Journal of Research in Mathematics Trends and Technology
Journal homepage: https://talenta.usu.ac.id/jormtt

Comparison of Tsukamoto and Mamdani Methods for Forecasting Rice Production in North Sumatra for 2024

Enita Dewi*[1], Meni Nurmasita Nababan[2], Vepita Vemka Manik[2], Theresia Defi Lasmaria Panggabean[2]

[1]*Statistics Department, Universitas Sumatera Utara, Medan, 20155, Indonesia*
[2]*Mathematics Department, Universitas Sumatera Utara, Medan, 20155, Indonesia*
*Corresponding Author: enitadewi@usu.ac.id

ARTICLE INFO

Article history:
Received: 05 July 2023
Revised: 06 August 2023
Accepted: 28 September 2023
Available online: 30 September 2023

E-ISSN: 2656-1514
P-ISSN: -

How to cite:
Dewi, Enita., Nababan, M.N., Manik, V.V., Panggabean, T.D.L, "Comparison of Tsukamoto and Mamdani Methods in Forecasting Rice Production in North Sumatra". Journal of Research in Mathematics Trends and Technology, Vol. V5, No. 2, Sep. 2023,
doi: 10.32734/jormtt.v5i2.16900

http://doi.org/10.32734/jormtt.v5i2.16900

ABSTRACT

The application of the Tsukamoto and Mamdani methods is widely used in predicting an object based on the objective function to be achieved. This study compares both methods for determining rice production to identify the best method for prediction processes based on error values or forecasting accuracy levels. In predicting rice production, fuzzification and defuzzification stages occur. Actual data that is vague is processed into crisp numbers. Based on the calculation of error values or forecasting accuracy results for each method, the Mean Absolute Percentage Error (MAPE) value for the Mamdani method is 30% and the Tsukamoto method is 22%. Therefore, the forecasting system using the Tsukamoto method is sufficiently effective to predict production results.

Keyword: Defuzzification, Forecast, Fuzzification, Mamdani, Tsukamoto

1. INTRODUCTION

Not all processes in the real world can be modeled exactly. Processes with incomplete information leads to uncertain and ambiguous situations. Processes with this uncertainty have limitations that must be modeled. Uncertainty, unclear, or vague things are also interpreted as fuzzy. Fuzzy theory uses linguistic variables to describe uncertain situations so that they are easier to understand [4]. Based on this fuzzy theory, Lotfi A. Zadeh, a researcher from the University of California (1965), attempted to modify the set theory with the degree of membership in the interval of real numbers [0, 1]. The set was introduced as a fuzzy set. Fuzzy sets allow for gradual assessment through their membership functions. The truth value is not only true or false, but there are other values that lie between true and false [9].

Fuzzy logic is the science of uncertainty that can map an input space into an output space with precision [12]. Fuzzy logic theory uses the concept of a fuzzy system consisting of four stages in the prediction process: fuzzification, fuzzy rule formation, fuzzy reasoning, and defuzzification. One method that uses fuzzy logic is a fuzzy decision support system (fuzzy inference system). Fuzzy Inference System (FIS) is a system of inference from a number of fuzzy rules according to available data to assist decision-making using fuzzy logic. Fuzzy inference systems can use three methods, namely the Tsukamoto method, the Mamdani method, and the Sugeno method. Fuzzy inference is used to model relationships and interactions between variables in a problem [2]. A fuzzy inference system has been implemented in various fields, including forecasting and prediction (Ansar, 2024). By using fuzzy logic, a model such as an uncertain production quantity forecast model can be generated [12].

In this study, the methods used were Tsukamoto's fuzzy inference method and Mamdani's fuzzy inference method. [9] states that in the Tsukamoto method, every rule is represented in the form of IFTHEN, with the result of the calculation being converted to a crisp value. Similarly, to fuzzy logic, the Tsukamoto technique is also completed in four stages, with the rule stage using IF-Then. [6] states the Mamdani fuzzy method, known as the Max-min method, which requires 4 stages to obtain the output as with the Tsukamoto method but has differences when searching for the z value result.

Some studies that have obtained results with a fairly good percentage using the Tsukamoto fuzzy logic inference method include research [8], which uses the Tsukamoto method to predict rainfall with a good level of accuracy. On the other hand, [10] states that Mamdani fuzzy is a method that allows flexibility and tolerance for the existence of data, as in research [15], which compares Tsukamoto fuzzy and Mamdani fuzzy in predicting rainfall intensity. rainfall in Sumenep district.

