

Application of Mamdani's Fuzzy Inference System in the Diagnosis of Pre-eclampsia

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ABSTRACT

Pre-eclampsia is the second of the top three causes of death in pregnant women after bleeding and followed by infection. By knowing the risk factors, early detection of pre-eclampsia in pregnant women needs to be done so that later it can be treated more quickly to prevent further complications. This study aims to design a practical application of a decision-making system for the diagnosis of pre-eclampsia in pregnant women using the Fuzzy Inference System (FIS) method so it can be used efficiently and effectively for the early diagnosis of pre-eclampsia. The method used in data analysis is the FIS Mamdani method with defuzzification using the centroid method. The designed system considers blood pressure and proteinuria as input variables and pre-eclampsia status as output variables. The research results show that the system has 7.27% of Mean Absolute Percentage Error (MAPE) value and when comparing the final diagnosis of the system and expert diagnoses (doctors) from 20 patients at two hospitals, it was found that the system diagnosis was 100% in accordance with the expert diagnoses.



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A. INTRODUCTION

Maternal Mortality and Perinatal Mortality Rates in Indonesia is still very high. According to the results of the Inter-Census Population Survey conducted by the Central Bureau of Statistics in 2015, the maternal mortality rate was 305 per 100,000 live births. When compared to the target that the government wants to achieve in 2010 of 125/100,000 live births, this figure is still relatively high (Bardja, 2020). Maternal mortality in East Nusa Tenggara in 2017 was 163 per 100,000 live births (Nassa, 2018), and the Maternal Mortality Rate (MMR) in North Timor Tengah District in 2014 was 137 people. The direct causes of death include pre-eclampsia/eclampsia at 5%, bleeding at 50%, infection at 17%, and other causes at 28% (Yogi et al., 2014).

Pre-eclampsia is a disorder with unknown etiology specifically in pregnant women. This syndrome is characterized by hypertension, and proteinuria that occurs after the 20th week of gestation. Eclampsia is pre-eclampsia which is characterized by seizures

(Muhani and Besral, 2015). Severe pre-eclampsia and eclampsia are risks that endanger the mother in addition to endangering the fetus through the placenta. Every year around 50,000 mothers die in the world because of eclampsia. The incidence of eclampsia in developing countries ranges from 1 : 100 to 1 : 1700 (Lindayani, 2018). The incidence of pre-eclampsia and eclampsia ranges from 5 – 10% of all pregnancies (Muhani and Besral, 2015). According to data from the North Central Timor District Health Office, and data from the Maternal and Child health poly at Kefamenanu regional public hospitals in 2021, out of 600 pregnant women examined 35 pregnant women with pre-eclampsia (Yogi et al., 2014).

The impact that can be caused by preeclampsia on the mother is premature birth, oliguria, and death. In contrast, the impact on the baby is stunted fetal growth and oligohydramnios which can also increase morbidity and mortality (Yogi et al., 2014). Pre-eclampsia with seizures, or what is known as eclampsia, which is not properly controlled can lead to permanent disability or even cause the death of the mother and baby. If eclampsia is not treated quickly there will be loss of consciousness and death due to heart failure, kidney failure, liver failure, or brain hemorrhage. Therefore the occurrence of seizures in patients with eclampsia must be avoided (Lindayani, 2018). Risk factors for pre-eclampsia are maternal age (less than 16 years or more than 45 years), primigravida, presence of hypertension before pregnancy, multiple pregnancies, molar pregnancies, obesity, and history of pre-eclampsia in previous pregnancies (Muhani and Besral, 2015). By knowing the risk factors, early detection of pre-eclampsia in pregnant women needs to be done so that later it can be treated more quickly to prevent further complications.

Several tests will be carried out to detect whether a pregnant woman has pre-eclampsia, namely blood pressure, urinalysis, and several other optional screening tests to measure protein levels (PAPP-A) and measure fetal alpha-fetoprotein (AFP) levels, as well as monitor the development of the babies (Lindayani, 2018). This examination is always carried out in hospitals, health centers, or other health clinics. With a practical application that can be applied efficiently and effectively for the early diagnosis of pre-eclampsia, ordinary people can make an early diagnosis and can immediately start treatment (Niswati et al., 2016).

There are several decision-making systems used in diagnosing a disease, one of which is a fuzzy decision-making system or often called the Fuzzy Inference System (FIS). There are 3 FIS methods that can be used in processing decisions, namely the Tsukamoto method, the Mamdani method, and the Sugeno method (Nizar et al., 2021). There are many researchers who have applied FIS in the process of diagnosing diseases, including diagnosing fever in toddlers (Ukkas et al., 2014), diagnosing coronary heart disease (Wardani, 2014), diagnosing diabetes mellitus (Niswati et al., 2016), diagnosis of ear, nose and eye disease (Yunus, 2017), detection of lymph node disease (Rizki and Maulana, 2018), diagnosis of eye disease (Putra et al., 2018) and risk diagnosis of heart disease (Athiyah et al., 2021) but to detect pre-eclampsia in pregnant women has never been done before. The difference between this research and previous research lies in the type of disease discussed, namely pre-eclampsia in pregnant women. The design of a pre-eclampsia diagnosis system based on the Mamdani FIS with the centroid defuzzification method is new in the field of mathematics and its application in the health sector. The diagnostic system developed will be beneficial because it can be used by ordinary people in detecting pre-eclampsia as early as possible which can be a prevention for maternal deaths due to pre-eclampsia.

