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Prediction of Water Quality in Ponds Based on Temperature, Water Clarity, pH, and Dissolved Oxygen Using Mamdani Fuzzy Logic

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Abstract

Water quality is pivotal for successful fish breeding, particularly in pond-based systems. This paper reviews several studies on water quality assessment in fish ponds, analyzing physical and chemical parameters such as temperature, water clarity, pH, and dissolved oxygen (DO). However, existing studies often need help in precisely evaluating water quality due to uncertainties in the obtained values. This study suggests applying fuzzy logic; specifically, the Mamdani method-to produce more accurate and conclusive assessment values to overcome this problem. Fuzzy logic enables the processing of vague information, overcoming existing uncertainties. The study highlights four key parameters; temperature, water clarity, pH, and dissolved oxygen-consistently influencing water quality assessment. By incorporating Mamdani fuzzy logic into water quality evaluation, this research aims to enhance the accuracy and effectiveness of assessment methods, thereby advancing previous research efforts in fisheries cultivation.

Keywords: dissolved oxygen**.** fuzzy logic, pH, temperature, water clarity.

INTRODUCTION

Water quality is a crucial indicator that significantly affects the success of fish breeding (Indriati and Hafiludin, 2022). This also holds for fish breeding in ponds; it is imperative to maintain water quality in fish ponds. Several parameters can influence water quality: temperature, acidity level or pH of water, dissolved oxygen content, and water clarity (Fauzia and Suseno, 2020).

In the study "*Water Quality Assessment for Milkfish (Chanos Chanos Forsskal) Cultivation in Ponds in Samataring Village, East Sinjai District*," testing was conducted regarding the water quality in milkfish ponds, focusing on physical parameters such as temperature, clarity, salinity, pH, nitrate, and phosphate. All these parameters were compared with the standard values specified in the Indonesian National Standard (SNI) (Wahyuni *et al*., 2020).

In "*The Study Of Physical And Chemical Water Parameters Suitability For Fish Culture Development Area Using Floating Net Cages In Ie Sayang Lake*," temperature, current velocity, depth, pH, clarity, and dissolved oxygen (DO) concentration were among the physical and chemical parameters that were analyzed. In order to determine the evaluation standards for satisfactory water quality in this investigation, analysis was performed on the obtained values by referring to several modified references from Yulitius et al. (Rahmayanti et al., 2021).

Furthermore, in the study "*The Monitoring System for Water Temperature at Koi Fishponds Based on Internet of Things*," temperature observations were conducted in fish ponds to determine the growth, appetite, and weight of koi fish produced (Indriyanto et al., 2020). Numerous studies have been conducted to determine the excellent water quality in fisheries cultivation.

However, those studies must improve the assessment criteria as they provide uncertain values outside the existing standards. This research will utilize fuzzy logic to clarify the values to be assigned. Fuzzy logic enables processing vague information and addresses existing uncertainties (Cahyaningrum, 2023).

Various parameters can be used to analyze water quality. Four parameters consistently present in each study serve as important indicators of water quality: temperature, water clarity, pH, and dissolved oxygen (DO) levels. This research will use fuzzy logic to use these three parameters to assess water quality for fish ponds. Fuzzy logic plays a role in providing more optimal output than mere observation to further the previous research.

METHODS

The study was conducted over a two-month period spanning from January 25, 2024, to March 8, 2024, at the Hardware Lab of IPB University College of Vocational Studies. It was employed using quantitative research methodology with two main methods; data collecting and data analysis. Data and information were acquired through a comprehensive literature review, drawing upon the expertise of scholars in the field of fish pond management, with particular emphasis on parameters such as temperature, water clarity, pH, and dissolved oxygen (DO). The research design entailed meticulous and systematic data collection procedures.

Engaging in theoretical analysis, we meticulously examined and amassed data, subsequently processing it through Matlab. Employing quantitative techniques, we scrutinized the gathered data, leveraging a plethora of statistical tools and methodologies to extract meaningful insights. Inputs pertaining to temperature, water clarity, pH, and dissolved oxygen (DO) were meticulously subjected to designated rules delineated by domain experts to achieve output for fuzzy logic.

