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Implementation of the Mamdani Fuzzy Method for Gourami Aquaculture Water Quality Control Using Pump Systems

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Abstract

Water quality stability is a critical factor in the cultivation of gourami fish (*Osphronemus gouramy*), as this species is highly sensitive to environmental changes. This study aims to implement the Mamdani fuzzy logic method in a pump-based water quality control system. The system is designed to analyze three primary parameters: temperature, ammonia concentration, and pH. Sensor data are processed by an ESP32 microcontroller through fuzzification, rule evaluation, aggregation, and centroid defuzzification. A total of 48 fuzzy rules are formulated to adaptively determine the pump operating duration, allowing the system to adjust according to actual pond conditions.

The experimental results show that at a temperature of 28.7 °C, an ammonia concentration of 0.28 ppm, and a pH value of 8.15—consistent with the simulation—the system produces a defuzzification output of 60 seconds, representing the pump operating duration. These findings confirm that the proposed system can generate flexible control decisions by considering the combined influence of multiple environmental parameters rather than relying on fixed threshold values. The implementation of the Mamdani fuzzy logic method improves system responsiveness in maintaining water quality stability in gourami aquaculture.

Keywords: fuzzy logic, water quality control, gourami aquaculture, ammonia concentration, pH monitoring

INTRODUCTION

Gourami fish (*Osphronemus gouramy*) aquaculture is one of the leading freshwater fisheries commodities with high economic value in Indonesia. The success of gourami cultivation is strongly influenced by the stability of water quality, which plays a crucial role in supporting fish growth and survival (Muhammad Fajarudin et al., 2024; Zain et al., 2021). Gourami are known to be highly sensitive to environmental changes, making water quality management a critical aspect of sustainable aquaculture practices (Kristiyanto et al., 2023). Key parameters such as temperature, pH, and ammonia concentration significantly affect fish health. The optimal temperature range for gourami growth is 24–30 °C, while the ideal pH ranges from 6.5 to 7.5 (Prasetya et al., 2022). Deviations from these ranges, along with increased turbidity and accumulation of toxic compounds, can become major constraints in aquaculture systems (Nindra Kristiantya et al., 2022; Pujiharsono & Kurnianto, 2020).

In intensive aquaculture systems, the accumulation of organic waste and uneaten feed is a primary source of ammonia, a toxic compound that can harm fish even at low concentrations (Guntoro et al., 2019; Ketut & Mahardani, 2024). The toxicity of ammonia increases with rising temperature and pH, as these conditions favor the formation of un-ionized ammonia, which is more harmful to aquatic organisms. Therefore, temperature, pH, and ammonia are interrelated parameters that must be monitored and controlled simultaneously to maintain optimal pond conditions (Maulana & Ratama, 2023).

Recent advancements in Internet of Things (IoT) technology have enabled real-time monitoring of water quality parameters using sensors integrated with microcontrollers such as Arduino and ESP32. These systems allow data transmission to web platforms or mobile applications, facilitating remote monitoring and improving management efficiency (Fikri et al., 2021; Utama et al., 2024). However, most existing studies primarily focus on monitoring systems without incorporating adaptive decision-making mechanisms that integrate multiple parameters simultaneously.

The Mamdani fuzzy method has been applied in several studies for water quality classification in aquaculture and aquascape systems, demonstrating its capability to handle uncertainty and provide flexible decision-making compared to conventional threshold-based approaches (Pujiharsono & Kurnianto, 2020; Qomaruddin et al., 2024). Nevertheless, its application as an adaptive control system—particularly for regulating water quality in gourami aquaculture using multiple key parameters—remains limited. Existing control methods often rely on fixed thresholds, which are less responsive to dynamic environmental fluctuations (Badruzzaman et al., 2024; Rahmawati et al., 2024).

Based on this gap, this study proposes an IoT-based adaptive control system using the Mamdani fuzzy logic method to regulate water quality in gourami aquaculture. The system integrates three primary parameters—temperature, pH, and ammonia concentration—and processes them through membership functions and fuzzy rules to determine optimal pump operating duration using centroid defuzzification. This approach is expected to provide a more adaptive and efficient solution for maintaining water quality compared to conventional methods.

METHODS

This study adopts an experimental approach focused on prototype development in the form of a simulation and employs a Mamdani-type Fuzzy Inference System (FIS). The application of IoT-based water quality monitoring and control systems has been widely reported in previous studies, as such systems have been proven to improve efficiency and directly maintain the stability of aquaculture environments. (Siskandar et al., 2022).

The application of the Mamdani fuzzy method in water quality management has also been proven effective in addressing environmental data uncertainty and providing more flexible decision-making compared to traditional methods that rely on fixed threshold values (Qomaruddin et al., 2024).

This system focuses on three primary parameters that are critical for gourami aquaculture, namely temperature, ammonia concentration, and pH. Previous studies have shown that temperature and pH are important indicators of fish growth. (Nurhidayah et al., 2024), Meanwhile, high ammonia concentrations are toxic and can reduce fish survival rates.

For measurement purposes, a DS18B20 temperature sensor, an MQ-137 ammonia sensor, and an analog pH sensor connected to the ESP32 analog-to-digital converter (ADC) channel were utilized. The integration of multiple sensors to measure water quality in IoT-based monitoring systems has been widely applied in aquascape and ornamental fish cultivation research. (Ardana & Sembiring, 2025; Kamil & Dahliyusmanto, 2025; Rahman & Salim, 2022). In similar Arduino-based studies, the DS18B20 sensor demonstrated temperature measurement accuracy of up to 99.83% (Abiyaksa et al., 2020).