Rice is a food commodity in Indonesia. The amount of rice production is uncertain and can be excessive or insufficient. The uncertainty can be calculated by applying fuzzy logic. Forecasting the amount of rice production can help the government and the community stabilize the quantity of rice production. In previous research related to forecasting the amount of rice production, research entitled "Comparison of Fuzzy Logic Analysis and Multiple Linear Regression in Determining National Rice Production" by [4] obtained a relative error from using the Tsukamoto method below 0,1. Then, research on predicting rice production with the Tsukamoto fuzzy system [14] produces a fairly accurate average amount of production and calculation results. As well as in the research suggestions mentioned, other researchers can add four or more variables for more accurate results. In 2023, North Sumatra's total rice production based on BPS SUMUT data was 2.080.663,46 tons of rice (BPS, 2024). This amount of production decreased from 2022 by about eight thousand tons. Therefore, rice production in North Sumatra is also uncertain. In the last five years, there has been no prediction of the amount of rice production in North Sumatra province in 2024. Therefore, researchers are interested in conducting research with the same method but different subjects and variables in the hope that, through the prediction results, the North Sumatra Government can maintain food stability for the coming year 2025.

2. METHODS

The methods used in this research are the Tsukamoto fuzzy method and the Mamdani fuzzy method to see a picture of rice production in North Sumatra province in 2024. This method is part of a fuzzy inference system that contains the concept of decision-making through fuzzy logic.

2.1 Fuzzy Logic and Membership Functions

Fuzzy logic is a method of describing an input as an output [5]. In contrast to the concept of classical logic, which states everything with a binary concept (0), fuzzy logic is a method of describing an input (input) into an output (output) [5]. or 1), fuzzy logic has possible membership values between 0 and 1, so there is the possibility of states occurring simultaneously, "True and False." The amount of existence and error depends on the membership value it has. This value between 0 and 1 indicates the value of the degree of membership of a fuzzy set. A fuzzy set has two attributes, namely:

1. Linguistic, which is the naming of a group that represents a certain state or condition using natural language such as cheap, medium, and expensive.
2. Numeric, which is a value (number) that shows the size of a variable, such as 3, 3.5, 4, and so on [13].

A membership function is a curve that shows the mapping of input data points into membership degrees in a closed interval expressed in real numbers [0, 1]. If the membership function of the fuzzy set $\tilde{A}$ in universe X is defined as X, then the fuzzy set $\tilde{A}$ with membership degree $\mu(t)$ is defined as

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(t)) | x \in X\} \tag{1}$$

$$\mu_{\tilde{A}}(t): X \rightarrow [0,1] \tag{2}$$

2.2 *Fuzzy* Metode Tsukamoto

The decision-making process using the Tsukamoto fuzzy method is carried out with the following data processing stages [1] and [8]:

a) Fuzzification

Fuzzification is the process of forming fuzzy sets from input variables (crisp values) to outputs (vague or fuzzy values) with membership functions. This process converts system inputs that have crisp values into linguistic variables with membership functions in the fuzzy knowledge base. The database contains membership functions of fuzzy sets according to the values of the linguistic variables used [12].

b) Formation of basic fuzzy

The formation of a fuzzy membership base (rule in the form of IF-THEN), namely the form of the Tsukamoto fuzzy model, is

IF (X is A) and (Y is B) and (Z is C)

where A, B, and C are fuzzy sets. The proportion following the word "if" is called the antecedent, and the one following the word "then" is called the consequent [11].

c) Inference Engine

To obtain the value of the α −predicate (antecedent) of each rule $(\mu_1, \mu_2, \dots, \mu_i)$ the Tsukamoto method, the MIN implication function in the inference engine process will be used to calculate the crisp inference result output of each rule $(z_1, z_2, \dots, z_i)$.

d) Defuzzification

Defuzzification is the process of forming the fuzzy output of the inference engine into a crisp value using the appropriate membership function in fuzzification. In the Tsukamoto method, the defuzzification process (final result) is obtained using the following average formula (weighted average method of summing Z values)

$$Z = \frac{\sum_{i=1}^{n} \mu_i z_i}{\sum_{i=1}^{n} \mu_i} \tag{3}$$

By

$\mu_i = a - i$th predicate

z_i = output at antecedent of rule$-i$

2.3 Fuzzy Mamdani Method

The Mamdani or MIN-MAX method is one of the fuzzy logic methods used to predict or solve fuzzy or uncertain problems through four stages, namely the formation of fuzzy sets, application of implication functions in the form of MIN values, rule composition, and defuzzification.

1. Fuzzy Set Formation

   The variables contained in a case are defined in a fuzzy set represented through a curve by first finding the membership degree value of the membership function. A fuzzy set is formed based on its condition according to the interval in the membership degree. Variables can be presented in several conditions, such as low, high, less, medium, and others.

2. Implication, Function, and Application

   The rules in the Mamdani method are formed using an implication function, where the rules of the implication function are obtained based on the conditions in the given data. The implication function used in the Mamdani method is the MIN function, which takes the minimum degree of membership of the input variable to be used as output. The formula in the application of the Mamdani implication function is IF... AND..., THEN... = min (a, b).

