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Application of Mamdani Fuzzy Logic in Monitoring Dissolved Oxygen, pH, and Temperature in Koi *Cyprinus rubrofuscus* Raising Ponds

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Abstract

Water quality is very important for the success of ornamental fish rearing, especially in raising koi fish *Cyprinus rubrofuscus*. Koi fish are a very popular ornamental fish commodity, so the use of fuzzy logic in water quality testing will shorten and simplify the process of determining water quality status. This research develops a water quality monitoring system using the Mamdani fuzzy logic method based on three main parameters, namely temperature, pH, and dissolved oxygen (DO). The system was designed to handle the uncertainty and indecisiveness often encountered in water quality assessment, particularly in aquaculture environments. Temperature parameters are classified into cold, normal, and hot categories; pH into acidic, neutral, and alkaline categories; and DO into low, medium, and high categories. Simulation and implementation of the fuzzy inference system were conducted using MATLAB software. Through the process of fuzzification, rule-based inference, and defuzzification, the system successfully predicts the water quality status from bad, normal and good categories. The system is proven to be effective in evaluating water quality status and has the potential to support smarter and more adaptive management of koi fish farming environments.

Keywords: fuzzy logic, water quality

INTRODUCTION

Cyprinus rubrofuscus koi fish is one of the freshwater ornamental fish commodities that has high economic value, both in domestic and international markets (Amelia et al., 2024). In 2023, national koi fish production reached 102,261.75 fish, exceeding the production target of 96,948.91 fish (Fauzan et al., 2024). The success of sustainable koi fish farming is highly dependent on the availability of superior seeds (Rahim et al., 2025). Optimal cultivation management is the key to producing quality koi seeds, both in terms of body morphology and color intensity (Ishaqi & Sari, 2019). The main attraction of koi fish lies in the unique colors and patterns that appear on its back (Kifly et al., 2020).

The main obstacle in koi fish farming is the rapidly declining water quality, which requires constant water changes. Water media in aquaculture systems are very susceptible to being polluted by various activities (Damayanti et al., 2021). Environmental activities and waste from land can pollute waters (Lembang & Kuing, 2021). Water is a vital component in fish life because it directly affects their survival (Jele et al., 2023). Poor water quality can cause stress, reduce growth rates, trigger disease, and even cause death in cultured fish (Hertika et al., 2022). Some factors that affect water quality in aquaculture activities include temperature, pH, and dissolved oxygen levels (Scabra et al., 2022).

Dissolved oxygen is an important element that supports the life of aquatic organisms, both animals and plants. Water has the capacity to supply oxygen needed by living things in it (Novianta et al., 2021). Fish farming systems with high density and intensive feeding, the accumulation of residual feed and feces in the maintenance media can increase, which then has an impact on reducing water quality, including dissolved oxygen levels, and leads to decreased fish productivity (Sofarini et al., 2022). Another obstacle is caused by changes in temperature or unstable temperatures, so that koi fish become stressed and die. In addition, unstable temperatures also cause fish growth to slow down, this is because temperature greatly affects the metabolic process of fish (Amelia et al., 2024).

A pH that is too low (acidic), for example below 6, can damage the gills and external tissues of the fish body, disrupt the osmoregulation process, and reduce the ability of blood to bind oxygen (Humairah et al., 2024). These conditions can also increase the solubility of heavy metals such as aluminum and iron in water, which are toxic to fish (Soegianto, 2023). On the other hand, a pH that is too high (alkaline), for example above 9, can cause irritation to the skin and gills, disrupting the function of important enzymes, which is very harmful to koi fish (Lembang & Kuing 2021). Therefore, there is a need for a system that can control these water quality parameters in the aquarium. The system to be designed is expected to reduce the number of fish deaths and can improve the quality of koi fish (Sugiarto & Zakariyah, 2024).

METHODS

This research was conducted for five months, starting from January 2025 to May 2025 at the Hardware Laboratory and Aquaculture Production Laboratory of Vocational School, IPB University. This research was conducted using a quantitative approach through two main methods, namely data collection and data analysis (Azhari & Tomasoa, 2018). Data and information were obtained through a comprehensive literature review, utilizing the expertise of academics in the field of koi fish farming (Satriawan et al., 2023). Special emphasis was given to important parameters such as water temperature, pH, and DO (Jailani & Saksitha, 2024). The research design was organized with data collection procedures carried out carefully and systematically to ensure the accuracy of the research results.