The ESP32 microcontroller serves as the central unit for data processing and decision-making. (Salim & Rahman, 2022) It has been stated that the Mamdani fuzzy method can be implemented on microcontrollers such as the ESP8266 to determine the duration of water pump activation. In this system, a 12 V DC water pump is controlled via a single-channel relay to regulate water circulation as a means of maintaining water quality. (Badruzzaman et al., 2024). Pump-based actuation methods have been applied in fuzzy-based systems for turbidity monitoring and water quality regulation. (Maulana & Ratama, 2023).

The Mamdani fuzzy method is implemented through five main stages, namely fuzzification, rule base construction, implication, aggregation, and defuzzification using the centroid method. (Pujiharsono & Kurnianto, 2020; Qomaruddin et al., 2024). During the fuzzification stage, the crisp input values of temperature, pH, and ammonia concentration are converted into degrees of membership using triangular and trapezoidal membership functions. (Rahmawati et al., 2024).

The combination of the three input variables—temperature, ammonia concentration, and pH—results in 48 fuzzy rules that are used to determine the pump operating duration as the output variable. The defuzzification results are subsequently applied to control the pump activation time, enabling the system to respond to changes in water quality in a dynamic and adaptive manner, as illustrated in Figure 1.

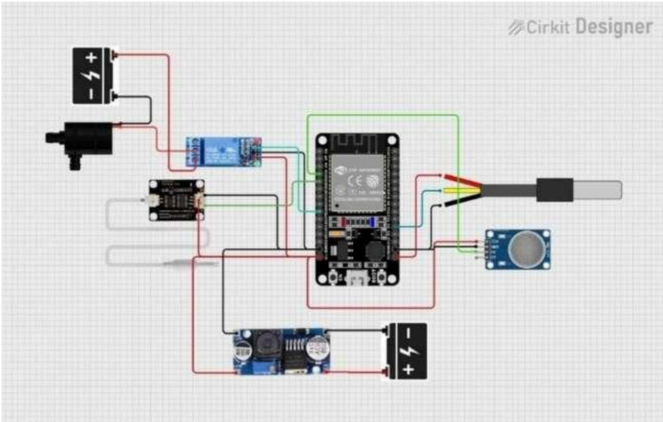

Figure 1. System Circuit Simulation

The pin configuration used to connect the sensors and actuators to the microcontroller is presented in detail in Table 1.

Table 1. Pin Configuration

No	Components	Component Pin Configuration	Connected to the ESP32	Description
1	Step-down Converter	OUT+ (5V)	VIN	Main 5V power supply
2	Step-down Converter	OUT- (GND)	GND	System ground
3	Relay 1 Channel	VCC	VIN (5V)	Relay power supply
4	Relay 1 Channel	GND	GND	Relay ground
5	Relay 1 Channel	IN	GPIO 26	Pump control
6	Pompa DC 12V	(+)	COM Relay	Current path from the battery
7	Pompa DC 12V	(-)	(-) Baterai	Pump ground
8	DS18B20	VCC	3.3V	Temperature sensor voltage
9	DS18B20	GND	GND	Sensor ground
10	DS18B20	DATA	GPIO 4	Temperature reading
11	MQ-137	VCC	VIN (5V)	Ammonia sensor voltage
12	MQ-137	GND	GND	Sensor ground
13	MQ-137	AO	GPIO 34 (ADC)	Ammonia analog input

Fuzzy logic process: The decision-making method in this system employs the Mamdani fuzzy approach due to its capability to handle environmental data uncertainty and to model linguistic variables such as low and medium. This approach has also been widely applied in Internet of Things (IoT)-based water quality monitoring systems (Qomaruddin et al., 2024; Siskandar et al., 2022).

A. Fuzzification

The numerical values obtained from the sensors are converted into linguistic variables using trapezoidal membership functions. Temperature is grouped into three categories: Dingin, Sedang_Normal, and Panas. Ammonia concentration is divided into Rendah, Sedang, and Tinggi, while pH is classified into Low (Acidic), Sedang_Normal, Normal, and Tinggi (Alkaline).

The use of overlapping ranges allows the system to respond to changes in conditions gradually, as applied in studies on fuzzy logic design for water quality assessment (Burhanuddin et al., 2025; Rahmawati et al., 2024).

B. Rule Base Evaluation

This system uses 48 If–Then rules, which are combinations of three input variables. The structure of these rules is designed to reflect real conditions in aquaculture, where the combination of temperature, ammonia, and pH determines the duration of pump operation. The MIN operator is used for AND logic, while the MAX operator is applied for rule aggregation, in accordance with the standard Mamdani fuzzy theory commonly used in environmental control systems. (Burhanuddin et al., 2025; Mukti et al., 2022).

C. Defuzzification

The defuzzification process is performed to convert the aggregated fuzzy results into a crisp output in the form of pump operating time. In this study, the centroid method is selected because it provides more stable results and offers better representativeness in control systems that employ Mamdani fuzzy logic. (Fikri et al., 2021; Rahmawati et al., 2024). Systematically, the centroid method is expressed as:

$$Z = \frac{\int z\,\mu(z)dz}{\int \mu(z)dz}$$

RESULTS AND DISCUSSION

This study employs the Mamdani fuzzy method to regulate water quality in gourami aquaculture based on three main parameters: temperature (°C), ammonia concentration (ppm), and pH. The system design and testing steps were first carried out through simulation using MATLAB software. This simulation was used to create membership function models, design fuzzy rules, and perform the defuzzification process, allowing the system design to be validated before implementation on hardware. The system output is the pump operating time in seconds.