Research conducted by Nizar (Nizar et al., 2021) stated about diagnosed diabetes using the three FIS methods and obtained the result that the Sugeno method had the highest level of accuracy in analyzing, namely 97.33%, followed by the Mamdani method at 95.33% and the Tsukamoto method had the highest accuracy. smaller than the Mamdani method, for errors in analysis, the Sugeno method is only 2.67%, the Mamdani method is 4.67% and the Tsukamoto method is 5.78%, for manual calculation time, the Tsukamoto method is the method that requires the least time compared to the Mamdani and Sugeno's method while for calculations, the Mamdani method is the most complicated method. In processing data using FIS, the help of Matlab software can be used. However, this software only contains the Mamdani method, while the Sugeno method and the Tsukamoto method are not available. Even with the help of Matlab software, a GUI (Graphical User Interface) can be made from the FIS that has been made so that later the system can be more easily used by medical staff or the general public (Away, 2014). This study aims to design a decision-making system for diagnosing pre-eclampsia in pregnant women based on blood pressure and proteinuria. After designing the system using Mamdani's Fuzzy Inference System, it will then be compared with the doctor's diagnostic decision to check how accurate the system that has been built is. The contribution of this research is to create a more effective and efficient pre-eclampsia diagnosis system for the community so that early detection of pre-eclampsia can be carried out in order to prevent the death of pregnant women due to delays in treatment.

B. RESEARCH METHOD

This research is a literature study and applied research. A literature study was conducted to find theories about Mamdani's FIS and pre-eclampsia and its examination indicators which would later become the basis for making a diagnostic system. After the system design process, pre-eclampsia case data will be collected from two Regional General Hospitals, namely Atambua Hos-

pital and Kefamenanu Hospital. The data taken is secondary data in the form of medical record data for measuring blood pressure, checking for proteinuria, and doctors' diagnoses of pre-eclampsia patients from 2021 to 2022. The data is then processed using the Mamdani FIS method with the following steps:

1. Fuzzification

The process of converting input variables with crisp values into fuzzy-valued variables uses a membership function that has been developed. There are 3 membership function curves that will be used in this study, namely:

a. Linearly Increasing Membership Function

Definition 1. (Mada et al., 2022) A membership function μ is said to be linearly increasing (on (a, b)) if it can be represented as equation (1),

$$\mu(x) = \begin{cases} 0 & ; x \leq a \\ \frac{x-a}{b-a} & ; a \leq x \leq b, \\ 1 & ; x \geq b \end{cases} \quad (1)$$

For more details, the geometric shape of this function can be seen in Figure 1(a)

b. Linearly Decreasing Membership Function

Definition 2. (Mada et al., 2022) A membership function μ is said to be linearly decreasing (on (a, b)) if it satisfies the equation (2),

$$\mu(x) = \begin{cases} 1 & ; x \leq a \\ \frac{b-x}{b-a} & ; a \leq x \leq b, \\ 0 & ; x \geq b \end{cases} \quad (2)$$

For more details, the geometric shape of this function can be seen in Figure 1(b)

c. Triangular Membership Function

Definition 3. (Mada et al., 2022) A membership function μ is said to be triangular (on (a, b)) if it can be written as equation (3),

$$\mu(x) = \begin{cases} 0 & ; x \leq a \vee x \geq c \\ \frac{x-a}{b-a} & ; a \leq x \leq b, \\ \frac{c-x}{c-b} & ; b \leq x \leq c, \\ 1 & ; x = b \end{cases} \quad (3)$$

For more details, the geometric shape of this function can be seen in Figure 1(c)

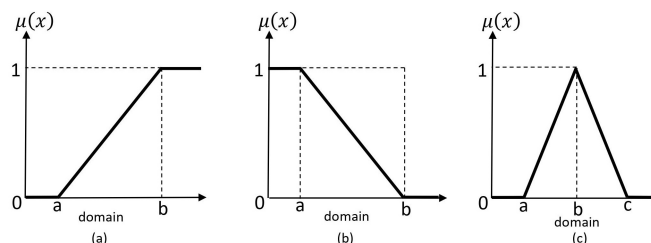


Figure 1. (a) Linearly Decreasing, (b) Linearly Increasing, and (c) Triangular Membership Function

2. Inferencing (Rule Base)

The stage of changing the fuzzy input into fuzzy output by following the IF-AND-THEN rules. Furthermore, at this stage calculations are also carried out for fuzzy decision-making. The Mamdani FIS method is often referred to as the Min-Max

method because the process of determining the final decision uses the Min operation and the Max operation. The Min operation is performed to determine the membership value as a result of the operation of two or more sets, often referred to as fire strength or $\alpha - predicate$ by using the AND operator with the equation formulation shown in (4),

$$\alpha - predicate_i = \mu_{A \cap B}(x) = \min\{\mu_A(x), \mu_B(x)\} \tag{4}$$

where i denotes the i -th rule of the combination of rules formed from any data.

Next, the Max operation is performed, which is an operation to determine the combination of all existing $\alpha - predicates$. This operation is performed using the OR operator with the equation defined by (5),

$$\begin{aligned} \mu(x) &= [R_1] \cup [R_2] \cup \dots \cup [R_n] \\ &= \max\{\alpha - predicate_1, \alpha - predicate_2, \dots, \alpha - predicate_n\} \end{aligned} \tag{5}$$

with $[R_i], i = 1, 2, n$ stating the number of rules formed from any data.

3. Defuzzification

The process of converting back from fuzzy-valued output obtained from inference into crisp-valued output uses the membership function. The process of defuzzification of the Mamdani FIS method in this study uses the Centroid method with the equation defined by (6),

$$z^* = \frac{\int_a^b z \mu(z)}{\int_a^b \mu(z)} \tag{6}$$

After the system design process is complete, then a comparison of the results of the diagnosis is carried out based on processing with the diagnostic system that has been made, and the diagnosis is based on the decision of the expert (doctor) to validate how accurate the diagnostic system that has been made is.

4. Mean Absolute Percentage Error (MAPE)

Before designing a diagnostic system using the Matlab fuzzy toolbox, we first check the prediction accuracy of the system that has been built, using MAPE through the equation defined by (7),

$$MAPE = \frac{\sum_{i=1}^N \left| \frac{X_t - \hat{X}_t}{X_t} \right|}{N} \times 100\% \tag{7}$$

where N = the number of forecasting periods, X_t = the true value at time t , \hat{X}_t = the forecasting value at time t .

Overall, the research stages can be seen in Figure 2.