Theoretical analysis was carefully conducted to examine and collect data, which was processed using MATLAB software (Wardani et al., 2024). The collected data were analyzed by utilizing various statistical tools and methodologies to extract relevant insights. Inputs relating to temperature, pH and dissolved oxygen (DO) are carefully processed according to predefined rules, in order to produce outputs in the fuzzy logic system. The Indonesian National Standard (SNI 7734:2011) on temperature is 20-26ºC, pH is 6.5-8.5 and DO is >5 mg/L. This range of temperature, pH, and DO is considered a decent water quality standard for koi fish life.

The data obtained is refined through the application of the fuzzification process, a sophisticated method rooted in Mamdani fuzzy logic (Muttaqi & Widya Ningsih, 2022). Precise numerical data were converted into fuzzy set form through the method to accommodate the uncertainty and variation inherent in water quality data.An integration of quantitative analysis and fuzzification approach containing elements will be conducted to deepen the understanding of the complex interrelationship between water quality parameters in koi fish pond management (Abrori & Primahayu, 2015). Data were classified into three fuzzy categories, namely: low (0-4), normal (3-7), and good (6-10), based on predetermined standards (Ramdani et al., 2025).

RESULTS AND DISCUSSION

This research develops a water quality status system using mamdani fuzzy logic based on temperature, pH and dissolved oxygen (DO) parameters. This fuzzy logic has the ability to detect vague or unclear water quality status that can be found in water quality status such as temperature, pH and DO (Duta, 2025). The temperature value measurement is divided into three sets, namely cold, normal, and hot, pH is divided into acidic, neutral and alkaline sets, while DO is divided into low, normal, and good sets. The standard levels of temperature 20-28, pH 6.5-8, and DO> 5 are based on SNI 7734: 2017.

Table 1. *Cyprinus rubrofuscus* Defined Standard Temperature Values

Temperature Value	**Temperature Sets**
<20 ºC	Cold
20-28 ºC	Regular
>28 ºC	Hot

Source: SNI 7734:2017

The results of temperature observations during the study showed that the temperature conditions of the rearing media can be classified based on the SNI 7734: 2017 standard for *Cyprinus rubrofuscus* fish. The temperature range is categorized into three groups, namely cold (<20°C), regular (20-28°C), and hot (>28°C) (Daud et al. 2023). These temperature categories are used as a reference in analyzing the effect of temperature on fish performance (Razqa et al., 2024). Based on the data obtained, most of the temperatures during the rearing period were within the regular temperature range, which is the optimal condition for growth and physiological activities of *Cyprinus rubrofuscus* fish (Jele et al., 2023). This indicates that the ambient temperature was within suitable limits to support fish survival and growth during the study.

Table 2. *Cyprinus rubrofuscus* Defined Standard pH Values

Temperature Value	**Temperature Sets**
<6,5	Acite
6,5-8	Neutral
>8	Alkaline

Source: SNI 7734:2017

Analysis of pH parameters during the study refers to the standard pH value according to SNI 7734:2017 for *Cyprinus rubrofuscus* fish. Based on this classification, a pH value of less than 6.5 is categorized as an acidic condition, a pH between 6.5 and 8 is classified as neutral, while a pH above 8 is included in the alkaline category (Barus et al., 2018). The measurement results show that the pH of the rearing media is generally in the neutral range, which is an ideal condition for physiological activities and ionic balance in fish. The presence of pH within these appropriate limits supports optimal metabolic processes and nutrient absorption, and indicates the stable quality of the rearing media throughout the study period.

Table 3. *Cyprinus rubrofuscus* Standard Defined Dissolved Oxygen Values

Temperature Value	**Temperature Sets**
<5	Low
5-8	Moderate
>8	High

Source: SNI 7734:2017

Measurement of dissolved oxygen levels during the study was evaluated based on the SNI 7734:2017 standard for *Cyprinus rubrofuscus* fish. In the standard, dissolved oxygen levels are classified into three categories, namely low (<5 mg/L), medium (5-8 mg/L), and high (>8 mg/L). During the observation period, dissolved oxygen values were generally in the medium to high category. This condition indicates that the water medium has adequate oxygen content to support respiration activities, growth, and physiological stability of fish. The availability of sufficient oxygen also indicates that the aeration system is functioning properly and there is no significant deterioration in water quality during rearing (Apriani & Noordin, 2025).