3. Rule Composition

   In contrast to the implication function, the formation of rule composition uses the MAX function, which takes the maximum value in the rules obtained in the application of the implication function. The maximum value will be processed so that the membership function of the fuzzy solution area is obtained.

4. Defuzzification

   Defuzzification is called affirmation, which means converting fuzzy sets into crisp numbers. The fuzzy solution obtained in the rule composition will be processed into a crisp number through defuzzification so that the output is a number in the domain of the fuzzy set. Defuzzification is called affirmation, which means converting fuzzy sets into crisp numbers. The fuzzy solution obtained in the rule composition will be processed into a crisp number through defuzzification so that the output is a number in the domain of the fuzzy set.

   Defuzzification formula in Mamdani method

$$Z^{*} = \frac{\int \mu(z).z\,dz}{\int \mu(z)dz} \tag{4}$$

2.4 Linear Representation

The input process into membership degrees is represented linearly as a straight line. High and low linear representation

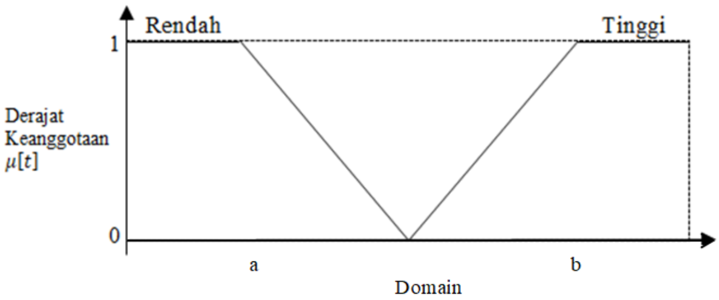

Figure1. Fuzzy set membership graph

Equation form for descending and ascending linear representations [7]

$$\mu_{DOWN}[t] = \begin{cases} 1 & ; t \leq a \\ \dfrac{b-t}{b-a} & ; a \leq t \leq b \\ 0 & ; t \geq b \end{cases} \tag{5}$$

$$\mu_{UP}[t] = \begin{cases} 0 & ; t \leq a \\ \dfrac{t-a}{b-a} & ; a \leq t \leq b \\ 0 & ; t \geq b \end{cases} \tag{6}$$

where

$\mu[t]$ = membership value of t

a, b = domain value with membership degree

t = input or output value to be converted into fuzzy numbers.

2.5 Determining Inference

The initial step in running Tsukamoto's fuzzy inference is to establish the "IF-THEN" rule. Then the degree of membership of each linguistic variable in the data will be calculated so that the α-predicate value can be counted. Fuzzy Tsukamoto uses the MIN implication function, so each value is searched for the minimum value in each rule [8].

2.6 Fuzzy Operator

Based on Zadeh's research, there are 3 operators specifically defined to combine and transform fuzzy sets, namely AND, OR, and NOT [12].

3. The result of an operation with the AND operator is obtained by taking the smallest membership value of each element in the corresponding set intersection (AND) operator relates to the intersection operation on fuzzy sets A and B expressed as $A \cap B$. The result of an operation with the AND operator is obtained by taking the smallest membership value of each element in the corresponding set

$$\mu_{A \cap B} = min\big(\mu_A(x), \mu_B(y)\big) \tag{7}$$

4. The Union Operator (OR) is related to the joint operation on fuzzy sets A and B expressed as $A \cup B$. The result of the operation with the OR operator is obtained by taking the largest membership value of each element in the set concerned

$$\mu_{A \cup B} = max\big(\mu_A(x), \mu_B(y)\big) \tag{8}$$

5. The complement (NOT) operator deals with the complement operation on fuzzy
The result of the operation with the NOT operator is obtained by taking the largest membership value of each element in the corresponding

$$\mu_{A'} = 1 - \mu_A(x) \tag{9}$$

2.7 Forecasting Accuracy Calculation

The prediction method aims to obtain the optimum forecast with the smallest error rate. The accuracy of the model can be calculated using MSE and MAPE.

MSE (Mean Square Error)

This prediction criterion is done by squaring each error and then dividing by the amount of data. The calculation formula [3] is

$$MSE = \frac{\sum_{i=1}^{n}(X_t - F_t)^2}{n} \tag{10}$$

where

X_t = Original data value at time t

F_t = Forecasted data value at time t

n = Number of data

MAPE (Mean Absolute Percentage Error)

After calculating the Tsukamoto fuzzy method, the accuracy of the error (error measure) in each period is then measured using the MAPE value. The MAPE calculation uses the absolute error of each period t and compares the forecasting results with the real value to see the amount of error in forecasting. MAPE is calculated by the formula

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

where

X_t = Original data value at time t

F_t = Forecasted data value at time t

n = Number of data

According to [8], the model is said to have accurate forecasting ability if the MAPE value is lower and very good if the MAPE value is $<$ 10%, good forecasting for MAPE 10–20%, adequate forecasting if the value is 20–50%, and if the MAPE value is $>$ 50%, then the forecasting accuracy is not accurate.