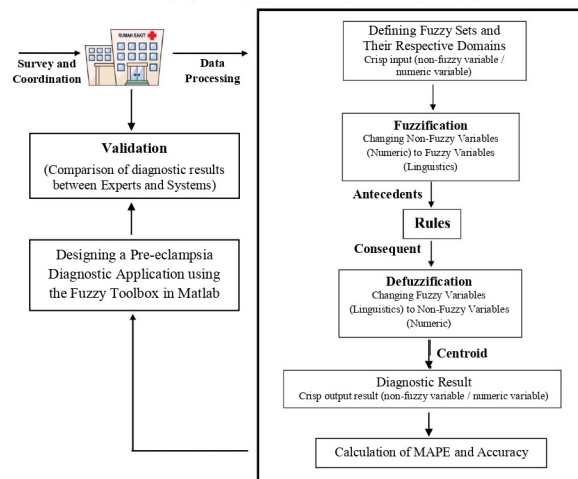


Figure 2. Research Stages

C. RESULT AND DISCUSSION

1. Mathematical Design of the Fuzzification and Rule Formation Stages

a. Fuzzification

Determination of the decision to diagnose pre-eclampsia is based on 2 factors, namely blood pressure, and proteinuria. These two variables then become input variables for the Mamdani FIS diagnostic system.

Input Variable Blood Pressure

Based on (Wantania, 2015) and (Fiano and Purnomo, 2017), the fuzzy set for the blood pressure input variable is divided into 4 sets, namely low blood pressure, normal blood pressure, grade I hypertension, and grade II hypertension. The domains of the 4 fuzzy sets can be seen in the membership function graph presented in Figure 3.

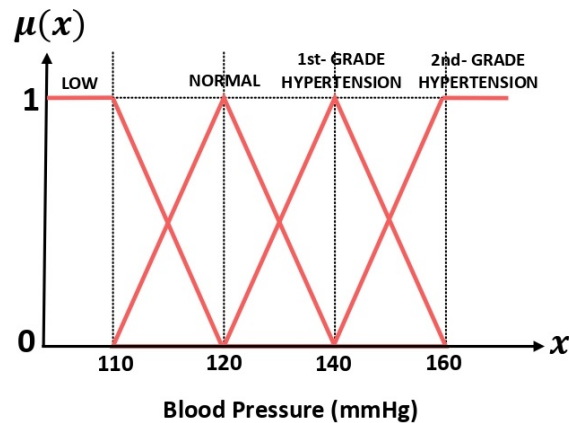


Figure 3. Membership Function Graph of Blood Pressure

While the membership function of the blood pressure variable based on the graph satisfies (8), (9), (10), and (11).

$$\mu_{LOW-BP}(x) = \begin{cases} 1 & ; x \leq 110 \\ \frac{120-x}{10} & ; 110 \leq x \leq 120, \\ 0 & ; x \geq 120 \end{cases} \quad (8)$$

$$\mu_{NORMAL-BP}(x) = \begin{cases} 0 & ; x \leq 110 \vee x \geq 140 \\ \frac{x-110}{10} & ; 110 \leq x \leq 120, \\ \frac{140-x}{20} & ; 120 \leq x \leq 140, \\ 1 & ; x = 120 \end{cases} \quad (9)$$

$$\mu_{I-GH}(x) = \begin{cases} 0 & ; x \leq 120 \vee x \geq 160 \\ \frac{x-120}{20} & ; 120 \leq x \leq 140, \\ \frac{160-x}{20} & ; 140 \leq x \leq 160, \\ 1 & ; x = 140 \end{cases} \quad (10)$$

$$\mu_{II-GH}(x) = \begin{cases} 0 & ; x \leq 140 \\ \frac{x-140}{20} & ; 140 \leq x \leq 160, \\ 1 & ; x \geq 160 \end{cases} \quad (11)$$

where BP = Blood Pressure, I-GH = First-Grade of Hypertension, II-GH = Second Grade of Hypertension

Input Variable Proteinuria

Based on (Pardede et al., 2014) and (Chandra et al., 2020), there are 5 categories to describe the amount of protein in the urine (proteinuria). The five indicators are determined based on the protein precipitate test by heating the urine to a boil (boiling test). This examination is carried out by inserting 10-15 mL of urine into a tube and heating the top of the tube until

it boils and then observing changes in the urine sample in the tube. The interpretation of the five indicators is presented in Table 1.

Table 1. Conditions and Categories of Proteinuria Examination

No.	Category	Condition
1.	Negative (-)	No fog
2.	Positive 1 (+1)	Light fog
3.	Positive 2 (+2)	Clear fog
4.	Positive 3 (+3)	White turbidity
5.	Positive 4 (+4)	There are white lumps

From here, then a fuzzy set and its domain are formed as presented by the graph of the membership function in Figure 4.

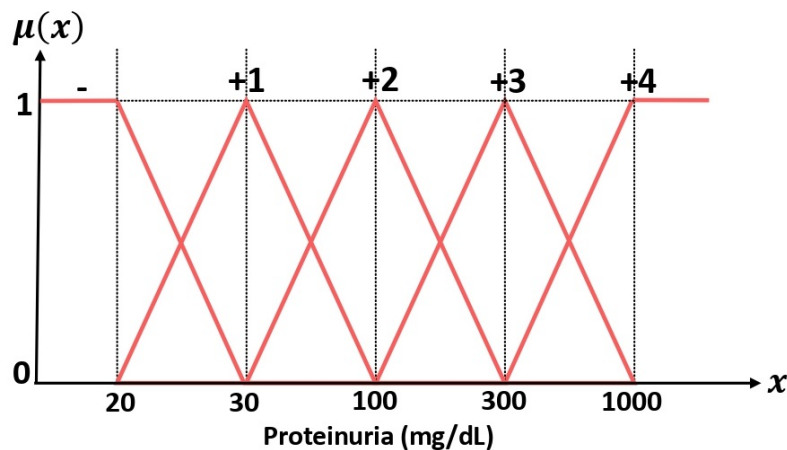


Figure 4. The Union of Membership Function Graph of Proteinuria

While the membership function of the proteinuria variable based on the graph satisfies (12), (13), (14), (15), and (16).