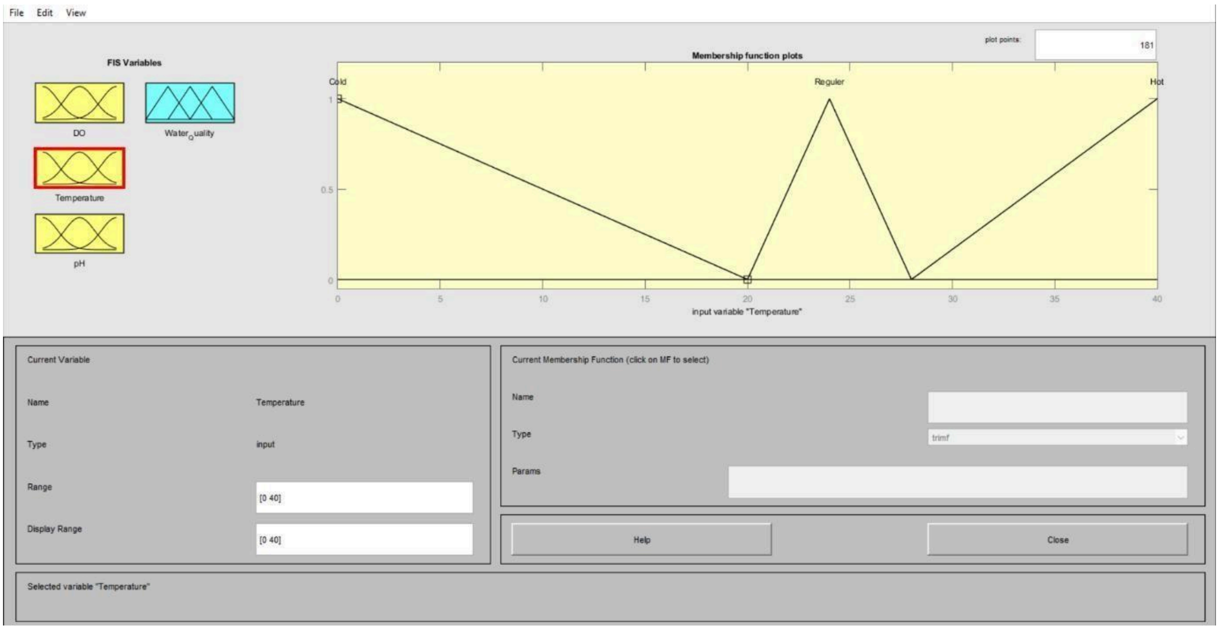

Figure 1. Fuzzification of Temperature Variable as Input for *Cyprinus rubrofuscus*

Figure 1 shows the fuzzification process of the temperature variable as one of the inputs in the fuzzy logic system for *Cyprinus rubrofuscus* fish. This fuzzification process aims to convert crisp temperature values into membership degree values in three linguistic categories, namely "Cold", "Regular", and "Hot". Each category is represented by a triangular membership function, which describes the degree of belonging of a temperature value to each category. Based on the membership function graph, temperatures below 20°C fall into the "Cold" category, temperatures between 20°C and 28°C are classified as "Regular", and temperatures above 28°C fall into the "Hot" category. The range and shape of this membership function are designed in accordance with the optimal temperature standard for *Cyprinus rubrofuscus* based on SNI 7734:2017. Thus, the system can process temperature values flexibly in fuzzy logic-based decision making.