Subsequently, these insights underwent further refinement through the application of fuzzification, a sophisticated method rooted in Mamdani fuzzy logic, which facilitates the conversion of precise numerical data into fuzzy sets, thereby accommodating inherent uncertainties and variations. By adeptly integrating quantitative analysis with the nuanced approach of fuzzification, the research aspired to deepen the comprehension of intricate interrelationships between various water quality parameters inherent in fish pond management.

RESULTS AND DISCUSSION

In this study, we developed a water quality prediction system for a pond using Mamdani fuzzy logic based on input conditions such as temperature, water clarity, pH, and dissolved oxygen. Mamdani's fuzzy logic is grounded in its ability to address the uncertainty and ambiguity often encountered in water quality measurements, such as temperature, pH, water clarity, and dissolved oxygen.

Temperature measurements are defined into three fuzzy sets: cold, regular, and hot. The values for each set are based on references from previous studies, such as the research on "*The Monitoring System for Water Temperature at Koi Fishponds Based on Internet of Things,"* which discusses cold temperature values below 25℃, typical temperature values around 25℃ - 27℃, and hot temperature values exceeding 27℃. Based on the journal references, a temperature value table was derived as follows.

Table 1. The Standard Temperature Value Sets

Temperature Value	Temperature Sets
< 25 ℃	Cold
25 - 30 ℃	Regular
> 30 ℃	Hot

Source : Indriyanto, S., Syifa, F. T., & Permana, H. A. (2020)

The measurement of pH or acidity values is defined into three fuzzy sets: acidic, neutral, and alkaline. The values for each set are based on references from previous studies, such as the research on *"Mamdani Fuzzy Inference System for Mapping Water Quality Level of Biofloc Ponds in Catfish Cultivation,"* which discusses the standard pH value for catfish being around 6.5 - 8.5 pH values below 4 or above 11 will render the catfish unable to survive, while pH values around 4 - 6.4 or 8.6 - 11 will hinder catfish growth. The following pH value table was created using the journal references as a guide. The measurement of pH or acidity values is defined into three fuzzy sets: acidic, neutral, and alkaline.

Table 2. The Standard pH Value Sets

pH Value	pH Sets
< 6	Acidic
6 - 8,5	Neutral
> 8,5	Alkaline

Source : Pujiharsono, H., & Kurnianto, D. (2020)

The measurement of water clarity is defined into three fuzzy sets: low, moderate, and high. The values for each set are based on references from previous studies, such as the research on "*The Study Of Physical And Chemical Water Parameters Suitability For Fish Culture Development Area Using Floating Net Cages In Ie Sayang Lake,"* which defines good water clarity as ranging from 30 to 40 cm. The table below represents the water clarity values created using the previously given journal references.

Table 3. The Standard Water Clarity Value Sets

Water Clarity Value	Water Clarity Sets
< 25 cm	Low
25 - 40 cm	Moderate
> 40 cm	High

Source : Fitria Rahmayanti & Nurul Najmi. (2021)

Dissolved oxygen (DO) levels are measured into three fuzzy sets: low, moderate, and high. The values for each set are based on references from previous studies, such as the research on "*Management Of Water Quality For Tilapia (Oreochromis Niloticus) Hatching Fish At Balai Benih Ikan Teja Timur Pamekasan,*" which defines the optimal dissolved oxygen level in water as ranging from 6.1 to 14.5 mg/L. The following table for dissolved oxygen (DO) readings was created using the previously described journal as a reference.

Table 3. The Standard Dissolved Oxygen (DO) Value Sets

DO Value	DO Sets

< 3 mg/L	Low
3 - 5 mg/L	Moderate
> 5 mg/L	High

Source : Indriati, P. A., & Hafiludin, H. (2022)

Based on the values of these sets, the fuzzification process can be created for each input variable used. The membership values of the output variable water quality are divided into two categories: Good and Poor, with a scale of values from 0 to 10. The highest value for Good is 10, and the highest value for Poor is 0. Therefore, the fuzzification process can be formulated as follows.