$$\mu_{P-}(x) = \begin{cases} 1 & ; x \leq 20 \\ \frac{30-x}{10} & ; 20 \leq x \leq 30, \\ 0 & ; x \geq 30 \end{cases} \quad (12)$$

$$\mu_{P+1}(x) = \begin{cases} 0 & ; x \leq 20 \vee x \geq 100 \\ \frac{x-20}{10} & ; 20 \leq x \leq 30, \\ \frac{100-x}{70} & ; 30 \leq x \leq 100, \\ 1 & ; x = 30 \end{cases} \quad (13)$$

$$\mu_{P+2}(x) = \begin{cases} 0 & ; x \leq 30 \vee x \geq 300 \\ \frac{x-30}{70} & ; 30 \leq x \leq 100, \\ \frac{300-x}{200} & ; 100 \leq x \leq 300, \\ 1 & ; x = 100 \end{cases} \quad (14)$$

$$\mu_{P+3}(x) = \begin{cases} 0 & ; x \leq 100 \vee x \geq 1000 \\ \frac{x-100}{200} & ; 100 \leq x \leq 300, \\ \frac{1000-x}{700} & ; 300 \leq x \leq 1000, \\ 1 & ; x = 300 \end{cases} \quad (15)$$

$$\mu_{P+4}(x) = \begin{cases} 0 & ; x \leq 300 \\ \frac{x-300}{700} & ; 300 \leq x \leq 1000, \\ 1 & ; x \geq 1000 \end{cases} \quad (16)$$

where $P-$ = Proteinuria Negative, $P+1$ = Proteinuria Positive 1, $P+2$ = Proteinuria Positive 2, $P+3$ = Proteinuria Positive 3, $P+4$ = Proteinuria Positive 4.

Output Variable Pre-eclampsia Status

Because the data on the diagnosis of pre-eclampsia is not quantitative, a measure is needed that represents the status of pre-eclampsia in numbers so that the system can process it. (Masan, 2019) discusses the use of the Poedji Rochjati score to represent the severity of the disease. This score will then be used in determining the fuzzy set for the pre-eclampsia category. There are 4 fuzzy sets for this output variable, non-pre-eclampsia, pre-eclampsia, severe pre-eclampsia type I, and severe pre-eclampsia type II. The domains for each of these fuzzy sets can be seen in the membership function graph of pre-eclampsia status presented in Figure 5.

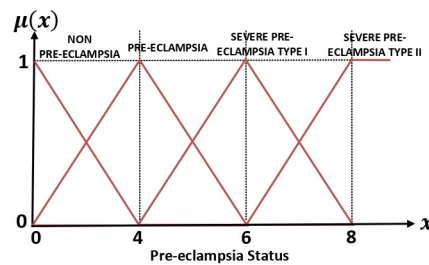


Figure 5. Membership Function Graph of Pre-eclampsia Status

While the membership function of the pre-eclampsia status variable based on the graph satisfies (17), (18), (19), and (20).

$$\mu_{NON-PRE}(x) = \begin{cases} 1 & ; x \leq 0 \\ \frac{4-x}{4} & ; 0 \leq x \leq 4, \\ 0 & ; x \geq 4 \end{cases} \quad (17)$$

$$\mu_{PRE}(x) = \begin{cases} 0 & ; x \leq 0 \vee x \geq 6 \\ \frac{x}{4} & ; 0 \leq x \leq 4, \\ \frac{6-x}{2} & ; 4 \leq x \leq 6, \\ 1 & ; x = 4 \end{cases} \quad (18)$$

$$\mu_{SPE-I}(x) = \begin{cases} 0 & ; x \leq 4 \vee x \geq 8 \\ \frac{x-4}{2} & ; 4 \leq x \leq 6, \\ \frac{8-x}{2} & ; 6 \leq x \leq 8, \\ 1 & ; x = 6 \end{cases} \quad (19)$$

$$\mu_{SPE-II}(x) = \begin{cases} 0 & ; x \leq 6 \\ \frac{x-6}{2} & ; 6 \leq x \leq 8, \\ 1 & ; x \geq 8 \end{cases} \quad (20)$$

where NON-PRE = Non Pre-eclampsia, PRE = Pre-eclampsia, SPE-I = Severe Pre-eclampsia Type I, SPE-II = Severe Pre-eclampsia Type II.

Example 1

Data from a Patient at Kefamenanu Hospital with the initials K. T., has Blood Pressure (BP): 143/83 mmHg (Belongs to 1st-Grade Hypertension and 2nd-Grade Hypertension categories), while Proteinuria: +3.

Based on equation (10) is obtained

$$\mu_{I-GH}(143) = \frac{160 - 143}{20} = 0.85 \quad (21)$$

Furthermore, based on equation (11) is obtained

$$\mu_{II-GH}(143) = \frac{143 - 140}{20} = 0.15 \quad (22)$$

Meanwhile, because the results of the medical record only showing proteinuria +3, it is assumed that the degree of membership for proteinuria is $\mu_{P+3}(x) = 1$.

b. Fuzzy Rule Formulation

The fuzzy rule creation stage uses IF ... AND ... THEN logic. Based on (Fiano and Purnomo, 2017), (Wantania, 2015), (Pardede et al., 2014), (Chandra et al., 2020), and (Masan, 2019) as well as the opinions of experts (doctors and nurses), 27 rules were formed which are presented in Table 2.