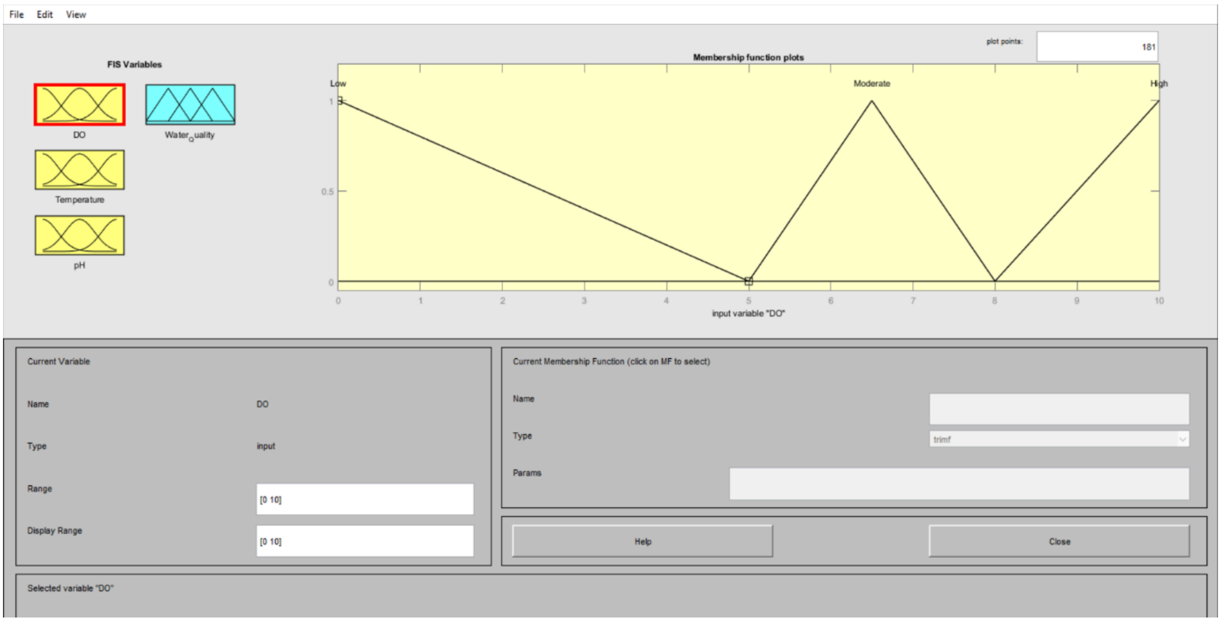

Figure 2. Fuzzification of Dissolved Oxygen Variable as Input for *Cyprinus rubrofuscus*

The fuzzification results on the dissolved oxygen (DO) variable are shown in Figure 2, which illustrates the fuzzy logic-based membership function as the initial stage in the decision-making system. The DO variable is classified into three linguistic sets, namely "Low", "Moderate", and "High", according to the range of values based on SNI 7734:2017. The membership function used is a triangular model, which forms a membership degree curve to the input value of dissolved oxygen. DO values below 5 mg/L have a high membership degree in the "Low" category, while values between 5-8 mg/L are more dominant in "Moderate", and values above 8 mg/L are included in "High". This visualization shows that the system is able to recognize and classify oxygen conditions flexibly, and makes an important contribution to water quality assessment based on dynamic DO inputs.

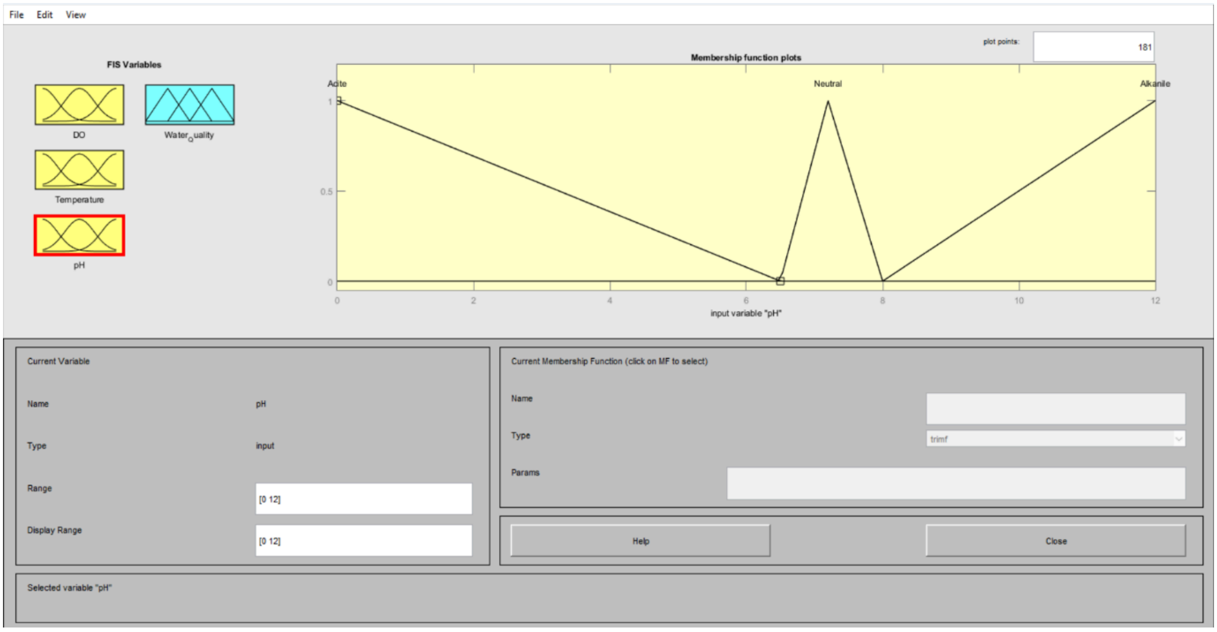

Figure 3. Fuzzification of pH Variable as Input for *Cyprinus rubrofuscus*

Figure 3 presents the fuzzification results of the pH variable as one of the input parameters in the fuzzy logic system for *Cyprinus rubrofuscus* fish. The pH range used in this model is divided into three linguistic categories, namely "Acidic", "Neutral", and "Alkaline". This fuzzification process allows the conversion of numerical pH values into linguistic representations that can be processed by a fuzzy rule-based system. As illustrated in the membership function graph, pH values below 6.5 have the highest membership level in the "Acidic" category, while values between 6.5 to 8 fall under "Neutral", and values above 8 belong to "Alkaline". With this approach, the system is able to capture gradual variations in pH values, making the interpretation of aquatic environmental conditions more adaptive and realistic in supporting water quality management decision-making.

