

Implementation of Fuzzy Logic in Environmental Control and Disease Diagnosis of Sumatran Fish *Puntius tetrazona*

Ilham Ardiansyah^{1*}

^{1*}Technology and Fish Hatchery Management, College of Vocational Studies, IPB University
ardiansyahilham@apps.ipb.ac.id

Varel Raihan Rivasa², Syaqra Nindya Nurafni³, Indah Permata Sari Maha⁴, Mutiara Citra Dewi⁵,
Hasna Nursabirah⁶, Dzahabiyah Febrika Zain⁷, Nurul Lisnawati⁸, Apan Sopian⁹, Justin Khaliq
Satriadana¹⁰, Revanda Maulana Zahradiaz¹¹, Rakha Akbar Riyanto¹², Joandah Rayla Nabila Annuru¹³,
Rizqullah Zaky Yudawirja¹⁴, Hilal Surya Hilmansyah¹⁵

²³⁴⁵⁶⁷⁸⁹¹⁰¹¹¹²¹³¹⁴¹⁵Technology and Fish Hatchery Management, College of Vocational Studies, IPB University

²varelraihanrivasa@apps.ipb.ac.id, ³syaqra23nurafni@apps.ipb.ac.id, ⁴indah0862indah@apps.ipb.ac.id,
⁵tiamutiara@apps.ipb.ac.id, ⁶hasnasabirahasna@apps.ipb.ac.id, ⁷502211783400dzahabiyah@apps.ipb.ac.id,
⁸nurullisna08nurul@apps.ipb.ac.id, ⁹apan05apan@apps.ipb.ac.id, ¹⁰Justinkhaliq@apps.ipb.ac.id,
¹¹revandamaulana@apps.ipb.ac.id, ¹²rakhaakbar@apps.ipb.ac.id, ¹³joandahrayla@apps.ipb.ac.id,
¹⁴rzakyyzaky@apps.ipb.ac.id, ¹⁵hilal0804hilmansyah@apps.ipb.ac.id

Abstract

Water quality management in rearing media is an important factor to maintain fish health and survival. Optimal water quality can help fish growth and prevent disease. This research aims to develop and implement a Fuzzy Logic-based system to automate water quality management in Sumatran *Puntius tetrazona* fish aquariums and perform early diagnosis of several diseases that commonly attack Sumatran *Puntius tetrazona* fish. The use of fuzzy logic using MATLAB is very helpful in monitoring media water quality and fish diseases. The conclusion is that the use of fuzzy logic methods in monitoring the water quality of Sumatran fish rearing media makes it easier to make decisions so that fish are not attacked by disease and fish diagnostics can be carried out.

Keywords: Water Quality, Fuzzy, Disease

INTRODUCTION

Freshwater ornamental fish are increasingly popular as pets. One of the popular ornamental fish species is the Sumatran *Puntius tetrazona*, known as the Sumatran zebra fish. This fish is found in public waters such as rivers, swamps, reservoirs and lakes. At first Sumatran fish was found on Sumatra Island and Kalimantan (Rananda et al., 2020). Keeping ornamental fish is one of the hobbies that is favored by many Indonesians, because the maintenance is not so difficult (Kadir SF, 2019). This fish is popular because of its bright colors and peaceful nature. However, like other fish, *Puntius tetrazona* is susceptible to various diseases and environmental problems. Water quality management in aquariums is an important factor to maintain fish health and survival. Optimal water quality can aid fish growth and prevent disease. Water as a living medium for aquatic biota certainly contains dissolved oxygen which is used for the breathing process and as a source of several minerals for organisms (Siskandar et al., 2022). Daily monitoring of water quality parameters, such as dissolved oxygen, temperature, and Ph (Wiyoto et al., 2022). Accurate and timely diagnosis of disease in sick fish is also important to prevent the spread of disease and increase the chances of recovery.

Traditionally, water quality management in aquariums is done manually. Controllers had to periodically measure environmental parameters such as temperature, pH, and dissolved oxygen levels, and then make manual adjustments if necessary. Diagnosis of disease in fish is also generally done visually based on the experience and knowledge of the controller. This traditional method of water quality management and disease diagnosis has several limitations. First, manual management requires a large amount of time and labor. Second, manual management is prone to human error, potentially causing fluctuations in environmental parameters that are detrimental to fish. Third, visual disease

diagnosis is sometimes inaccurate, especially in the early stages of disease. The development of new methods for water quality management and disease diagnosis in freshwater ornamental fish is important to overcome the limitations of traditional methods (Biondo & Burki, 2020). In recent years, artificial intelligence (AI) has attracted the attention of researchers in the field of aquaculture as a potential solution to improve the efficiency and effectiveness of fish farm management. Advances in information technology and embedded systems in the era of digitalization has increasingly led to the study of control systems and automation systems (Siskandar et al., 2020). Fuzzy logic is often used in solving a problem that explains the system not through numbers, but linguistically, or variables that contain uncertainty (Yulmaini, 2015). Fuzzy mamdani is often used to solve optimization problems (Haque & Sriani, 2023). With these capabilities, Fuzzy Logic can potentially automate the process of water quality management and disease diagnosis in ornamental fish, thereby improving the efficiency, accuracy and effectiveness of fish care.