A. Membership Association

1. Membership Function Temperature

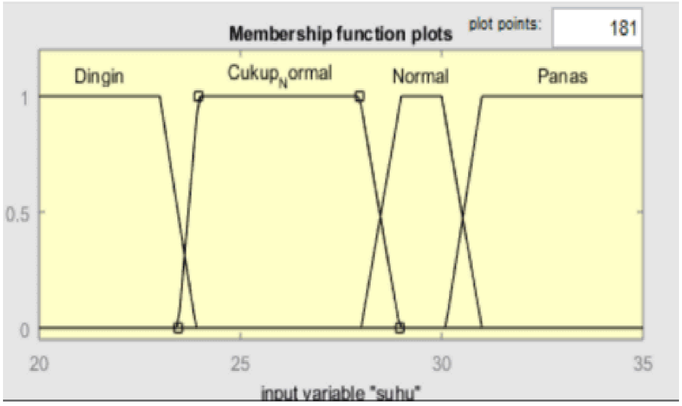

Figure 2. Temperature Input

The initial input variable is temperature, represented as a linguistic variable with four fuzzy groups: Dingin, Cukup Normal, Normal, and Panas, as shown in Figure 2. The type of membership function employed is trapezoidal with overlapping areas, allowing the system to detect gradual changes in temperature. The membership functions for each category are defined as follows:

$$\mu Dingin(x) = \{1, \quad 0 \le x \le 23 \quad \frac{23.9-x}{23.9-23}, \quad 23 < x < 23.9 \quad 0, \quad x \ge 23.9$$

$$\mu Cukup\_Normal(x) = \{0, \quad x \le 23.5 \ or \ x \ge 28.9 \quad \frac{x-23.5}{24-23.5}, \quad 23.5 < x < 24 \quad 1,$$

$$\mu Normal(x) = \{0, \quad x \le 28 \ or \ x \ge 30.5 \quad \frac{x-28}{29-28}, \quad 28 < x < 29 \quad 1,$$

$$\mu Panas(x) = \{0, \quad 0 \le 30.1 \quad \frac{x-30.1}{31-30.1}, \quad 30.1 < x < 31 \quad 1, \quad 31 \le x \le 35$$

2. Membership Function Ammonia Concentration

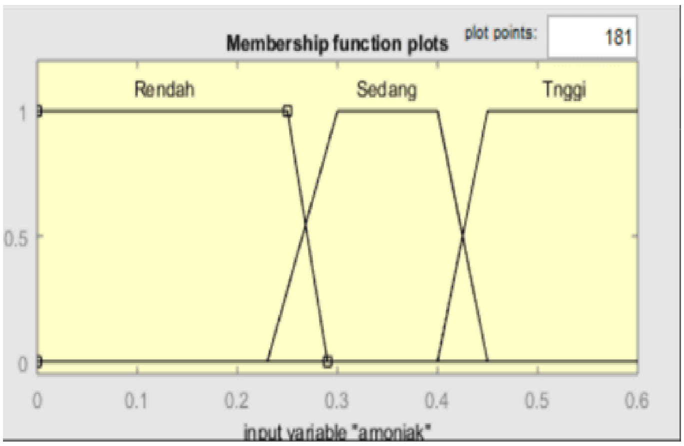

Figure 3. Ammonia Concentration Input

The ammonia concentration variable is represented as a linguistic variable consisting of three fuzzy sets, namely Rendah, Sedang, and Tinggi, as illustrated in Figure 3.

Similar to the temperature input variable, trapezoidal membership functions are employed. These functions are intentionally designed with overlapping regions to enable the system to detect gradual variations in ammonia concentration. The overlapping structure facilitates smooth transitions between linguistic states, thereby enhancing the sensitivity and stability of the fuzzy inference process. The membership functions for each category are defined as follows:

$$\mu Rendah(x) = \{1, \quad 0 \leq x \leq 0.25 \quad \frac{0.29-x}{0.29-0.25}, \quad 0.25 < x < 0.29 \quad 0, \quad x \geq 0.29$$

$$\mu Sedang(x) = \{0, \quad x \leq 0.26 \; or \; x \geq 0.45 \quad \frac{x-0.26}{0.3-0.26}, \quad 0.26 < x < 0.3 \quad 1,$$

$$\mu Tinggi(x) = \{0, \quad x \leq 0.4 \quad \frac{x-0.4}{0.45-0.4}, \quad 0.4 < x < 0.45 \quad 1, \quad 0.45 \leq x \leq 0.6$$

3. Membership Function pH

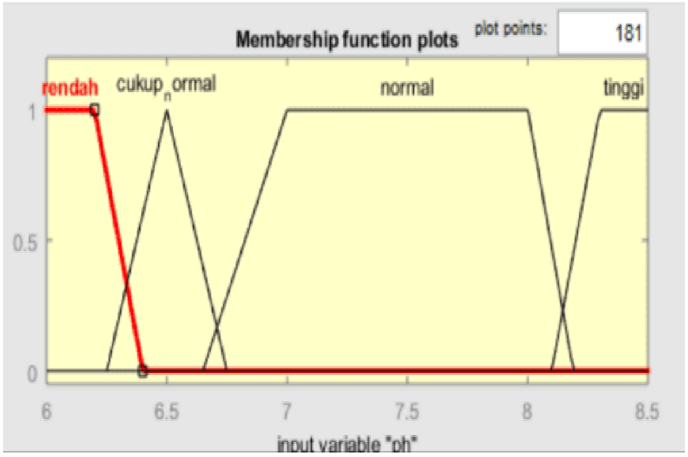

Figure 4. pH Input

The pH variable is modeled as a linguistic variable composed of four fuzzy sets: Rendah (Acidic), Cukup Normal, Normal, and Tinggi (Alkaline), as depicted in Figure 4. Trapezoidal and triangular membership functions are employed, with overlapping regions between adjacent sets. This overlapping configuration enables smooth state transitions and allows the system to respond adaptively to gradual fluctuations in pH levels within the aquaculture environment. The membership functions for each category are defined as follows:

$$\mu Rendah(x) = \{1, \quad 0 \leq x \leq 6.2 \quad \frac{6.4-x}{6.4-6.2}, \quad 6.2 < x < 6.4 \quad 0, \quad x \geq 6.4$$

$$\mu Cukup\_normal(x) = \{0, \quad x \leq 6.25 \; or \; x \geq 6.75 \quad \frac{x-6.25}{6.5-6.25}, \quad 6.25 < x < 6.5 \quad \frac{6.75-x}{6.75-6.5}, \quad 6.5 \leq x \leq 6.75$$

$$\mu Normal(x) = \{0, \quad x \leq 6.65 \; or \; x \geq 8.2 \quad \frac{x-6.65}{7-6.65}, \quad 6.65 < x < 7 \quad 1, \quad 7 \leq x \leq 8 \quad \frac{8.2-x}{8.2-8},$$

$$\mu Tinggi(x) = \{0, \quad x \leq 8.1 \quad \frac{x-8.1}{8.3-8.1}, \quad 8.1 < x < 8.3 \quad 1, \quad 8.3 \leq x \leq 8.5$$

4. Membership Function Pump

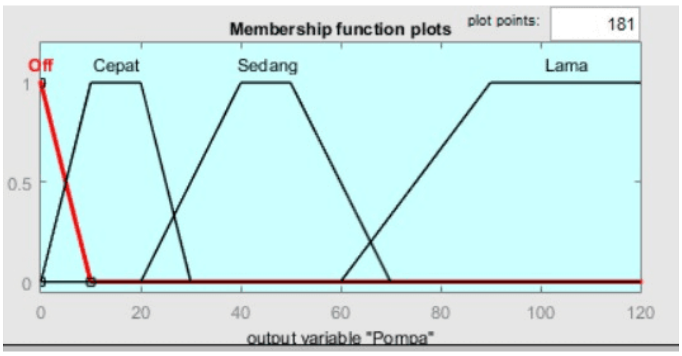

Figure 5. Pump Output

The output variable in this system is the pump operating duration used as a water quality control method. This output is represented by a linguistic variable consisting of four fuzzy sets, namely OFF, Cepat, Sedang, and Lama.

The membership functions applied are trapezoidal with overlapping boundaries. This method allows the system to determine the pump operating duration gradually, so that changes in water quality do not cause overly extreme responses. Therefore, the pump operating duration can adjust to the decline in water quality in a more balanced and responsive manner.

B. Rules

After defining the membership functions, the system establishes 48 inference rules, derived from the combination of three input parameters: temperature, ammonia concentration, and pH level. These rules are designed to represent various possible water quality conditions in freshwater aquaculture. As shown in Table 1:

Tabel 1. Rule Base

No	Temperature	Ammonia	pH	Pump Operation
1	Dingin	Rendah	Rendah	Sedang
2	Dingin	Rendah	Cukup Normal	Cepat
3	Dingin	Rendah	Normal	Cepat
4	Dingin	Rendah	Tinggi	Sedang
5	Dingin	Sedang	Rendah	Sedang
6	Dingin	Sedang	Cukup Normal	Sedang
7	Dingin	Sedang	Normal	Sedang
8	Dingin	Sedang	Tinggi	Lama
9	Dingin	Tinggi	Rendah	Lama
10	Dingin	Tinggi	Cukup Normal	Lama
11	Dingin	Tinggi	Normal	Lama
12	Dingin	Tinggi	Tinggi	Lama
13	Normal	Rendah	Rendah	Cepat
14	Normal	Rendah	Cukup Normal	OFF
15	Normal	Rendah	Normal	OFF
16	Normal	Rendah	Tinggi	Cepat
17	Normal	Sedang	Rendah	Sedang
18	Normal	Sedang	Cukup Normal	Sedang
19	Normal	Sedang	Normal	Sedang
20	Normal	Sedang	Tinggi	Lama
21	Normal	Tinggi	Rendah	Lama
22	Normal	Tinggi	Cukup Normal	Lama
23	Normal	Tinggi	Normal	Lama
24	Normal	Tinggi	Tinggi	Lama
25	Panas	Rendah	Rendah	Sedang
26	Panas	Rendah	Cukup Normal	Cepat
27	Panas	Rendah	Normal	Cepat
28	Panas	Rendah	Tinggi	Sedang
29	Panas	Sedang	Rendah	Lama
30	Panas	Sedang	Cukup Normal	Sedang
31	Panas	Sedang	Normal	Sedang
32	Panas	Sedang	Tinggi	Lama

No	Temperature	Ammonia	pH	Pump Operation
33	Panas	Tinggi	Rendah	Lama
34	Panas	Tinggi	Cukup Normal	Lama
35	Panas	Tinggi	Normal	Lama
36	Panas	Tinggi	Tinggi	Lama
37	Cukup Normal	Rendah	Rendah	Sedang
38	Cukup Normal	Rendah	Cukup Normal	OFF
39	Cukup Normal	Rendah	Normal	OFF
40	Cukup Normal	Rendah	Tinggi	Cepat
41	Cukup Normal	Sedang	Rendah	Sedang
42	Cukup Normal	Sedang	Cukup Normal	Sedang
43	Cukup Normal	Sedang	Normal	Sedang
44	Cukup Normal	Sedang	Tinggi	Lama
45	Cukup Normal	Tinggi	Rendah	Lama
46	Cukup Normal	Tinggi	Cukup Normal	Lama
47	Cukup Normal	Tinggi	Normal	Lama
48	Cukup Normal	Tinggi	Tinggi	Lama

C. Fuzzification

At the fuzzification stage, the crisp input values obtained from the sensors are converted into membership degrees within the predefined fuzzy sets. In this experiment, three main parameters are used, namely a temperature of 28.7 °C, an ammonia concentration of 0.28 ppm, and a pH value of 8.15.