3. RESULTS AND DISCUSSION

3.1 Data Results

The data used in this study are secondary data from the Central Bureau of Statistics (BPS) for 2011–2022, as shown in Table 1 below.

Table 1. Rice Production Data of North Sumatra

Year	Harvested Area (Ha)	Rice Production (Ton)	Total Population (Inhabitants)	Consumption (Ton)
2011	757.547	3.607.403	13.220.936	1.359.984,80
2012	765.099	3.715.513	13.408.202	1.309.257,29
2013	742.968	3.727.681	13.590.250	1.323.744,71
2014	717.318	3.631.039	13.766.851	1.338.192,98
2015	781.769	4.044.829	13.937.797	1.366.601,00
2016	885.575,9	4.609.790,9	14.102.911	1.418.343,86
2017	988.068	5.136.186	14.262.147	1.392.570,30
2018	408.176,45	2.108.284,72	14.415.391	1.391.993,40
2019	413.141,24	2.078.901,59	14.562.549	1.375.767,69
2020	388.591,22	2.040.500,19	14.703.532	1.382.426,08
2021	385.405	2.004.142,51	14.936.148	1.409.703,52
2022	411.462,10	2.088.583,81	15.115.206	1.413.407,80
2023	406.109,49	2.090.475,17	15.386.640	1.443.128,35

3.2 Fuzzification (fuzzy set formation)

Fuzzy values from the fuzzification process are obtained in the form of fuzzy sets, each of which will have a membership degree between 0 and 1. There are 4 variables used, namely three variables (harvest area, population, and consumption) as inputs and one variable (rice production) as output. The following is a table of fuzzy set values for each variable.

The fuzzy membership function is obtained by determining the domain value. The domain value can be determined by using the quartile value of each variable so that the following domain value is obtained:

Table 2. Tsukamoto and Mamdani Fuzzy Sets

Function	Variables	Fuzzy Set Name	Universe of Discourse	Domain
Input	Harvested Area	Down	[385.405, 988.068]	[385.405, 717.318]
		Middle		[407.143, 773.434]
		Up		[717.318, 988.068]
	Total Population	Less	[13.220.936, 15.386.640]	[13.220.936, 14.262.147
		Many		[14.262.147, 15.386.640]
	Consumption	Increased	[1.309.257, 1.443.128]	[1.309.257, 1.382.426]
		Decreased		[1.382.426, 1.443.128]
Output	Rice Production	Down	[2.004.143, 5.136.186]	[2.004.143, 3.631.039]
		Middle		[2.083.743, 3.880.171]
		Up		[3.631.039, 5.136.186]

Then, using MATLAB software, a linear representation is formed with the output:

Fuzzification of the Harvest Area Variable

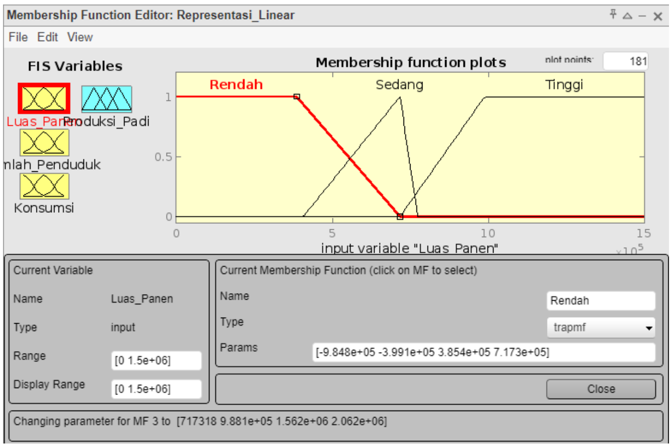

Figure2. Representation of the Tsukamoto and Mamdani Fuzzy Set Values of the Harvested Area Variable

The membership functions of the down, middle, and up sets in the range [385.405, 988.068] for the harvest area variable $\mu[t]$ are

$$\mu_{down}[t] = \begin{cases} 1 \quad ; t \leq 385.405 \\ \dfrac{717.318 - t}{717.318 - 385.405} \quad ; 385.405 \leq t \leq 717.318 \\ 0 \quad ; t \geq 717.318 \end{cases} \tag{12}$$

$$\mu_{middle}[t] = \begin{cases} 0 \quad ; t \leq 407.143 \text{ or } t \geq 773.434 \\ \dfrac{t - 407.143}{717.318 - 407.143} \quad ; 407.143 \leq t \leq 717.318 \\ \dfrac{773.434 - t}{773.434 - 717.318} \quad ; 717.318 \leq t \leq 773.434 \end{cases} \tag{13}$$

$$\mu_{up}[t] = \begin{cases} 0 \quad ; t \leq 717.318 \\ \dfrac{t - 717.318}{988.068 - 717.318} \quad ; 717.318 \leq t \leq 988.068 \\ 1 \quad ; t \geq 988.068 \end{cases} \tag{14}$$

