAPE value using the original rainfall data in 2022 and the predicted data. MAPE, or Mean Absolute Percentage Error, is a statistical calculation tool used to measure the accuracy of a statistical model to make predictions (Chan, Fitriyah, & Widasari, 2023). The following equation is the MAPE formula.

$$MAPE = \frac{\sum_{i=1}^{n} \frac{|A_i - F_i|}{A_i}}{n} \times 100\% \quad \text{.....(5)}$$

Description:
A_i = actual value
F_i = predicted value
n = number of iterations the addition occurs

RESULTS AND DISCUSSION

Fuzzification

From this fuzzification process, a fuzzy membership function value is generated. The results of the fuzzification process for input in January each year are shown in Table 3 below.

Table 3. Fuzzification Results in January

Inputan	Low	Medium	High
Zi-1	0	0.257	0.743
Zi-2	0	0.883	0.117
Zi-3	0	0.15	0.85
Zi-4	0	0	1
Zi-5	0	0.143	0.857
Zi-6	0	0.577	0.423
Zi-7	0	0.553	0.447

From the fuzzification results, it will then proceed to the inference process, which will be adjusted to the fuzzy rule. Then, calculate the degree of membership and look for the a-predic value.

Defuzzification

At this stage, the process of converting the inference result value into a crisp value is carried out. From the calculations that have been carried out, the result of the rainfall prediction value for January is 570.7709. The defuzzification result value is obtained from the following formula.

$$Z = \frac{\sum(\alpha-\text{predict i} \times Z_i)}{\sum \alpha-\text{predict i}} \quad \text{.....(6)}$$

$$Z = \frac{5764.7870}{10.10}$$

$$Z = 570.7709$$

Then, from the value of the deffuzzification results, it is grouped into rainfall levels. For values less than 100, the level is low. For values between 100 and 300, it is a medium level, and if more than 300, it is high.

Evaluation

In this research, Fuzzy Logic has been applied to rainfall prediction in Sleman Regency. The author has been able to forecast rainfall every month in 2022 in this study. The forecasting results are outlined in Table 4.

Table 4. Predicted Value

Month	STATUS	PREDICTION	ACTUAL
January	Tinggi	570.77	255
February	Tinggi	430.64	251
March	Tinggi	577.61	422
April	Tinggi	384.58	339
May	Sedang	210.52	208
June	Sedang	198.09	280
July	Sedang	177.28	97
August	Rendah	36.47	53
September	Sedang	202.39	100
October	Tinggi	302.66	560
November	Tinggi	713.78	480
December	Tinggi	431.70	413

Based on Table 3, the MAPE value obtained from the forecasting results that have been carried out in this study is 49.31%.

Discussion

Prediction of rainfall in Sleman Regency was successfully carried out using Tsukamoto Fuzzy Logic. The system created in this research is easily accessible to users because the system is web-based. By using a website-based system, users can access it anywhere and anytime.

Based on Table 3, the high rainfall category occurs from the beginning of the year to April. This is in accordance with the season in Indonesia, especially the rainy season. Then, from May to September, the rainfall starts to decrease to a moderate level. In August, rainfall experienced its lowest level, with a rainfall value of 36.47. The season was changed again from dry to rainy season starting in October. This resulted in rainfall from October to December increasing to high levels. The predicted peak rainfall in 2022 is in November at 713.78.

From the predictions that have been made, the peak rainfall occurs in November, which is 713.78, while in the original data, the peak rainfall occurs in October, which is 560. The prediction of the lowest peak of rainfall in 2022 occurs in accordance with the fact that it occurs in October. The difference between the prediction and the original in October is relatively tiny at 16.53. However, the resulting error value per month is quite significant, so the MAPE value resulting from the prediction process is also quite large, which is 49.31%.

Implementation System

After the prediction process using Tsukamoto Fuzzy Logic, the next stage is to implement this prediction system into a web-based system. The design of this web-based system is made to make it easier for users to access the system because the interface is easy to understand, especially for farmers. The following is the interface of the system that has been made in this research.

1. Main Page Interface

On the main page display, there is a feature to upload files from rainfall data in CSV data format. The following is the initial display of this system.

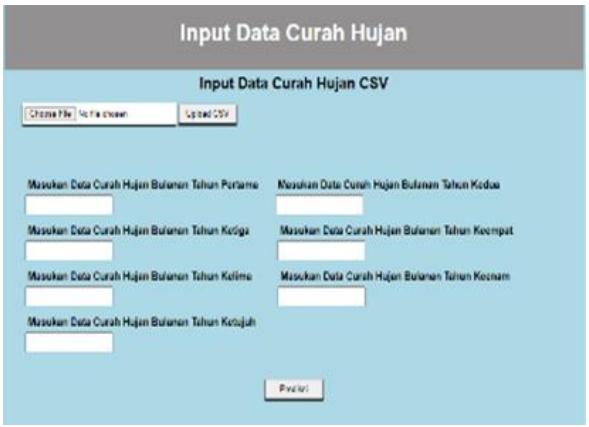


Figure 4. Initial Display on The Main Page

In Figure 4, users can upload files by clicking the Choose File button, selecting the data, and then clicking Upload CSV. Figure 5 below is the display after the user uploads data on the main page.