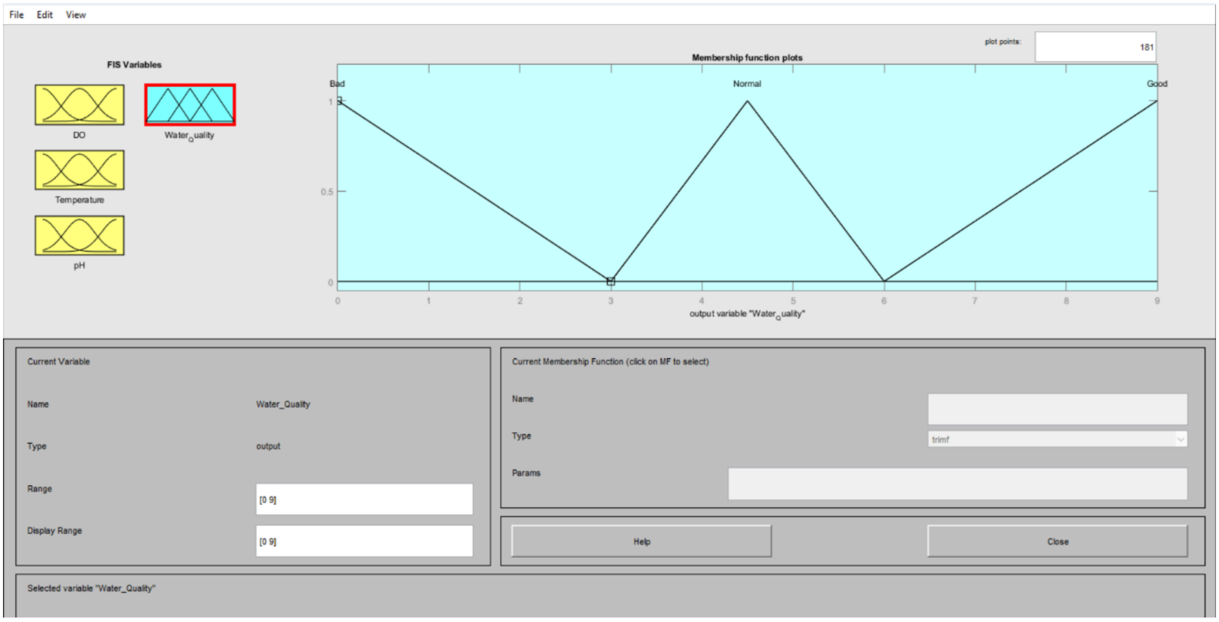

Figure 4. Fuzzification of *Cyprinus rubrofuscus* Water Quality as Output

Figure 4 displays the fuzzification results of the output variable, *Water Quality*, in the fuzzy logic system designed to evaluate the environmental suitability for *Cyprinus rubrofuscus* fish. This output is the result of the integration of the three input parameters (temperature, pH, and dissolved oxygen), which are classified into three linguistic categories: "Poor", "Normal", and "Good". The triangular membership function model used illustrates how strongly an environmental condition is associated with each water quality category. Fuzzy values close to 0 indicate "poor" quality, values close to 5 are classified as "Normal", and values close to 10 fall into the "Good" category. This visualization shows how the system is able to convert complex environmental data into linguistic interpretations that are easier to understand and use to support intelligent and measurable water management decision-making. The water quality status is generated in the rules shown in Table 3 below.

Table 3. Mamdani Rules Used for *Cyprinus rubrofuscus* Water Quality

If	Then
DO is low and temparature is cold and pH Acite	Water quality is bad
DO is low and temperature is regular and pH is neutral	Water quality is normal
DO is low and temperature is hot and pH is alkanline	Water quality is bad
DO is moderate and temperature is regular and pH is neutral	Water quality is normal

DO is moderate and temperature is regular and pH is alkanline	Water quality is normal

If	Then
DO is high and temperature is regular and pH is neutral	Water quality is good
DO is high and temperature is hot and pH is acite	Water quality is bad
DO is moderate and temperature is regular and pH is alkaline	Water quality is normal
DO is high and temperature is cold and pH is alkaline	Water quality is bad
DO is high and temperature is hot and pH is neutral	Water quality is normal
DO is moderate and temperature is hot and pH is alkaline	Water quality is bad
DO is moderate and temperature is cold and pH is alkaline	Water quality is bad
DO is high and temperature is cold and pH is neutral	Water quality is normal
DO is moderate and temperature is hot and pH is acite	Water quality is bad

Based on the results of Mamdani fuzzy logic rule generation (Priyo, 2017) and the fuzzification process in Table 3, the defuzzification results for water quality prediction are shown in Figure 5 below.