Fuzzification of Variables Total population

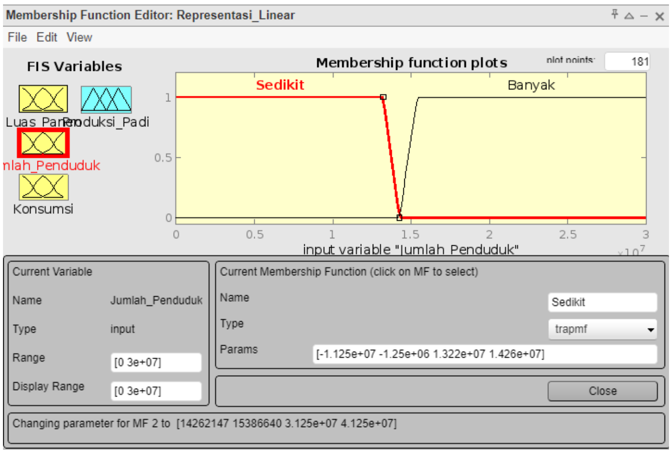

Figure3. Representation of Tsukamoto and Mamdani Fuzzy Set Values of Population Variables

The membership function of the set of few and many in the range [13.220.936, 15.386.640] for the population variable $\mu[t]$ is

$$\mu_{less}[t] = \begin{cases} 1 \quad ; t \leq 13.220.936 \\ \dfrac{14.262.147 - t}{14.262.147 - 13.220.936} \quad ; 13.220.936 \leq t \leq 14.262.147 \\ 0 \quad ; t \geq 14.262.147 \end{cases} \tag{15}$$

$$\mu_{many}[t] = \begin{cases} 0 \quad ; t \leq 14.262.147 \\ \dfrac{t - 14.262.147}{15.386.640 - 14.262.147} \quad ; 14.262.147 \leq t \leq 15.386.640 \\ 1 \quad ; t \geq 15.386.640 \end{cases} \tag{16}$$

Fuzzification of Consumption Variables

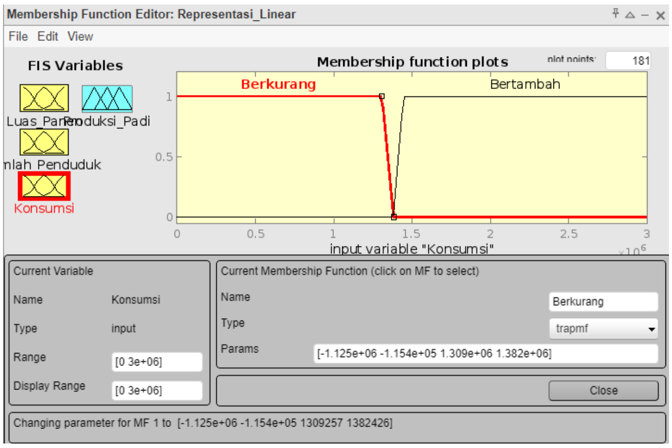

Figure4. Representation of Tsukamoto and Mamdani Fuzzy Set Value of Consumption Variables

The membership function of the decreasing and increasing set in the range [1.309.257, 1.443.128] for the consumption variable $\mu[t]$ is

$$\mu_{decreased}[t] = \begin{cases} 1 \quad ; t \leq 1.309.257 \\ \dfrac{1.382.426 - t}{1.382.426 - 1.309.257} \quad ; 1.309.257 \leq t \leq 1.382.426 \\ 0 \quad ; t \geq 1.382.426 \end{cases} \tag{17}$$

$$\mu_{increased}[t] = \begin{cases} 0 \quad ; t \leq 1.382.426 \\ \dfrac{t - 1.382.426}{1.443.128 - 1.382.426} \quad ; 1.382.426 \leq t \leq 1.443.128 \\ 1 \quad ; t \geq 1.443.128 \end{cases} \tag{18}$$

Fuzzification of Rice Production Variables

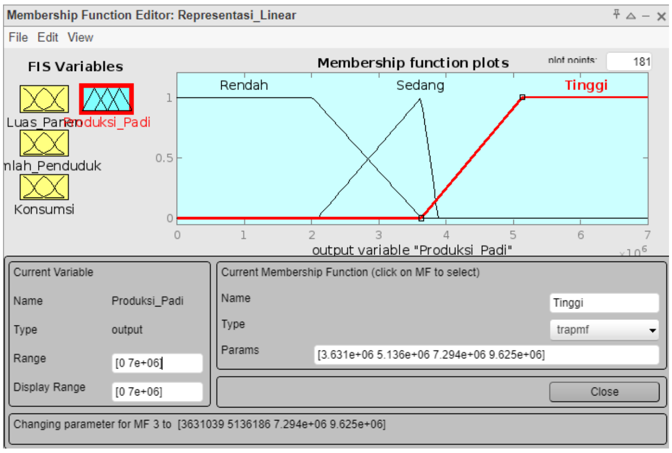

Figure5. Representation of Tsukamoto and Mamdani Fuzzy Set Values of Rice Production Variables