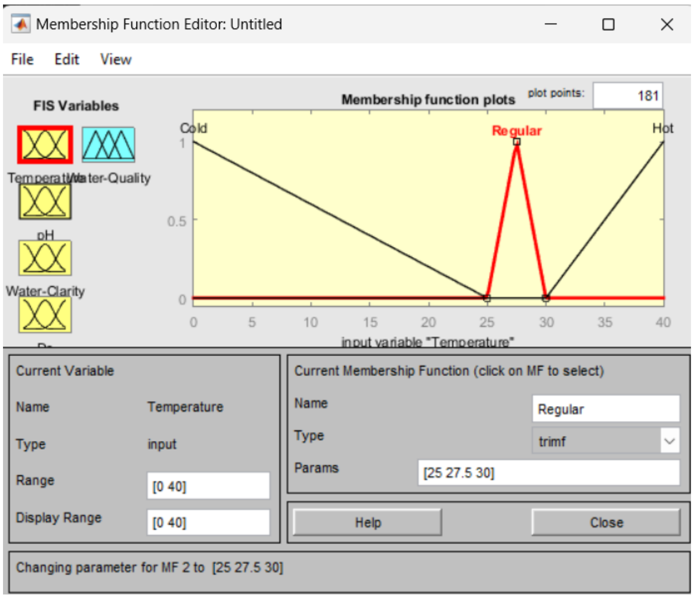

Figure 1. Fuzzification of Temperature Variable as Input

The set of temperature is divided into 3 subsets: Cold, Regular, and Hot, with respective values based on the reference from the journal by Indriyanto, S., Syifa, F. T., & Permana, H. A. (2020). Cold, Regular, and Hot each have a membership value of 1.

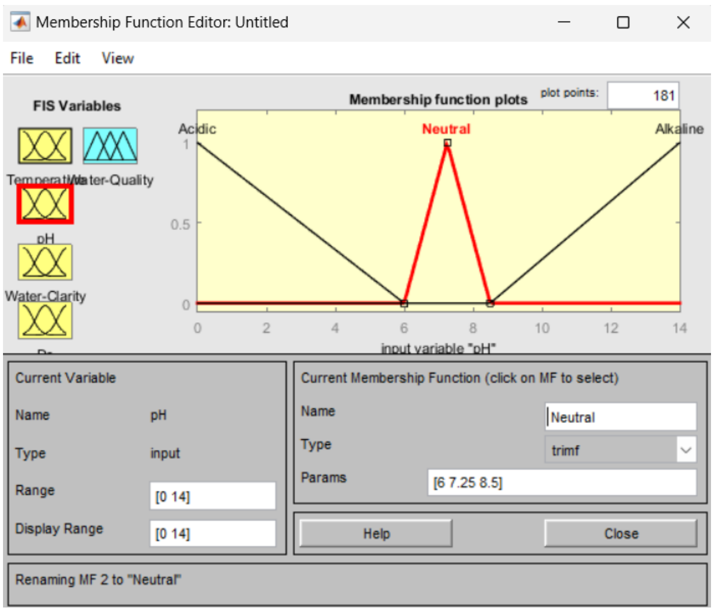

Figure 2. Fuzzification of pH Variable as Input

The pH set is partitioned into three subsets: Alkaline, Neutral, and Acidic. The values of each subset are determined by referencing the journal article written by Pujiharsono, H., and Kurnianto, D. (2020). The membership value for acidic, neutral, and alkaline substances is 1.