Table 2. Fuzzy Rules

RULE	IF	BLOOD PRESSURE	AND	PROTEINURIA	THEN	PRE-ECLAMPSIA STATUS
[R1]	IF	LOW	AND	-	THEN	NON PRE-ECLAMPSIA
[R2]	IF	LOW	AND	+1	THEN	NON PRE-ECLAMPSIA
[R3]	IF	LOW	AND	+2	THEN	NON PRE-ECLAMPSIA
[R4]	IF	LOW	AND	+3	THEN	NON PRE-ECLAMPSIA
[R5]	IF	LOW	AND	+4	THEN	NON PRE-ECLAMPSIA
[R6]	IF	NORMAL	AND	-	THEN	NON PRE-ECLAMPSIA
[R7]	IF	NORMAL	AND	+1	THEN	NON PRE-ECLAMPSIA
[R8]	IF	NORMAL	AND	+2	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R9]	IF	NORMAL	AND	+3	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R10]	IF	NORMAL	AND	+4	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R11]	IF	NORMAL	AND	-	THEN	PRE-ECLAMPSIA
[R12]	IF	NORMAL	AND	+1	THEN	PRE-ECLAMPSIA
[R13]	IF	1st-GRADE OF HYPERTENSION	AND	-	THEN	PRE-ECLAMPSIA
[R14]	IF	1st-GRADE OF HYPERTENSION	AND	+1	THEN	PRE-ECLAMPSIA
[R15]	IF	1st-GRADE OF HYPERTENSION	AND	+2	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R16]	IF	1st-GRADE OF HYPERTENSION	AND	+3	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R17]	IF	1st-GRADE OF HYPERTENSION	AND	+4	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R18]	IF	2nd-GRADE OF HYPERTENSION	AND	-	THEN	SEVERE PRE-ECLAMPSIA TYPE II
[R19]	IF	2nd-GRADE OF HYPERTENSION	AND	-	THEN	PRE-ECLAMPSIA
[R20]	IF	2nd-GRADE OF HYPERTENSION	AND	+1	THEN	PRE-ECLAMPSIA
[R21]	IF	2nd-GRADE OF HYPERTENSION	AND	+1	THEN	SEVERE PRE-ECLAMPSIA TYPE II
[R22]	IF	2nd-GRADE OF HYPERTENSION	AND	+2	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R23]	IF	2nd-GRADE OF HYPERTENSION	AND	+2	THEN	SEVERE PRE-ECLAMPSIA TYPE II
[R24]	IF	2nd-GRADE OF HYPERTENSION	AND	+3	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R25]	IF	2nd-GRADE OF HYPERTENSION	AND	+3	THEN	SEVERE PRE-ECLAMPSIA TYPE II
[R26]	IF	2nd-GRADE OF HYPERTENSION	AND	+4	THEN	SEVERE PRE-ECLAMPSIA TYPE I
[R27]	IF	2nd-GRADE OF HYPERTENSION	AND	+4	THEN	SEVERE PRE-ECLAMPSIA TYPE II

Example 2

Continuing the calculations in Example 1. Because the blood pressure of patient with the initials K. T. = 143/83 mmHg is in the category of 1st-Grade Hypertension and 2nd-Grade Hypertension while her proteinuria is +3, there are 2 rules that may occur, namely:

[R16] IF 1st-Grade Hypertension AND Proteinuria +3 THEN Severe Pre-eclampsia Type I.

[R24] IF 2nd-Grade Hypertension AND Proteinuria +3 THEN Severe Pre-eclampsia Type II.

Next, with AND operator in (4) we will search for the α - predicate value as the size of the intersection of antecedents each rule that is formed.

For [R16],

$$\begin{aligned} \mu(z_1) &= \alpha - predicate_1 = \mu_{I-GH}(143) \cap \mu_{P+3}(x) \\ &= \min\{\mu_{I-GH}(143), \mu_{P+3}(x)\} \\ &= \min\{0.85, 1\} \\ &= 0.85 \end{aligned}$$

Because the output in [R16] is severe pre-eclampsia type I, using equation (19) we obtain:

$$\begin{aligned} \mu(z_1) &= \frac{8-z_1}{2} \\ 0.85 &= \frac{8-z_1}{2} \Rightarrow z_1 = 6.3 \end{aligned}$$

For [R24],

$$\begin{aligned} \mu(z_2) &= \alpha - predicate_2 = \mu_{II-GH}(143) \cap \mu_{P+3}(x) \\ &= \min\{\mu_{II-GH}(143), \mu_{P+3}(x)\} \\ &= \min\{0.15, 1\} \\ &= 0.15 \end{aligned}$$

Because the output in [R24] is severe pre-eclampsia type II, using equation (20) we obtain:

$$\begin{aligned} \mu(z_2) &= \frac{z_2-6}{2} \\ 0.15 &= \frac{z_2-6}{2} \Rightarrow z_2 = 6.3 \end{aligned}$$

Because there are 2 rules that are formed, the OR operator in (5) will be applied as a measure of combining the 2 rules.

$$\begin{aligned} \mu(z^*) &= [R16] \cup [R24] \\ &= \max\{\alpha - predicate_1, \alpha - predicate_2\} \\ &= \max\{0.85, 0.15\} \\ &= 0.85 \end{aligned}$$

The geometric representation of the above process is presented in Figure 6

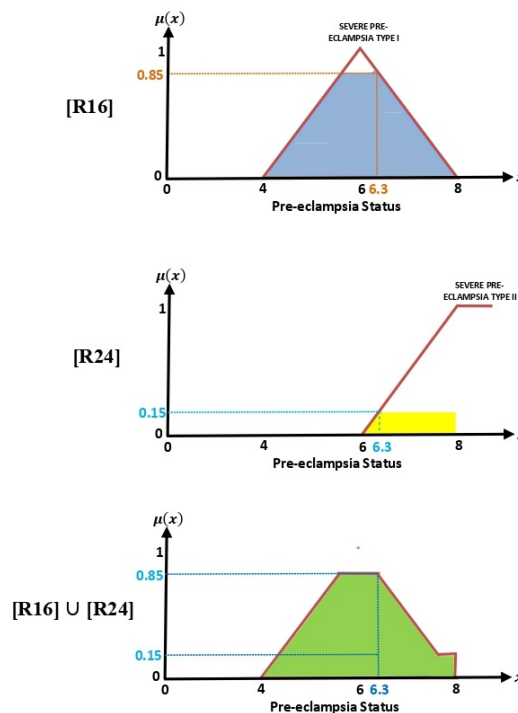


Figure 6. The Union of Consequent Fuzzy Sets [R16] and [R24]

c. Defuzzification

The defuzzification method used in this study is the centroid method with equation (6).