The membership functions of the down, middle, and up, sets in the range [2.004.143, 5.136.186] for the rice production variable $\mu[t]$ are

$$\mu_{down}[t] = \begin{cases} 1 & ; t \le 2.004.143 \\ \dfrac{3.631.039 - t}{3.631.039 - 2.004.143} & ; 2.004.143 \le t \le 3.631.039 \\ 0 & ; t \ge 3.631.039 \end{cases} \tag{19}$$

$$\mu_{middle}[t] = \begin{cases} 0 & ; t \le 2.083.743 \text{ or } t \ge 3.880.171 \\ \dfrac{t - 2.083.743}{3.631.039 - 2.083.743} & ; 2.083.743 \le t \le 3.631.039 \\ \dfrac{3.880.171 - t}{3.880.171 - 3.631.039} & ; 3.631.039 \le t \le 3.880.171 \end{cases} \tag{20}$$

$$\mu_{up}[t] = \begin{cases} 0 & ; t \le 3.631.039 \\ \dfrac{t - 3.631.039}{5.136.186 - 3.631.039} & ; 3.631.039 \le t \le 5.136.186 \\ 1 & ; t \ge 5.136.186 \end{cases} \tag{21}$$

3.3 Fuzzy Basic Rule Formation (Implication Function)

The rules in Tsukamoto fuzzy and Mamdani fuzzy use IF-THEN rules, with the Tsukamoto fuzzy model being [Rn] IF (X is A) and (Y is B) and (Z is C). By analyzing the boundaries of each fuzzy set for each of its variables, fuzzy rules are formed from three input variables and one input variable.

The output obtained 36 fuzzy rules.

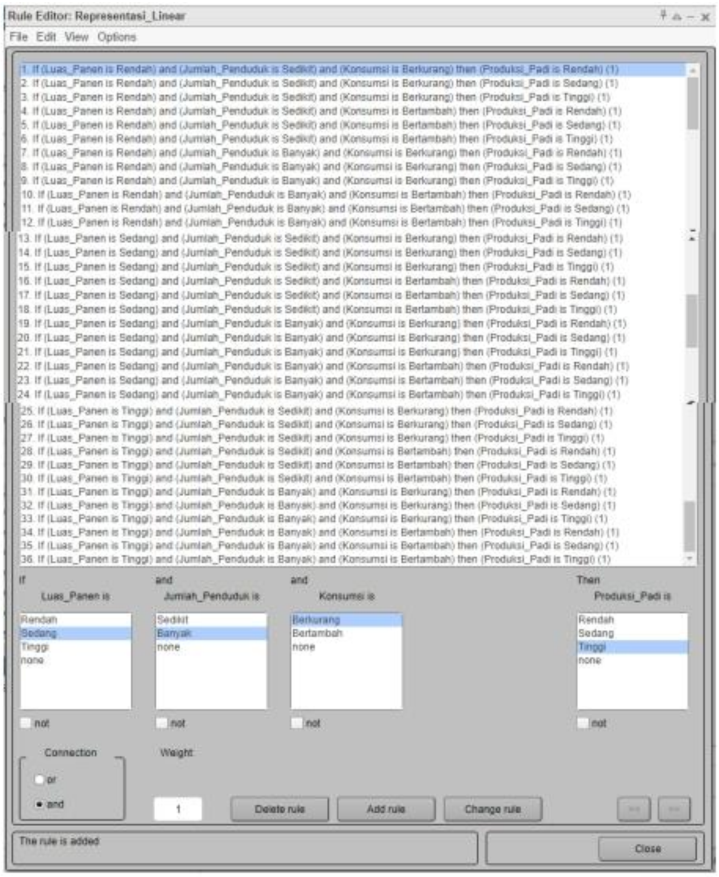

Figure 6. Tsukamoto and Mamdani Fuzzy Rules

3.4 Inference Engine

The value or degree of membership of each variable is calculated for each set of variables (the fuzzy set values are shown in Table 6). The calculation is done in the same way as the following calculation,