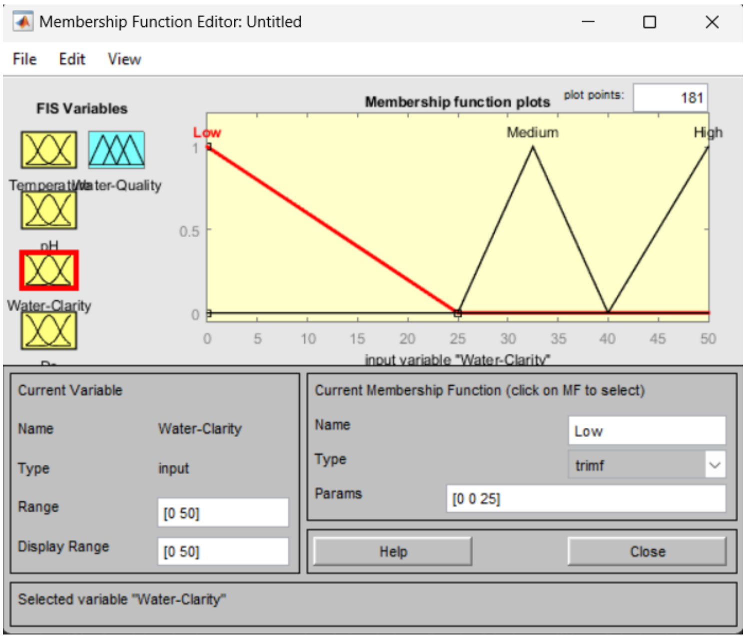

Figure 3. Fuzzification of Water Clarity Variable as Input

The water clarity set has been partitioned into three subsets: Low, Moderate, and High. The membership values of each subset are determined by referencing the journal article authored by Fitria Rahmayanti and Nurul Najmi (2021). The membership values of Low, Moderate, and High are all 1.

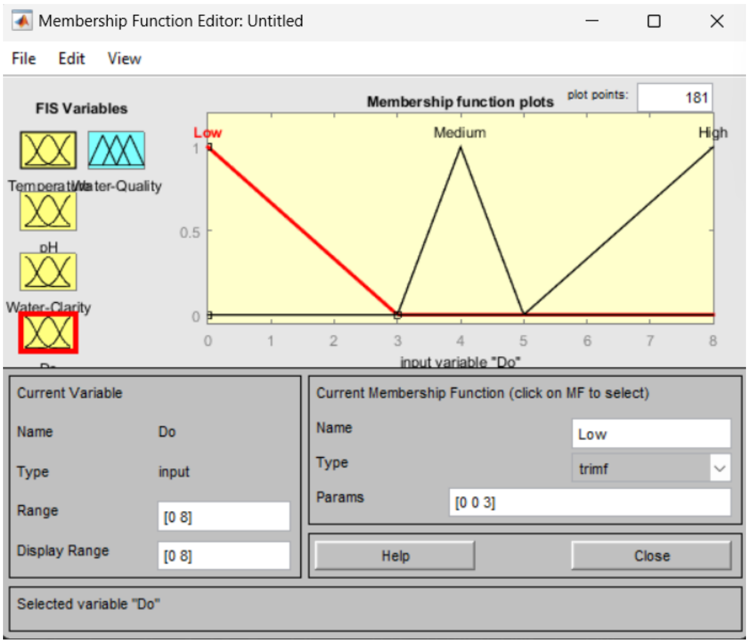

Figure 4. Fuzzification of DO Variable as Input

The dissolved oxygen set is partitioned into three subsets: Moderate, High, and Low. The membership values of each subset are derived from the journal article authored by Indriati, P. A., and Hafiludin, H. (2022). The membership values of Low, Moderate, and High are marked to be 1.