Based on the designed membership functions, the temperature value of 28.7 °C belongs to two fuzzy categories, namely *Cukup Normal* with a membership degree of 0.22 and *Normal* with a membership degree of 0.40. This condition indicates that the water temperature remains within the suitable range for gourami aquaculture.

For the ammonia parameter, the value of 0.28 ppm falls into two fuzzy sets, namely *Rendah* and *Sedang*, with membership degrees of 0.25 and 0.50, respectively. This result indicates that the ammonia level begins to increase and therefore requires attention in water quality management.

Meanwhile, the pH value of 8.15 belongs to two fuzzy categories, namely Normal and Tinggi, each with a membership degree of 0.25. This condition suggests that the water tends to be slightly alkaline.

The membership degrees of each parameter are then used to determine the activation level of the fuzzy rules using the MIN operator, which can be expressed as follows:

$$\alpha = min(\mu_{temperature}, \mu_{ammonia}, \mu_{pH})$$

Based on the rule evaluation results, four rules are activated, each with a firing strength value of 0.25. This indicates that the system decision is influenced by the combined effect of several water quality parameters simultaneously.

D. Final Composition Result

The result of the final composition indicates that the aggregated membership function has a value of 0.25 across the entire output range from 0 to 120, and zero outside this interval. This implies that, after the aggregation process using the MAX operator, all output sets are limited to the same membership level. Consequently, the final curve appears flat, and this shape serves as the basis for the centroid defuzzification process to obtain a precise value for the pump operating duration.

$$\mu_{COMPOSITION}(z) = \begin{cases} 0, & z < 0 \\ 0{,}25, & 0 \le z \le 120 \\ 0, & z > 120 \end{cases}$$

E. Centroid Defuzzification Method

The final stage in the Mamdani fuzzy inference system is defuzzification, which converts the aggregated fuzzy output into a crisp value used as the system decision. In this study, the centroid (center of gravity) method is applied because it provides a representative value of the entire output membership distribution. Mathematically, the centroid method is defined as:

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

Based on the aggregation results, the output membership function has a constant value of 0.25 over the range of 0 to 120 seconds. Under these conditions, the total area is calculated by multiplying the membership value by the length of the domain:

$$\text{Area} = 0{,}25 \times 120 = 30$$

This area represents the total region under the aggregated membership function curve used in the defuzzification process. The total moment is calculated to determine the center point of the distribution. Since the membership function is constant, the moment calculation becomes:

$$Moment\ = \int z \times 0.25\, dz (0–120)$$

From this calculation, the total moment is obtained as:

$$Moment\ = 1800$$

Using these values, the centroid (defuzzified output) is determined as:

$$Z^* = \frac{1800}{30} = 60$$

The defuzzification result indicates that the system determines a pump operating duration of 60 seconds under the given environmental conditions. This value reflects a moderate control response, as the system evaluates the combined influence of temperature, ammonia concentration, and pH in determining the pump operation duration.

F. Final Result

Through the centroid defuzzification process, the system produces an output of 60 seconds, which represents the pump operating duration according to the given input conditions.

The obtained output of 60 seconds indicates that the system responds moderately to the detected water quality conditions. Although the temperature is still within the optimal range for gourami cultivation, the ammonia concentration and slightly alkaline pH trigger the fuzzy system to activate the pump for a moderate duration. This behaviour demonstrates that the system evaluates the combined influence of multiple parameters simultaneously instead of relying on a single threshold value.

The fuzzy-based control mechanism enables smoother and more adaptive responses compared with conventional threshold-based control systems. Because overlapping membership functions are used, small variations in temperature, ammonia concentration, and pH do not immediately produce extreme control actions. Instead, the pump operation duration changes gradually, which helps maintain environmental stability in the aquaculture pond.

Compared with previous studies that primarily focused on monitoring water quality parameters (Qomaruddin et al., 2024), the proposed system integrates both monitoring and automatic control using fuzzy inference. Similar to the study conducted by Aztisyah et al. (2021), the Mamdani fuzzy method demonstrates flexibility in handling uncertainty in environmental sensor data. However, this research extends the implementation by incorporating ammonia concentration as an additional parameter in determining pump operation duration, thereby improving the adaptability of the water quality control mechanism.