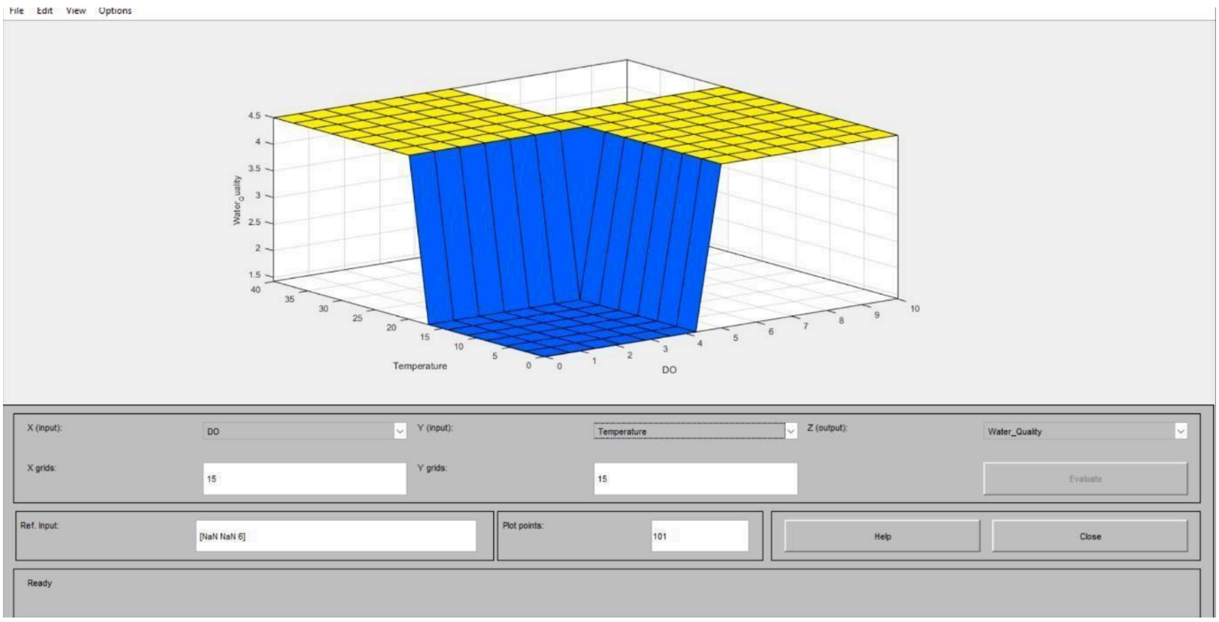

Figure 5. Defuzzification of Water Quality Predictions for DO and Temperature

Figure 5 shows the graph, the DO and temperature values of 15 each produce a high prediction of water quality, indicated by the yellow area on the surface of the graph. This process is carried out through a fuzzy logic system that processes DO and temperature inputs into fuzzy rules, then produces an output in the form of a *crisp* value of water quality (Fahmi & Saputra, 2020). These results show that under optimal DO and temperature conditions, water quality is in the good category. This interface is likely to be created using MATLAB Fuzzy

Logic Toolbox, which supports visualization and interactive testing of fuzzy inference systems.