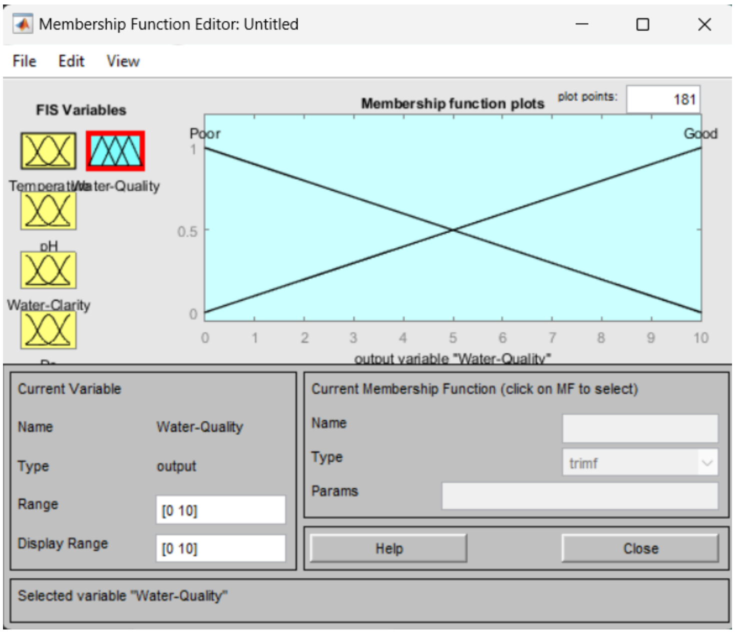

Figure 5. Fuzzification of Water Quality as Output

After successfully creating fuzzification, rules can be determined to obtain the desired defuzzified output values. The rules are established using a fuzzy inference system Mamdani method based on the reference from the journal "*Mamdani Fuzzy Inference System For Mapping Water Quality Level Of Biofloc Ponds In Catfish Cultivation*," which employs the same input variables such as temperature, pH, and dissolved oxygen. However, the difference lies in including water clarity as a distinguishing factor compared to the previous study. In the previous research, the Mamdani rules used are as follows.

Table 4. The Mamdani Rules as Reference

IF	THEN
Temperature is Cold or pH is Acidic or DO is Low	Poor
Temperature is Hot or pH is Alkaline or DO is High	Poor
Temperature is Regular or pH is Neutral or DO is Moderate	Good

Based on the previous rules, modifications can be made by adding the value of the water clarity input variable to each rule statement that has been created using the "or" operator. Moderate water clarity will be included in the statements to ensure good water quality. In contrast, low or high water clarity will be placed in the other statements, resulting in poor water quality. Using the "or" operator in each rule reflects that good water quality occurs when the pond's temperature, pH, dissolved oxygen, and water clarity are appropriate. The following fuzzy logic rules will be used.

Table 5. The Mamdani Rules Used

IF	THEN
Temperature is Cold or pH is Acidic or DO is Low or Water Clarity is Low	Poor
Temperature is Hot or pH is Alkaline or DO is High or Water Clarity is High	Poor
Temperature is Regular or pH is Neutral or DO is Moderate or Water Clarity is Moderate	Good

Based on the results of creating Mamdani fuzzy logic rules and the fuzzification process, the defuzzification results for predicting water quality are as follows.