6. The harvest area in 2011 is t = 757.547 ha, so degree of membership is

$\mu_{down}[757.547] = 0$

$$\mu_{middle}[757.547] = \begin{cases} 0 \\ \dfrac{773.434 - 757.547}{773.434 - 717.318} = 0{,}2831 \end{cases}$$

$$\mu_{up}[757.547] = \frac{757.547 - 717.318}{988.068 - 717.318} = 0{,}1485$$

7. The total population in 2011 was 13.220.936 people, so the degree of membership is

$\mu_{less}[13.220.936\ ] = 1$

$\mu_{many}[13.220.936\ ] = 0$

8. The total consumption in 2011 was 1.359.984,80 tons, so the degree of membership is

$$\mu_{decreased}[1.359.984{,}80] = \frac{1.382.426 - 1.359.984{,}80}{1.382.426 - 1.309.257} = 0{,}3067$$

$\mu_{increased}[1.359.984{,}80] = 0$

The same way is obtained for the following years in Table 3

Table 3. Membership Values of Tsukamoto and Mamdani Fuzzy Sets

Year	Harvested Area (Ha)			Total Population (Inhabitants)		Consumption (Ton)	
	μ_{down}	μ_{middle}	μ_{up}	μ_{less}	μ_{many}	$\mu_{decreased}$	$\mu_{increased}$
2011		0,2831	0,1485	1		0,3067	
2012		0,1485	0,1764	0,8201		1	
2013		0,5429	0,0947	0,6453		0,8019	
2014		1		0,4756		0,6045	
2015			0,2380	0,3115		0,2162	
2016			0,6214	0,1529			0,5917
2017			1				0,1671
2018	0,9313	0,0033			0,1362		0,1576
2019	0,9164	0,0193			0,2671		0,0909
2020	0,9904				0,3925		
2021	1				0,5993		0,4493
2022	0,9214	0,0139			0,7586		0,5103
2023	0,9376				1		1

3.5 Defuzzification

Each $\boldsymbol{\alpha}-\mathbf{predicate}$ value of each existing rule will be used to calculate the inference output strictly. Based on the input and output, the selected rule is the one with logic in the function. These rules and the results of the Tsukamoto inference calculation for the 2022 data are masing-masing rule

[R11] IF the harvest area is Down AND population is Many AND consumption is Increasing THEN rice production is Middle.

$\alpha_{11}=\min\left(\mu_{down}[411.462{,}10]\,,\mu_{many}[15.115.206],\mu_{increased}[1.413.407{,}80]\right)$

$\alpha_{11}=\min(0{,}9214;0{,}7586;0{,}5103)$

$\alpha_{11}=0{,}5103$

Thus, z_8 for Middle rice Production is obtained,

$\frac{z_8-2.083.743}{3.631.039\ -2.083.743}=0{,}5103\rightarrow z_8\ =2.873.329$

[R24] IF harvest area is Middle AND population is Many AND consumption is Increasing THEN rice production is Up.

$\alpha_{24}=\min\left(\mu_{middle}[411.462{,}10]\,,\mu_{many}[15.115.206],\mu_{increased}[1.413.407{,}80]\right)$

$\alpha_{24}=\min(0{,}0139;0{,}7586;0{,}5103)$

$\alpha_{24}=0{,}0139$

Thus, z_{24} for Up Rice Production is obtained,

$\frac{z_{24}-3.631.039}{5.136.186-3.631.039}=0{,}0139\rightarrow z_{24}\ =3.631.961$

In the Tsukamoto method, the defuzzification or strict z value is obtained by using the average $\boldsymbol{\alpha}-\mathbf{predicate}$ with the z rule value.

$$z=\frac{\alpha_1.z_1+\alpha_2.z_2+\ldots+\alpha_{12}.z_{12}+\ldots+\alpha_{24}.z_{24}+\ldots+\alpha_{36}.z_{36}}{\alpha_1+\alpha_2+\ldots+\alpha_{12}+\ldots+\alpha_{24}+\cdots+\alpha_{36}} \tag{22}$$

$z=\frac{0(3.631.039)+0(2.083.743)+\cdots+(0{,}5103)(2.873.329)+\cdots+0{,}0139(3.631.961)+\cdots+0(3.631.961)}{0+0+0+0{,}5103+0+0+0+0{,}0139+0+0}$

$z=\frac{1.466.260+50.485}{0{,}5242}$

$z=\frac{1.516.745}{0{,}5242}$

$z=2.893.447{,}1575734.$

Based on the results of this defuzzification, it is known that in 2022, the harvest area will be 411.462,10 ha, the population will be 15.115.206 people, consumption will be 1.413.407,80 tons, and the optimal amount of rice production in North Sumatra province using fuzzy logic in 2022 will be 2.893.448 tons.