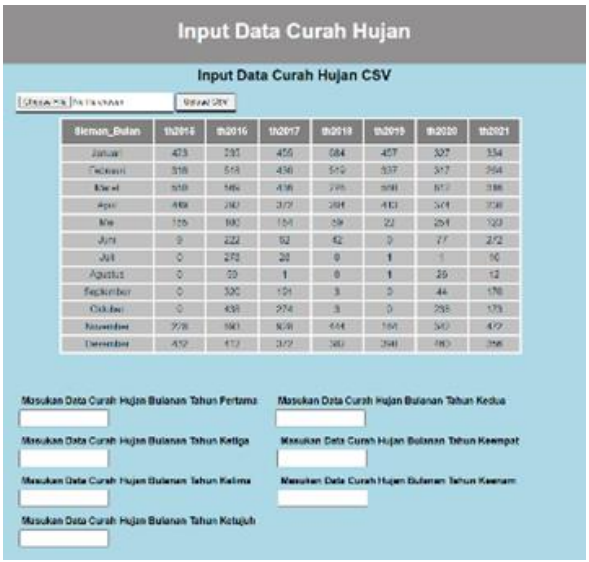


Figure 5. Display After Uploading Data on The Main Page

After the data is successfully entered, the user can enter data from each month that will be predicted in the next year, namely in this study in 2022. Users can enter the data by clicking directly on the desired month. After that, the user can press the Prediction button, as shown in Figure 6.

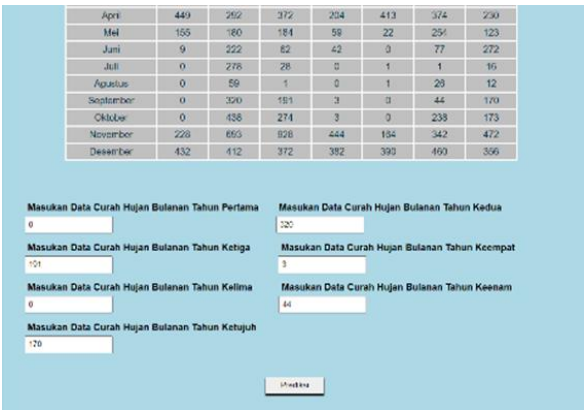
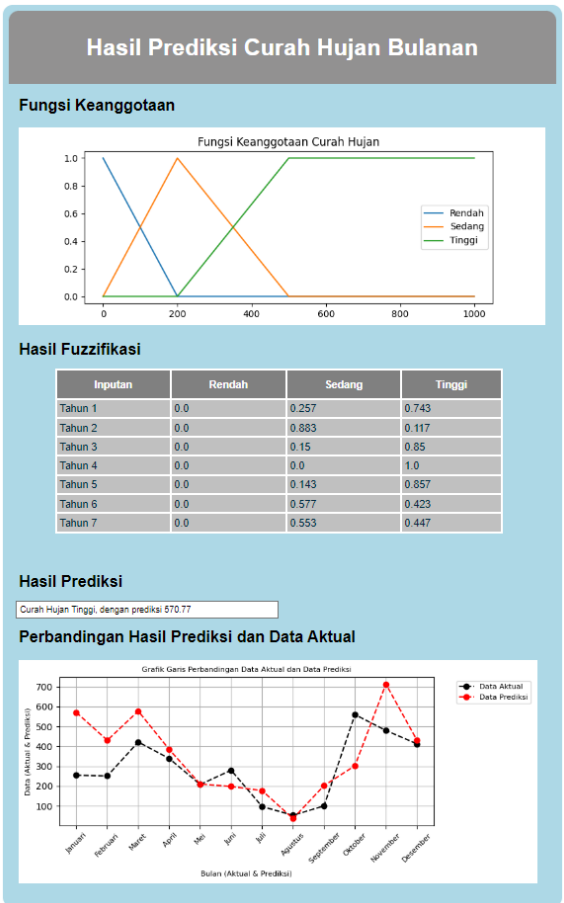


Figure 6. Display After Data Input Every Year

2. Result Page Interface

After the user clicks the Prediction button, the results page will appear, as in Figure 7. This page shows the results of fuzzy logic calculations using the Tsukamoto method.



Inputan	Rendah	Sedang	Tinggi
Tahun 1	0.0	0.257	0.743
Tahun 2	0.0	0.883	0.117
Tahun 3	0.0	0.15	0.85
Tahun 4	0.0	0.0	1.0
Tahun 5	0.0	0.143	0.857
Tahun 6	0.0	0.577	0.423
Tahun 7	0.0	0.553	0.447

Figure 7. Display on The Results Page

This page will display the fuzzification results and rainfall prediction results from the month to be predicted. It will display a comparison graph of the actual value with the predicted value.

CONCLUSIONS AND SUGGESTIONS

Conclusion

From this research, the author draws several conclusions. Tsukamoto Fuzzy Logic has been successfully applied to predict rainfall in Sleman Regency. From this research, Tsukamoto Fuzzy Logic produces poor accuracy compared to previous studies. In this study, we get a MAPE value of 49.31%. Meanwhile, research conducted by Muhandhis et al. (2021) managed to get a MAPE value of 10.64%. It can be concluded that Tsukamoto Fuzzy Logic is not appropriate when used to predict rainfall.

Suggestion

The disadvantage of this research is that its accuracy needs to be developed further. In addition, in the membership function section of monthly rainfall, maybe in further research, it can be added, which in this study only uses three criteria. More criteria can be added, such as very high, to get maximum results.

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