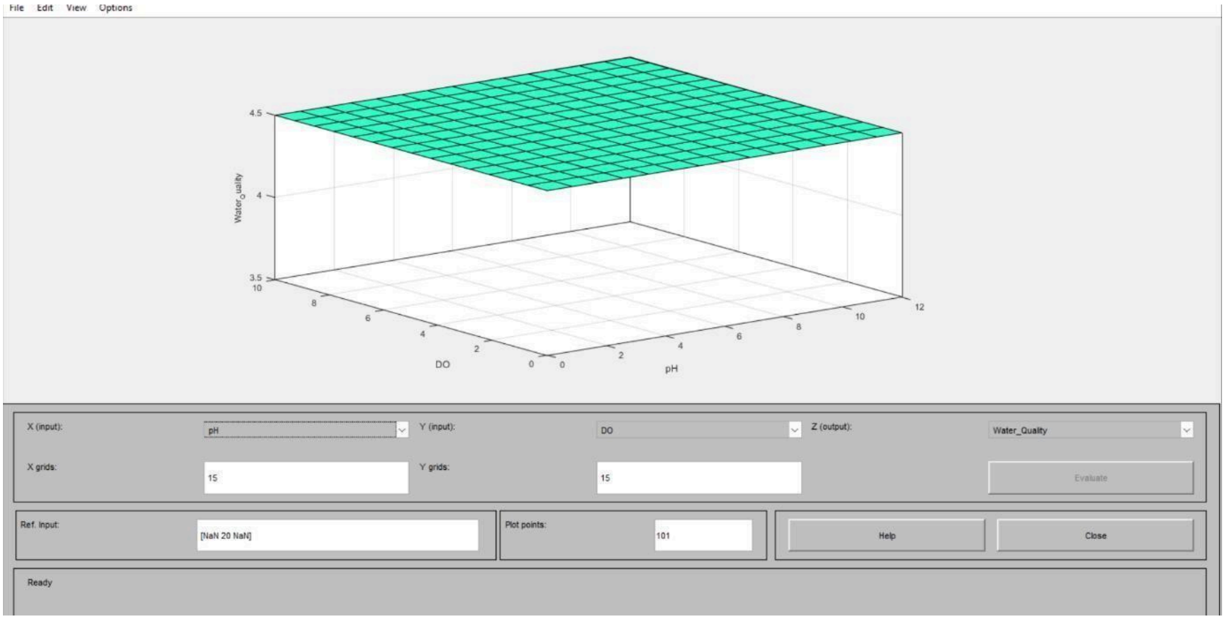

Figure 6. Defuzzification of Water Quality Predictions for pH and DO

Figure 6 shows the defuzzification results in water quality prediction based on two input parameters, namely pH and DO (*Dissolved Oxygen*). The 3D surface visualization shows that for all combinations of pH and DO values displayed, the predicted water quality has a constant and high value, as seen from the green flat surface at the top of the graph. This indicates that the fuzzy system considers the combination of these values to be in optimal or near-optimal conditions, resulting in consistently good water quality. In the input section, the pH and DO values are each filled with 15, and the predicted water quality results seem to remain high regardless of the input variation. This phenomenon could indicate that in the fuzzy model used, the effect of pH and DO variations on water quality is not very significant or that the fuzzy rules applied are not sensitive enough to distinguish water quality conditions based on changes in pH and DO in detail.