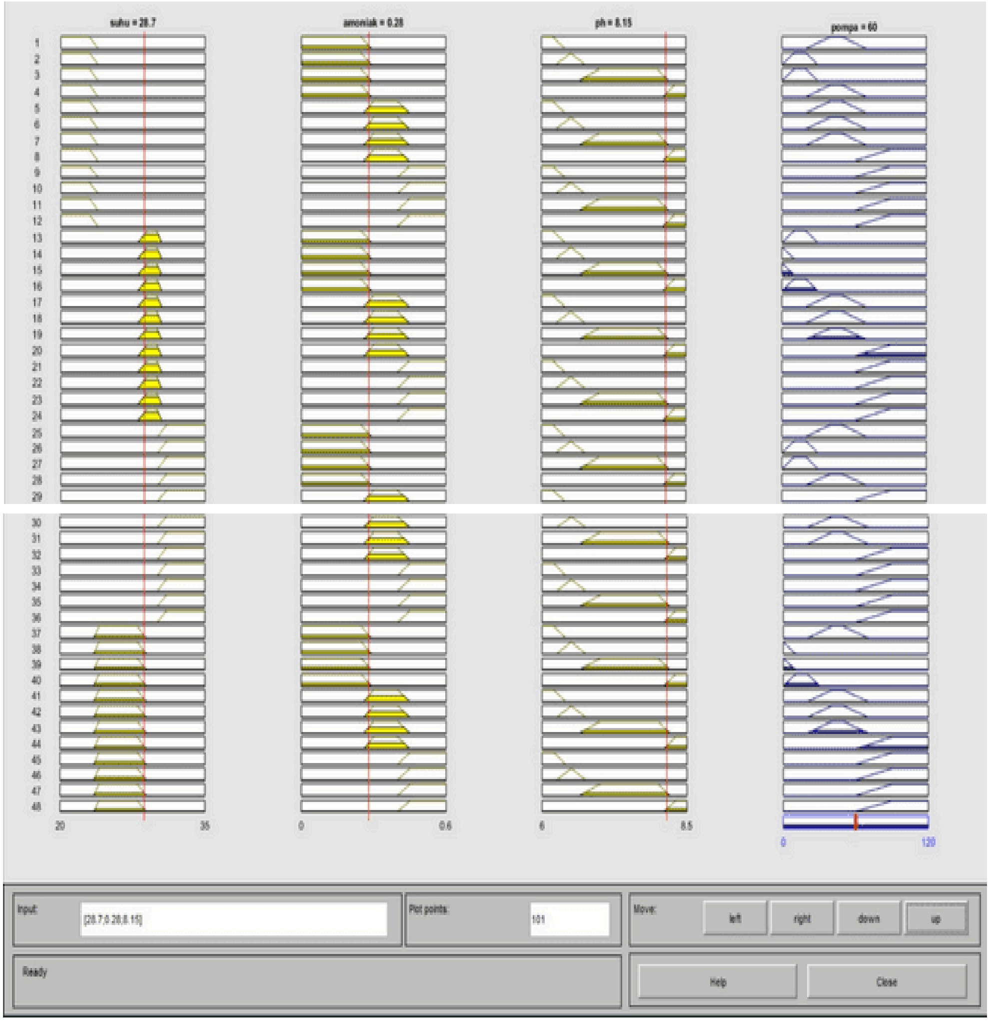

Figure 6. Output Results in Matlab Application

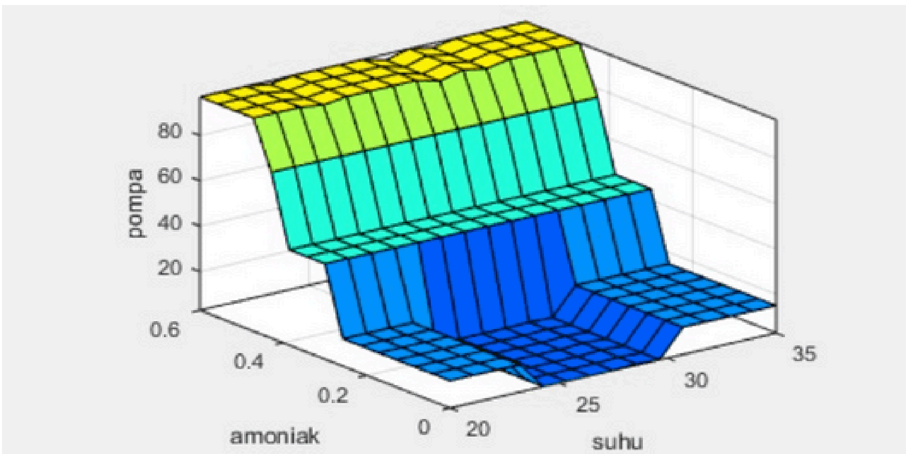

Figure 7. Surface Viewer

The Surface Viewer in Figure 7 illustrates the relationship between temperature and ammonia concentration with respect to the pump output value. The surface plot shows that higher temperature and ammonia levels generally lead to longer pump operation durations. This pattern indicates that the fuzzy inference system responds to deteriorating water quality conditions by increasing the circulation time of the pump.

The gradual slope of the surface demonstrates the effect of overlapping membership functions, which prevent abrupt changes in control decisions. As a result, the system produces smoother and more adaptive responses to variations in environmental parameters.

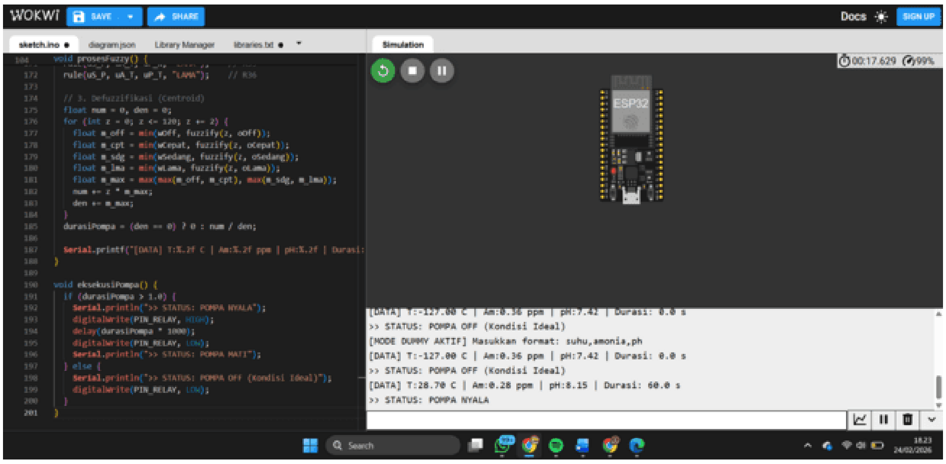

Figure 8. Microcontroller Simulation

CONCLUSION

This study successfully implemented a Mamdani fuzzy logic–based control system for regulating water quality in gourami aquaculture using pump actuation. The system processes three key parameters temperature, ammonia concentration, and pH to determine the appropriate pump operating duration.