Meanwhile, in the Mamdani method, the z value is obtained through MATLAB software with the following output results for 2022

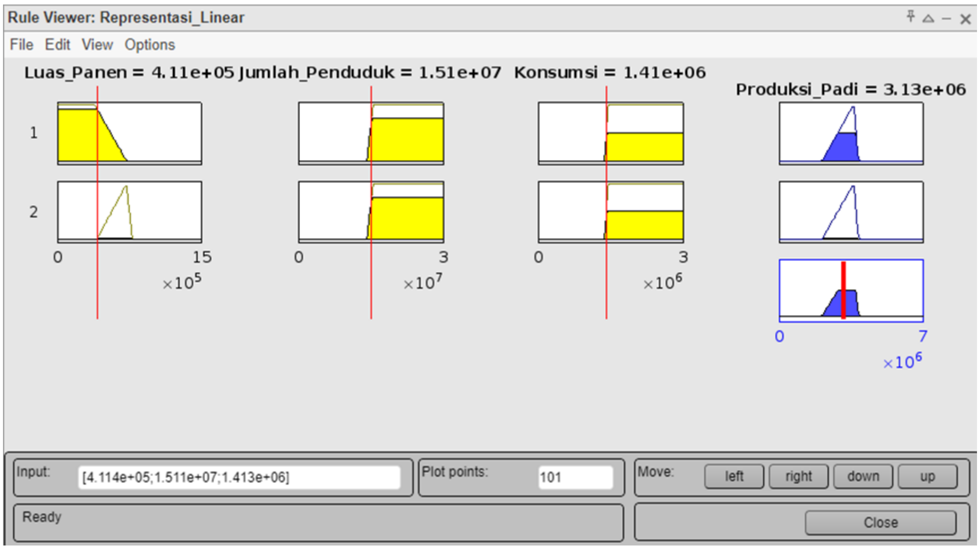

Figure7. Output Results Based on the Mamdani Method Fuzzy Rules (2022)

The same calculation for each year's production is shown in the following table

Table 4. Calculation Results and Comparison with Actual Values

Year	**Rice Production (Ton)**	**Fuzzy Mamdani**	**Fuzzy Tsukamoto**	$\frac{\lvert X_t - F_t \rvert}{X_t}$	
				Fuzzy Mamdani	***Fuzzy* Tsukamoto**
2011	3.607.403	3.070.000	2.875.616	0,148972266	0,148972266
2012	3.715.513	3.040.000	3.839.401	0,181808811	0,033343444
2013	3.727.681	3.140.000	3.761.502	0,157653243	0,009072933
2014	3.631.039	3.500.000	2.819.637	0,036088569	0,223462761
2015	4.044.829	5.420.000	3.956.452	0,339982481	0,021849379
2016	4.609.790,9	5.390.000	3.861.176	0,169250432	0,162396715
2017	5.136.186	5.390.000	5.136.186	0,049416824	0
2018	2.108.284,72	3.030.000	2.289.620	0,437187288	0,086010812
2019	2.078.901,59	3.500.000	3.503.556	0,683581376	0,685291895
2020	2.040.500,19	1.640.000	2.040.500	0,196275498	0,000000093
2021	2.004.142,51	1.630.000	2.900.075	0,186684584	0,447040311
2022	2.088.583,81	3.130.000	2.852.961	0,498623127	0,365978701
2023	2.090.475,17	3.200.000	3.534.488	0,530752456	0,690758183
Total	40.883.330	45.080.000	43.371.170	3,616276954	2,725205133

The average percentage of MAPE of rice production from 2011–2023 with Mamdani and Tsukamoto, respectively, is equal to

$$\mathrm{MAPE} = \frac{\sum_{i=1}^{n} \frac{|X_t - F_t|}{X_t}}{n} \tag{23}$$

Then, for Mamdani:

$$\mathrm{MAPE} = \frac{3{,}616276954}{12} \approx 30\%$$

Meanwhile, for Tsukamoto:

$$\mathrm{MAPE} = \frac{2{,}725205133}{12} \approx 22\%$$

4. CONCLUSION

Based on the research findings and discussions regarding the determination of rice production in North Sumatra Province from 2011 to 2023, the following conclusions can be drawn:

1. The Tsukamoto and Mamdani fuzzy methods, used to predict the supply quantity of food commodities based on data on harvested area, population, consumption, and rice production in North Sumatra Province from 2011 to 2023, can assist the government in making decisions for supplying rice commodities amounting to 43,371,170 tons and 45,080,000 tons, respectively.
2. The Mean Absolute Percentage Error (MAPE) obtained for the Mamdani method is 30%, and for the Tsukamoto method is 22%, with respective accuracy rates of 70% and 78%. This indicates that the forecasting models are reasonably reliable (fairly good). Therefore, it can be concluded that the Tsukamoto method is superior, as it yields a lower error percentage compared to the Mamdani method.
3. The Tsukamoto and Mamdani calculation systems designed can help optimize regional budget requirements for rice needs by considering relevant variables such as harvested area, population, and annual consumption, thus preventing overproduction or underproduction. Based on the MAPE value intervals, the forecasting system using the Tsukamoto method is adequate for predicting production outcomes and can serve as a projection for the following year's production results.

5. CONFLICT OF INTEREST

The Author declares that there is no conflict of interest**.**

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