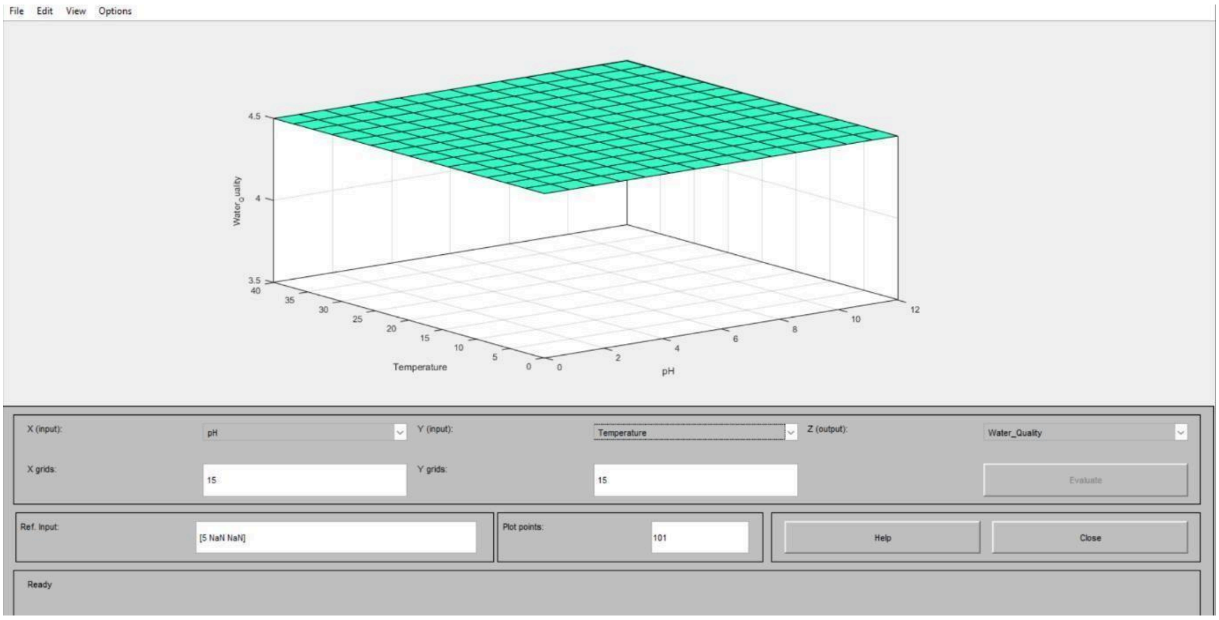

Figure 7. Defuzzification of Water Quality Predictions for Temperature and pH

Figure 7 shows the defuzzification results in the prediction of water quality based on two parameters, namely temperature and pH. The resulting 3D graph surface appears flat and at a high level, indicating that the fuzzy system predicts relatively constant and good water quality values across the combination of pH and temperature values tested. The input values, pH = 15 and temperature = 15, produced high water quality outputs. This indicates that the fuzzy model considers the entire range of pH and temperature values used to be under ideal conditions or have no significant impact on water quality degradation. However, this uniform result may also indicate that the fuzzy system used is less sensitive to changes in these two parameters, so it may be necessary to review the fuzzy rules or membership functions to be able to distinguish water quality conditions more accurately.

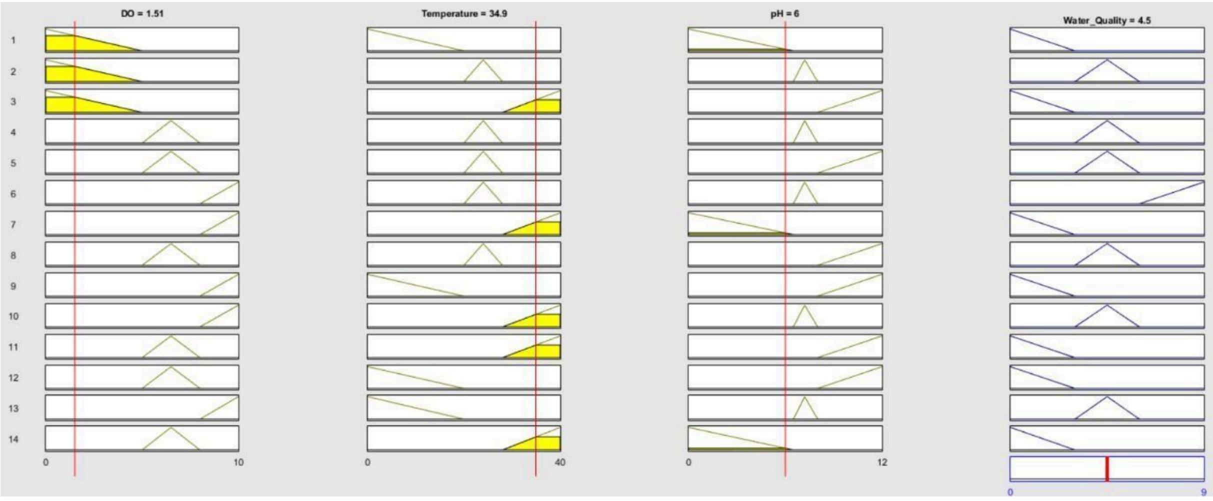

Figure 8. Value of Each Fuzzification

Figure 8 shows the results of the fuzzification and fuzzy inference process for water quality prediction based on three input parameters, namely DO, temperature, and pH, and one output parameter, namely Water Quality. The input values used are DO of 1.91, temperature of 34.9°C, and pH of 4.6. In each graph, the red vertical line shows the position of the input value against the fuzzy membership function, while the yellow area indicates the membership level to a particular category. Very low DO, high temperature, and acidic pH all fall under the category of conditions that are not ideal for water quality. The defuzzification results displayed on the output graph show a very low Water Quality value, around 0.5 on a scale of 0-5. This indicates that the combination of input values is processed by the fuzzy system as a poor water condition (Prayudha et al., 2018). Thus, the fuzzy model used has been able to accurately represent the logical relationship between environmental parameters and water quality (Fahmi & Saputra, 2020).

CONCLUSION

This research has successfully developed a Mamdani fuzzy logic-based water quality evaluation system using temperature, pH, and dissolved oxygen (DO) parameters. The numerical values of each parameter are converted into linguistic categories through the fuzzification process, then processed using fuzzy rules to produce water quality predictions. Based on the fuzzification and defuzzification results, the water quality can be accurately identified as poor, normal and good. Thus, this system is considered capable of representing the relationship between environmental parameters and water quality effectively under conditions of uncertainty.

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