Example 3

Continuing the calculations in Example 2. Look again at Figure 6 which is a combination of 2 inferences. To simplify the calculation, the union area is divided into 4 regions (I, II, III, IV) as shown in Figure 7.

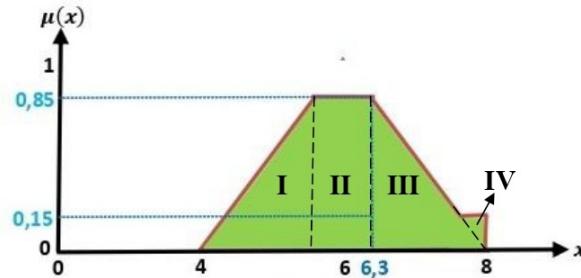


Figure 7. The Union of Consequent Fuzzy Sets [R16] and [R24]

Furthermore, based on Figure 7, equation (6) can be written as

$$z^* = \frac{\int_a^b z\mu(z)}{\int_a^b \mu(z)} = \frac{M_1 + M_2 + M_3 + M_4}{A_1 + A_2 + A_3 + A_4} \tag{23}$$

where M_i = moment from region i , A_i = area i , $i = 1, 2, 3, 4$.

By calculating the moment and area of each region and then substituting into equation (23), the final result is $z^* = 6.39$. Consequently, it can be said that the pre-eclampsia status of the patient with the initials K. T. is severe pre-eclampsia type I.

By applying the same calculation method as in examples 1, 2, and 3 for patient data for the other 19 patients data from Atambua Hospital and Kefamenanu Hospital, a MAPE value of 7.27% and a prediction accuracy of 92.73% was obtained. Based on the interpretation of the MAPE values presented by (Nabilah and Ranggadara, 2020), it can be concluded that FIS Mamdani has a very good ability to determine pre-eclampsia status.

2. The Development of a Pre-Eclampsia Diagnostic System Using the Fuzzy Toolbox in Matlab

After designing the mathematical calculations for FIS Mamdani, the next step is to establish a pre-eclampsia diagnostic system using the toolbox in Matlab. Starting with making membership functions for each variable based on equations (8) to (19). The designing process is presented in Figure 8(a) and Figure 8(b).

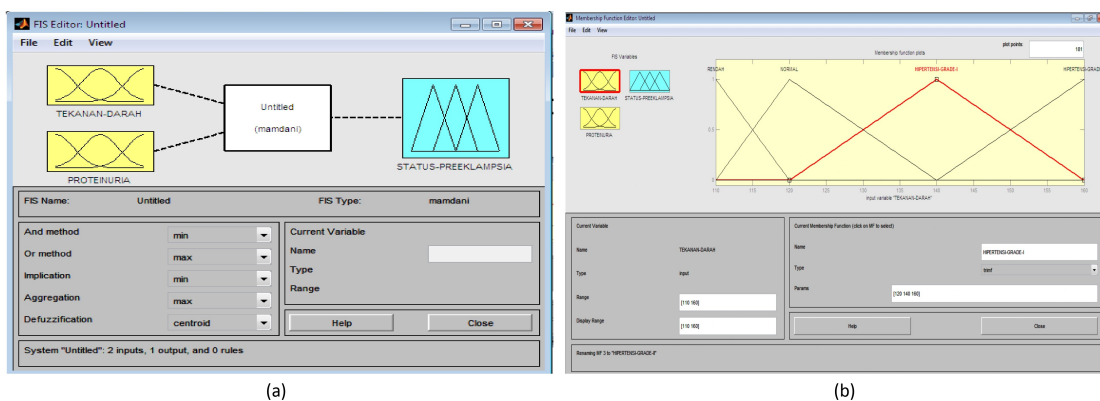


Figure 8. (a) Determination of Input and Output Variables; (b) Domain Settings of Each Fuzzy Set

The results of forming fuzzy sets and their domains are presented in Figure 9, Figure 10, and Figure 11.