Based on the simulation and inference process, the system produced an output of 60 seconds for the tested input conditions. The results demonstrate that the proposed fuzzy inference system can effectively integrate multiple environmental parameters to generate adaptive control decisions.

Compared with conventional threshold-based approaches, the fuzzy method provides smoother and more gradual responses to water quality changes. Therefore, the proposed system has the potential to improve water quality management in gourami aquaculture environments.

REFERENCES

Abiyaksa, D., Adi, S. H., & Siskandar, R. (2020). Pembuatan Prototype Smart Budidaya Ikan Mas Koki Berbasis Arduino. *Indonesian Journal of Science*, *1*(1), 45–50. https://doi.org/10.59897/jsi.v1i1.6

Andrian Harahap, D., Basino, & Aditya Ramadhan, M. (2023). Rancang Bangun Sistem Monitoring Suhu dan pH pada Aquascape Berbasis Internet of Things (IoT). *Prosiding Seminar Nasional Perikanan Indonesia Ke-24*, 12–2023. https://doi.org/10.15578/psnp.13945

Ardana, I. M. R., & Sembiring, J. P. (2025). Implementasi dan Monitoring Sistem Kualitas Air pada Akuarium Ikan Hias Menggunakan Metode Fuzzy Logic. *MALCOM: Indonesian Journal of Machine Learning and Computer Science*, *5*(4), 1570–1576. https://doi.org/10.57152/malcom.v5i3.0000

Aztisyah, D., Yuniati, T., & Setyoko, Y. A. (2021). Implementasi Logika Fuzzy Mamdani Pada pH Air dalam Sistem Otomatisasi Suhu dan pH Air Aquascape Ikan Guppy. *Journal of Informatics, Information System, Software Engineering and Applications*, *4*(1), 59–070. https://doi.org/10.20895/INISTA.V4I1

Badruzzaman, N., Bhakti, H., & Bachri, O. S. (2024). Implementasi Sistem Monitoring Suhu dan PH Air Kolam Budidaya Ikan Lele Menggunakan Arduino ESP8266 dan Arduino IDE. *Jurnal Informatika Dan Teknik Elektro Terapan*, *12*(3S1). https://doi.org/10.23960/jitet.v12i3s1.5355

Burhanuddin, A., Mukhtar, A., Hermana, R., Amirudin, M., Malik, M., Androva, A., Ma'mun, H., Fadillah, M., Prihantono, E. Z. Z., & Ma'mum, S. (2025). Desain Logika Fuzzy untuk Penilaian Kualitas Air Sumur Berdasarkan Parameter Salinitas, pH, dan Kekeruhan. *IRA Jurnal Teknik Mesin Dan Aplikasinya (IRAJTMA)*, *4*(3), 108–119. https://doi.org/10.56862/irajtma.v4i3.333

Cholilulloh, M., & Syauqy, D. (2018). Implementasi Metode Fuzzy Pada Kualitas Air Kolam Bibit Lele Berdasarkan Suhu dan Kekeruhan. *Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer*, *2*(5), 1813–1822. http://j-ptiik.ub.ac.id

Fikri, M., Musthafa, A., & Reza Pradhana, F. (2021). Design and Build Smart Aquascape Based on PH and TDS With IoT System Using Fuzzy Logic. *Seminar Nasional & Call Paper Fakultas Sains Dan Teknologi (SENASAINS 3rd)*, *2*(1). https://doi.org/10.21070/pels.v2i0.1166

Guntoro, D., Setiawan, G. E., & Fitriyah, H. (2019). Pengontrolan Derajat Keasaman (pH) Air Secara Otomatis Pada Kolam Ikan Gurame Menggunakan Metode Fuzzy Mamdani. *Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer*, *3*(1), 1047–1052. http://j-ptiik.ub.ac.id

Haryanto, H., Kristono, & Fadhil, M. (2021). Rancang Bangun Sistem Monitoring Kualitas Air (pH dan Kekeruhan) pada Akuarium Berbasis Internet of Things. *Go Infotech: Jurnal Ilmiah STMIK AUB*, *27*(2), 185–195. https://doi.org/10.36309/goi.v27i2.156

Kamil, F., & Dahliyusmanto. (2025). Sistem Kontrol Kualitas Air Aquascape Ikan Mas Koki Berbasis IoT. *Jurnal Sistem Informasi*, *7*(2), 649–663. https://doi.org/10.31849/gmk3t885

Ketut, N., & Mahardani, J. (2024). Perancangan dan Integrasi IoT pada Sistem Kendali Air Kolam dengan Metode Fuzzy Berdasarkan Ph dan Turbidity Berbasis Mikrokontroler. *EPSILON : Journal of Electrical Engineering and Information Technology*, *22*(1), 17–32. https://doi.org/10.55893/epsilon.v22i1.114

Kristiyanto, A., Fikriah, F. K., Inkiriwang, R., & Andriansah, Z. (2023). Monitoring dan Klasifikasi Kualitas Air Kolam Ikan Gurami Berbasis Internet of Things Menggunakan Metode Naive Bayes. *Jurnal Komtika (Komputasi Dan Informatika)*, *7*(2), 155–167. https://doi.org/10.31603/komtika.v7i2.10200

Maulana, A., & Ratama, N. (2023). Sistem Monitoring dan Controling Tingkat Kekeruhan Air pada Aquarium Menggunakan Metode Fuzzy Berbasis Arduino Uno. *JORAPI : Journal of Research and Publication Innovation*, *1*(2), 167–171.