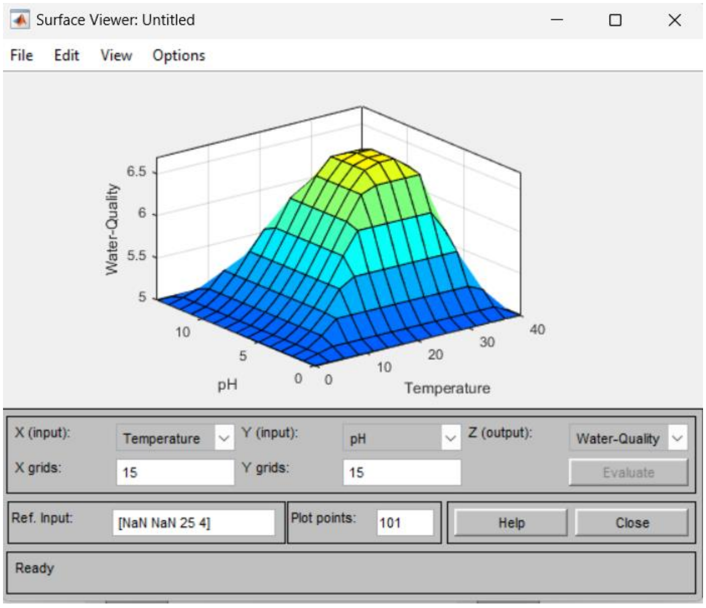

Figure 6. Defuzzification of Water Quality Prediction

Based on the defuzzified output, it is evident that for the input values of temperature, pH, water clarity, and dissolved oxygen the obtained defuzzified value of 6.1 indicates that the environmental condition is not yet approaching the optimal range for clean water quality. This suggests that further improvements or interventions may be necessary to achieve the desired level of water quality. The defuzzified value serves as a quantitative indicator of the environmental state, guiding decision-makers in prioritizing actions and allocating resources to address existing challenges.

In this study, a proposed theory's applicability was tested by examining multiple environmental parameters. The parameters investigated included temperature, pH level, water quality, and Dissolved Oxygen (DO) concentration. For instance, the observed temperature was recorded at 26°C, while the pH level was measured at 6.5. Additionally, water quality was assessed at a depth of 38.5 cm, and the concentration of Dissolved Oxygen was determined to be 3.5 mg/L. These values served as empirical data points to evaluate the proposed theory's validity and applicability within the studied environmental conditions. The manual calculation process is detailed below to provide a full understanding of the defuzzification procedure.

Temperature = 26°C

$\mu T[26]$

- Cold = 0
- Regular = 0.4 $\frac{x-a}{b-a} = \frac{26-25}{27.5-25} = \frac{1}{2.5} = 0.4$
- Hot = 0

PH = 6,5

$\mu P[6.5]$

- Acidic = 0
- Neutral = 0.4 $\frac{x-a}{b-a} = \frac{6.5-6}{7.25-6} = \frac{0.5}{1.25} = 0.4$
- Alkaline = 0

Water Quality = 38.5 cm

$\mu C[38.5]$

- Low = 0
- Moderate = 0.2 $\frac{c-x}{c-b} = \frac{40-38.5}{40-32.5} = \frac{1.5}{7.5} = 0.2$
- High = 0

Dissolved Oxygen (DO) = 3.5 mg/L

$\mu C[3.5]$

- Low = 0
- Moderate = 0.5 $\frac{x-a}{b-a} = \frac{3.5-3}{4-3} = \frac{0.5}{1} = 0.5$
- High = 0

The fuzzification process in the presented case study adhered to a set of predefined rules for converting crisp input variables into fuzzy sets. These rules were established to capture the linguistic uncertainties inherent in the measured environmental parameters.

1. IF T is Cold or ... then Poor

   $a_1 = \max(\mu T, \mu P, \mu C, \mu D)$

   $= \max(0, 0, 0, 0)$

   $= 0$

2. IF T is Hot or ... then Poor

   $a_2 = \max(\mu T, \mu P, \mu C, \mu D)$

   $= \max(0, 0, 0, 0)$

   $= 0$

3. IF T is Regular or ... then Good

   $a_3 = \max(\mu T, \mu P, \mu C, \mu D)$

   $= \max(0.8, 0.8, 0.67, 5)$

   $= 0.8$

As mentioned in an earlier study, the composition of the output from the case was derived through fuzzy inference, employing established rules to combine fuzzy sets representing environmental parameters. The calculation is as follows.

$$\mu G = \frac{x-a}{b-a}$$

$$0.5 = \frac{x-0}{10-0}$$

$$0.5 = \frac{x}{10}$$

$$x = 5$$

$$\mu SF_{[2]} = \{0.5\,,\ 5 \le x \le 10\}$$

$$\mu SF_{\ [2]} = \left\{\frac{x-0}{10-0}\,,\ 0 \le x \le 5\right\}$$

$$\mu SF_{[2]} = \{0.5\,,\ 5 \le x \le 10\}$$

$$\mu SF_{[2]} = \{0\,,\ x \le 0\}$$

$$\mu SF_{[2]} = \left\{\frac{x}{10}\,,\ 0 \le x \le 5\right\}$$

$$\mu SF_{[2]} = \{0.5\,,\ 5 \le x \le 10\}$$

The calculation of the area under the curve of the output obtained from the fuzzy inference process in the presented study served as a crucial metric to quantify the overall extent or severity of the environmental condition. Here is the computation.