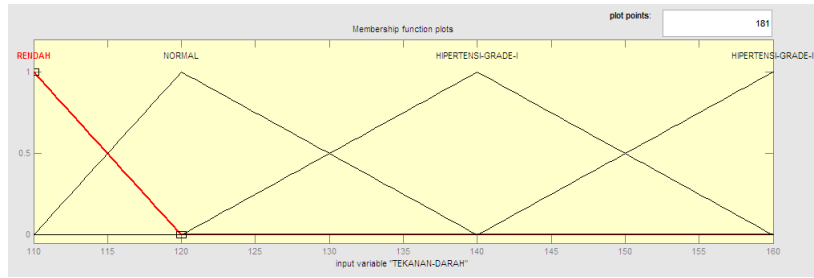


Figure 9. Graph of Blood Pressure variable Membership Function with Matlab

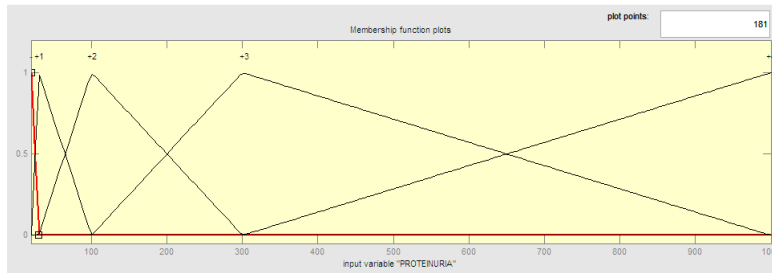


Figure 10. Graph of Proteinuria Membership Function with Matlab

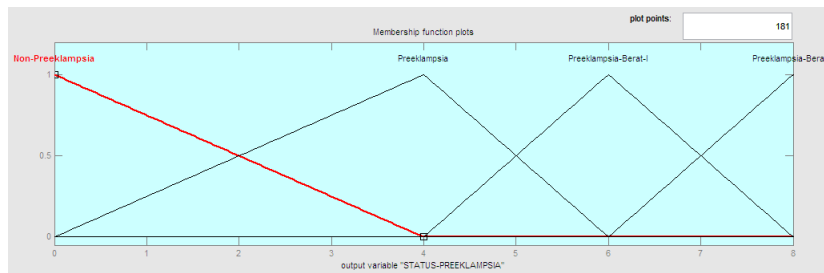
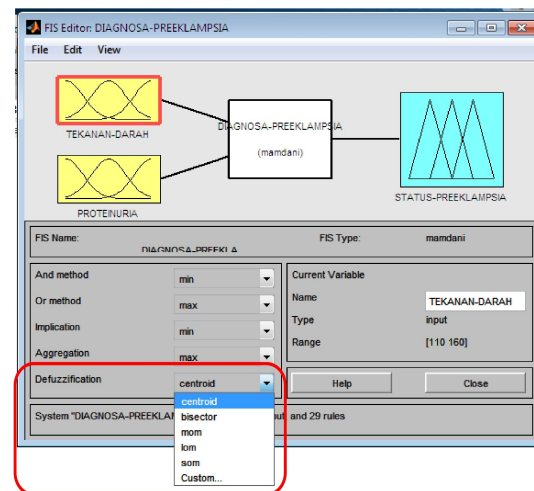


Figure 11. Graph of Pre-eclampsia Status Membership Function with Matlab

The 27 rules that have been made in Table 2 are arranged in the Matlab toolbox as shown in Figure 12(a). For the defuzzification stage, in the toolbox, there are five choices of method that can be changed as shown in Figure 12(b).

1. If (TEKANAN-DARAH is RENDAH) and (PROTEINURIA is -) then (STATUS-PREEKLAMPSIA is Non-Preeklampsia) (1)
2. If (TEKANAN-DARAH is RENDAH) and (PROTEINURIA is +1) then (STATUS-PREEKLAMPSIA is Non-Preeklampsia) (1)
3. If (TEKANAN-DARAH is RENDAH) and (PROTEINURIA is +2) then (STATUS-PREEKLAMPSIA is Non-Preeklampsia) (1)
4. If (TEKANAN-DARAH is RENDAH) and (PROTEINURIA is +3) then (STATUS-PREEKLAMPSIA is Non-Preeklampsia) (1)
5. If (TEKANAN-DARAH is RENDAH) and (PROTEINURIA is +4) then (STATUS-PREEKLAMPSIA is Non-Preeklampsia) (1)
6. If (TEKANAN-DARAH is NORMAL) and (PROTEINURIA is -) then (STATUS-PREEKLAMPSIA is Non-Preeklampsia) (1)
7. If (TEKANAN-DARAH is NORMAL) and (PROTEINURIA is +1) then (STATUS-PREEKLAMPSIA is Non-Preeklampsia) (1)
8. If (TEKANAN-DARAH is NORMAL) and (PROTEINURIA is +2) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
9. If (TEKANAN-DARAH is NORMAL) and (PROTEINURIA is +3) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
10. If (TEKANAN-DARAH is NORMAL) and (PROTEINURIA is +4) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
11. If (TEKANAN-DARAH is HIPERTENSI-GRADE-I) and (PROTEINURIA is -) then (STATUS-PREEKLAMPSIA is Preeklampsia) (1)
12. If (TEKANAN-DARAH is HIPERTENSI-GRADE-I) and (PROTEINURIA is +1) then (STATUS-PREEKLAMPSIA is Preeklampsia) (1)
13. If (TEKANAN-DARAH is HIPERTENSI-GRADE-I) and (PROTEINURIA is +2) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
14. If (TEKANAN-DARAH is HIPERTENSI-GRADE-I) and (PROTEINURIA is +3) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
15. If (TEKANAN-DARAH is HIPERTENSI-GRADE-I) and (PROTEINURIA is +4) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
16. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is -) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
17. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is +1) then (STATUS-PREEKLAMPSIA is Preeklampsia) (1)
18. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is +2) then (STATUS-PREEKLAMPSIA is Preeklampsia) (1)
19. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is +3) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
20. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is +4) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
21. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is +2) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
22. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is +3) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
23. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is +4) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
24. If (TEKANAN-DARAH is NORMAL) and (PROTEINURIA is +4) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
25. If (TEKANAN-DARAH is HIPERTENSI-GRADE-II) and (PROTEINURIA is +4) then (STATUS-PREEKLAMPSIA is Preeklampsia-Berat-I) (1)
26. If (TEKANAN-DARAH is NORMAL) and (PROTEINURIA is -) then (STATUS-PREEKLAMPSIA is Preeklampsia) (1)
27. If (TEKANAN-DARAH is NORMAL) and (PROTEINURIA is +1) then (STATUS-PREEKLAMPSIA is Preeklampsia) (1)

(a)



(b)

Figure 12. (a) Fuzzy Rules with Matlab; (b) Menu Defuzzification in Matlab

Example 4

Patient on behalf Mrs. V.D.B. has a blood pressure of 140/90 mmHg and proteinuria +1. By using the FIS diagnostics that have been developed, the diagnosis status is Severe Pre-eclampsia Type I. The defuzzification process is shown in Figure 13.