Muhammad Fajarudin, Handika Saputra Harahap, Irmansyah, Muhamad Al Habsy, Fardiana Yunita, Inna Novianty, Nanda Octavia, & Ivan De Nerol. (2024). Implementation of Fuzzy Logic to Regulate Water Quality in Maintaining the Aquascape Ecosystem. *Journal of Applied Science, Technology & Humanities*, *1*(4), 303–314. https://doi.org/10.62535/dvbdxn84

Mukti, P. B. A., Ichsan, M. H. H., & Setiawan, E. (2022). Pengembangan Sistem Deteksi Air Limbah Tekstil menggunakan Logika Fuzzy. *Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer*, *6*(12), 6059–6067. http://j-ptiik.ub.ac.id

Nindra Kristiantya, Y., Setiawan, E., & Prasetio, B. H. (2022). Sistem Kontrol dan Monitoring Kualitas Air pada Kolam Ikan Air Tawar menggunakan Logika Fuzzy berbasis Arduino. *Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer*, *6*(7), 3145–3154. http://j-ptiik.ub.ac.id

Nurhidayah, E., Suwarsito, S., & Nirwansyah, A. W. (2024). Kesesuaian Kualitas Air Budidaya Gurameh Dan Peran Masyarakat Dalam Konservasi Kualitas Air Kecamatan Kutasari Kabupaten Purbalingga. *Jurnal Pendidikan Geografi Undiksha*, *12*(2), 149–161. https://doi.org/10.23887/jjpg.v12i02.76208

Prasetya, E., Achmadi, S., & Rudhistiar, D. (2022). Penerapan IoT (Internet of Things) untuk Sistem Monitoring Air dan Controlling Pada Kolam Ikan Gurami Berbasis Website. *JATI (Jurnal Mahasiswa Teknik Informatika)*, *6*(2), 1184–1191. https://doi.org/10.36040/jati.v6i2.5400

Pujiharsono, H., & Kurnianto, D. (2020). Mamdani fuzzy inference system for mapping water quality level of biofloc ponds in catfish cultivation. *Jurnal Teknologi Dan Sistem Komputer*, *8*(2), 84–88. https://doi.org/10.14710/jtsiskom.8.2.2020.84-88

Qomaruddin, M., Riansyah, A., & Hermawan, H. M. (2024). Mamdani fuzzy-based water quality monitoring and control system in vannamei shrimp farming using the internet of things. *International Journal of Advances in Applied Sciences*, *13*(1), 180–187. https://doi.org/10.11591/ijaas.v13.i1.pp180-187

Rahman, A., & Salim, A. N. (2022). Sistem Kendali pH dan Kekeruhan Air pada Aquascape Menggunakan Wemos D1 Mini Esp8266 berbasis IoT. *Jurnal Teknologi Terpadu*, *8*(1), 22–30. https://doi.org/10.54914/jtt.v8i1.526

Rahmawati, D., Dwiky Ariyanto, K., Sukri, H., Purnamasari, D. N., Laksono, D. T., Ibadillah, A. F., & Ulum, M. (2024). Rancang Bangun Sistem Monitoring Untuk Penyediaan Kualitas Air Dengan Menggunakan Metode Fuzzy Mamdani. *SinarFe7*, *6*(1), 94–102.

Ratama, N., Munawaroh, & Zakaria, H. (2025). Sistem Otomatis Monitoring dan Pengendalian Kekeruhan Air Berbasis Arduino Dengan Metode Fuzzy. *Informatika: Jurnal Teknik Informatika Dan Multimedia*, *5*(1), 161–168. https://doi.org/10.51903/bbzqc642

Rusdian, A. D., Setiawan, E., & Munadhif, I. (2021). Rancang Bangun Pengendalian Kualitas Air pada Budidaya Ikan Nila Merah Menggunakan Metode Fuzzy Logic dengan Sistem Monitoring Berbasis Internet of Things. *Jurnal Conference on Automation Engineering and Its Application*, *1*, 220–226.

Salim, A. N., & Rahman, A. (2022). Implementasi Fuzzy-Mamdani untuk Pengendalian Suhu dan Kekeruhan Air Aquascape Berbasis IoT. *Jurnal Algoritme*, *2*(2), 159–169. https://doi.org/10.35957/algoritme.v2i2.2544

Siskandar, R., Santosa, S. H., Wiyoto, W., Kusumah, B. R., & Hidayat, A. P. (2022). Control and Automation: Insmoaf (Integrated Smart Modern Agriculture and Fisheries) on The Greenhouse Model. *Jurnal Ilmu Pertanian Indonesia*, *27*(1), 141–152. https://doi.org/10.18343/jipi.27.1.141

Utama, R. N., Midyanti, D. M., & Ristian, U. (2024). Sistem Kontrol dan Pemantauan Aquascape Berbasis Android (Studi Kasus: Galery X-Aquawolrd). *Jurnal Fokus Elektroda : Energi Listrik, Telekomunikasi, Komputer, Elektronika Dan Kendali)*, *9*(1), 31–35. https://doi.org/10.33772/jfe.v9i1.25

Wardhana, D. A., & Amini, S. (2024). Prototype Sistem IOT Pemantauan Suhu, Ketinggian, dan Kualitas Air Aquascape Berbasis Arduino dan Android. *Prosiding Seminar Nasional Mahasiswa Fakultas Teknologi Informasi (SENAFTI)*, *3*(2), 1083–1091.

Zain, M. Z., Misbah, & Astutik, R. P. (2021). Sistem Otomatisasi Perawatan Aquascape Berbasis IOT (Internet Of Things). *SinarFe7*, *4*(1), 50–57.