$$A = \frac{1}{2}(a+b)\,t$$

$$A = \frac{1}{2}(10+5)\,0.5$$

$$A = 3.75$$

The calculation of moments serves as a fundamental analytical tool to characterize the distribution and central tendencies of environmental data. The calculations are below.

$$M_1 = \int_0^5 \left(\frac{2}{10}\right)2$$

$$M_1 = \int_0^5 \left(\frac{2}{10}\right) dz$$

$$M_1 = \frac{5^3}{30} - \frac{0^3}{30}$$

$$M_1 = \frac{125}{30} - 0$$

$$M_1 = 4.1667$$

$$M_2 = \int_5^{10} (0.5)\ 2$$

$$M_2 = \int_5^{10} 0.52\ dz$$

$$M_2 = 0.252^2 \int_5^{10}$$

This numerical output provides stakeholders with a clear, quantifiable indication of the environmental condition, enabling prioritization of interventions and resource allocation strategies to address identified challenges effectively. Thus, defuzzification is crucial in translating fuzzy logic-based environmental assessments as insights.

$$z^\circ = \left(\frac{M1 + M2}{A}\right)$$

$$z^\circ = \frac{4.1667 + 18.75}{3.75}$$

$$z^\circ = 6.1$$

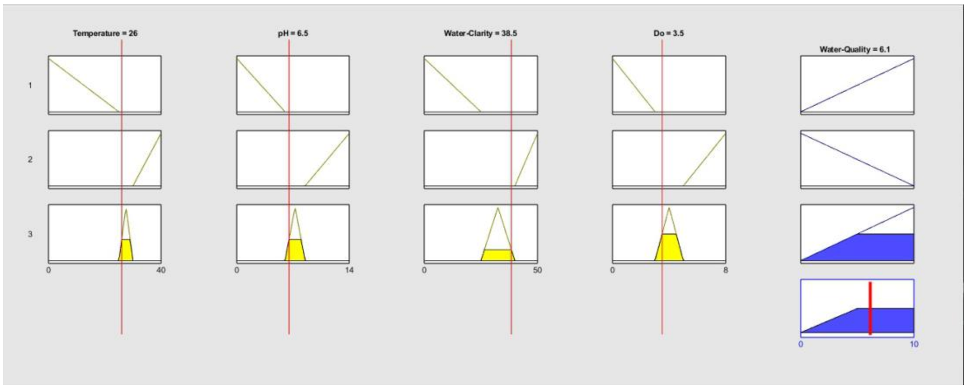

Figure 7. Value of Each Fuzzification

The output above is the value of each parameter processed through Matlab. The parameters are temperature, pH, water clarity, and dissolved oxygen.

CONCLUSION

In this study, we developed a comprehensive water quality prediction system for ponds using Mamdani fuzzy logic, integrating input conditions such as temperature, water clarity, pH, and dissolved oxygen. Mamdani's fuzzy logic method was chosen because it effectively addresses the uncertainty and ambiguity inherent in water quality measurements. By defining fuzzy sets for each input parameter and establishing rules based on reference studies, we successfully predicted assessing pond water quality.

The defuzzification process yielded predictions for water quality, categorized into two distinct outcomes: "Good" and "Poor." By considering multiple input variables and employing fuzzy logic principles, our system provides a more nuanced and reliable assessment of water quality in ponds.

Overall, this research contributes to advancing methodologies for predicting water quality assessment in fish breeding environments, offering a valuable tool for pond management and fisheries cultivation practices. We aim to support sustainable and efficient fish farming practices in various aquatic environments by integrating fuzzy logic into water quality prediction systems.

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