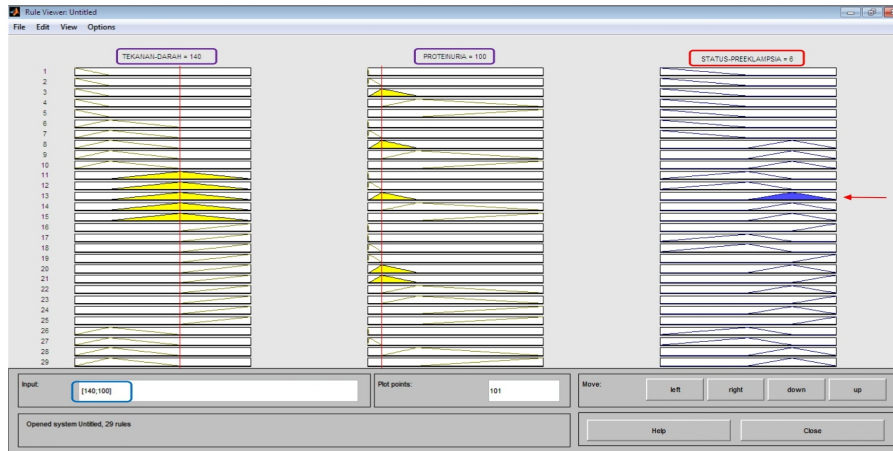


Figure 13. Results of Defuzzification of Pre-eclampsia Status

The blue box is a section for blood pressure and proteinuria values input. The final result as a diagnosis of pre-eclampsia is shown in the form of a score (red box) whose interpretation can be seen in the explanation of the membership function of pre-eclampsia status that has been presented previously while the red arrows indicate the combined set of fuzzy regions which become the centroid of the combination of rules formed for this patient data.

Validation

After designing the diagnostic system, validation was carried out to compare the suitability between the diagnosis results based on expert decisions and FIS. The system is said to be valid when there are more comparisons that are appropriate than those that are not. The following is a comparison of the results of diagnoses based on experts and systems from data on 20 patients from Atambua regional public hospital and Kefamenanu regional public hospital. The comparison is presented in Table 3 below.

Table 3. Comparison Between Calculations Obtained Through FIS Methods and The Actual Data

No.	Patient	Examination		Diagnostic Results		Validation (Appropriate / Inappropriate)
		Blood Pressure (mmHg)	Proteinuria	Expert	System	
1	V. D. B.	140/90	+1	PE	PE	Appropriate
2	R.R.	162/80	-	SPE II	SPE II	Appropriate
3	Y. A. N.	155/111	+3	SPE I	SPE I	Appropriate
4	M. B.	183/110	+1	SPE II	SPE II	Appropriate
5	E. M.	150/100	+2	SPE I	SPE I	Appropriate
6	A. F. F.	156/94	+2	SPE I	SPE I	Appropriate
7	Y. A. L.	141/95	+3	SPE I	SPE I	Appropriate
8	E. L.	200/120	+3	SPE II	SPE II	Appropriate
9	K. T.	143/83	+3	SPE I	SPE I	Appropriate
10	M. W. L.	140/90	+2	SPE I	SPE I	Appropriate
11	M. T.	156/107	+1	PE	PE	Appropriate
12	K. S.	200/140	+2	SPE II	SPE II	Appropriate
13	O. L. F.	110/70	+2	NPE	NPE	Appropriate
14	L. H.	149/95	+2	SPE I	SPE I	Appropriate
15	M. A. S.	107/74	-	NPE	NPE	Appropriate
16	V. M. A. T.	156/104	+2	SPE I	SPE I	Appropriate
17	G. N. M.	150/100	+2	SPE I	SPE I	Appropriate
18	I. D. S. G.	148/106	+2	SPE I	SPE I	Appropriate
19	M. H.	165/97	+3	SPE II	SPE II	Appropriate
20	M. J. A.	156/95	+2	SPE I	SPE I	Appropriate

Where NPE = Non Pre-eclampsia, PE = Pre-eclampsia, SPE I = Severe Pre-eclampsia Type I, SPE II = Severe Pre-eclampsia

Type II.

In the medical field, only severe pre-eclampsia is known and there is no division between type I and type II severe pre-eclampsia. This is only made for the purpose of combining rules at the inferencing stage (rule base) so even though the system diagnosis decision is written SPE I and SPE II, the two have no difference, either in further examination or treatment.

The second patient data with the initials R.R. have two possible diagnoses, namely SPE or NPE. Patients with these conditions will be diagnosed with SPE if, besides the results of this screening, there are other symptoms such as headache, vomiting, or blurred vision. If the patient does not have the intended symptoms then the patient is diagnosed with NPE. Meanwhile, the 13th and 15th patient data are examples of cases that are not cases of pre-eclampsia.

The findings of this research were obtained from a comparison of diagnoses between experts and FIS Mamdani which are presented in Table 3. This means that the diagnosis system can be used to assist the medical team or the community in detecting pre-eclampsia as early as possible so as to prevent pre-eclampsia and eclampsia which can cause death. The results of this research are in line with research conducted by (Fiano and Purnomo, 2017), (Niswati et al., 2016), (Nizar et al., 2021), and (Rizki and Maulana, 2018) where they used the FIS Mamdani method to diagnose heart disease, diabetes mellitus and lymph node disease. The system for diagnosing pre-eclampsia in pregnant women using the FIS Mamdani method has never been created before so this is something new in the field of Mathematics and also its application in the health sector.

D. CONCLUSION AND SUGGESTION

The pre-eclampsia diagnostic system based on input blood pressure and proteinuria, which was designed using Mamdani's FIS showed results that were in accordance with the diagnosis of experts (doctors). This means that, this system can be used to diagnose pre-eclampsia as early as possible in pregnant women as a prevention of further complications that can lead to death. The pre-eclampsia diagnostic system with FIS Mamdani is a new breakthrough in the field of Mathematics and Health because even though a similar system had previously existed, this system had never been implemented in cases of pre-eclampsia. For future researchers, they can expand this research by taking into account other risk factors such as age, primigravida, presence of hypertension before pregnancy, multiple pregnancies, molar pregnancies, obesity, and history of pre-eclampsia in previous pregnancies. The system that was built still uses the Matlab toolbox, so it is necessary to design a Graphical User Interface (GUI) for the system to make it easier to use by medical staff or the general public to use.

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AUTHOR CONTRIBUTION

All authors contributed to the writing of this article.

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COMPETING INTEREST

The authors declare no conflict of interest in this article.

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