Several previous studies have discussed the use of fuzzy logic for water quality management in consumer fish farming. However, these studies have not focused on the application of fuzzy logic for water quality management in ornamental fish aquariums, especially Sumatran *Puntius tetrazona* fish. In addition, research on the use of fuzzy logic for disease diagnosis in ornamental fish is still rare. This research focuses on developing a fuzzy logic-based system for environmental control and disease diagnosis in Sumatran *Puntius tetrazona* fish. Li Daolinang has conducted research on Toward developing a tele-diagnosis system on fish disease. This system is used toward developing a tele-diagnosis to develop and evaluate an internet web-oriented call center to consult on fish disease problems experienced by farmers and fish keepers. Expert system is a field of science from Artificial Intelligence that combines a knowledge base with conclusions and solutions (Cholilulloh & Syauqy, 2018). The expert system acts as an intelligent consultant in a particular field of expertise that is able to diagnose and provide advice as if it were an expert (Yazid et al., 2023). Based on the problems faced by freshwater ornamental fish farmers, an expert system is used to help freshwater ornamental fish farmers in identifying freshwater ornamental fish diseases. This expert system will provide convenience for anyone who wants to access it and be able to provide optimal information to both freshwater ornamental fish farmers and ordinary people. This system is expected to be an innovative solution to improve the health and welfare of ornamental fish.

This study supports previous research on the potential of artificial intelligence to improve fish farming management. However, this research is different because it focuses on the use of fuzzy logic for specific applications in Sumatran *Puntius tetrazona* ornamental fish. This research aims to develop and implement a Fuzzy Logic-based system to automate water quality management in Sumatran *Puntius tetrazona* fish aquariums and perform early diagnosis of several diseases that commonly attack Sumatran *Puntius tetrazona* fish. It is hoped that this system can improve the efficiency, accuracy, and effectiveness of Sumatran *Puntius tetrazona* ornamental fish care.

METHODS

Location and Time of the Study

This research was conducted on May 3-14, 2024 at the SV IPB University Fisheries study program St. Lodaya II Kp. Cilibende, RT.02 / RW.02, Babakan, Central Bogor District, Bogor City, West Java. In this study to design an environmental control system and diagnose diseases in fish in Sumatra fish rearing containers using fuzzy logic-based controllers.

Data Collection Method

The general method used in this study is the experimental method, where researchers manipulate environmental variables and disease symptoms in Sumatran fish under controlled conditions to see the impact. In addition, developmental research methods are also used to design, develop and test fuzzy logic models and new control and diagnosis systems based on findings from previous research. These two methods are often used together, with the experimental method for testing hypotheses and the development method for designing new solutions or technologies. The first step is to identify environmental variables critical to the health of Sumatran fish, such as water temperature, dissolved oxygen level, pH, ammonia and other relevant parameters, as well as the most common symptoms of disease in Sumatran fish. Next, experiments will be planned involving the measurement of environmental variables and disease symptoms in Sumatran fish under various conditions. The rearing ponds will be set up according to the experimental requirements and equipped with the necessary sensors to measure relevant environmental parameters. Regular measurements of environmental data will be taken using these sensors, while disease symptoms observed in Sumatran fish will be recorded

on a set schedule. Once the data is collected, data processing will be conducted to ensure quality and accuracy, and to analyze the relationship between environmental parameters and disease symptoms. The results of this analysis will be the basis for the development of a fuzzy logic model for environmental control systems and disease diagnosis in Sumatran fish. The developed system will then be implemented in an experimental environment and evaluated for performance through testing against predetermined scenarios.

Design of Fuzzy Logic Control System

The design of a fuzzy control system in the implementation of fuzzy logic for environmental control and disease diagnosis in Sumatran fish *Puntius tetrazona* begins with the identification of relevant input and output variables, such as water temperature, pH, and ammonia level for the environment, and the health condition of the fish as the output. The design of fuzzy logic is divided into three stages, namely determining the membership set, fuzzy rule-based, and defuzzification process (Siskandar et al., 2020). There are 2 methods of fuzzy logic, namely the mamdani method and the sugeno method. The mamdani method is one part of the fuzzy inference system that is used to draw conclusions or a best decision in uncertain problems. While the sugeno method, the fuzzy inference method for the rule is represented in the form of IF-THEN where the sisten output is not a fuzzy set but a constant or linear (Kurniawan et al. 2022). After that, fuzzy sets are formed for each variable with appropriate membership functions, which are then used to determine fuzzy rules based on knowledge gained from literature and expert consultation. The fuzzy inference process is then used to combine the fuzzy rules and produce fuzzy outputs, which are further defuzzified into concrete values. Implementation of the fuzzy control system is done using a specific programming language, followed by testing and validation using collected environmental data and fish health conditions. Furthermore, the system can be optimized and routinely maintained to ensure its effective performance in environmental control and disease diagnosis in Sumatran fish *Puntius tetrazona*.

Data Analysis

Data analysis in this study will begin with a data pre-processing step, which includes evaluation of data quality, normalisation where necessary, and elimination of invalid data. Next, descriptive analysis will be used to understand the data distribution and key characteristics of the environmental variables and disease symptoms in Sumatran fish. The next step is to evaluate the correlation between environmental variables such as water temperature, oxygen level, pH, turbidity, and disease symptoms, using Pearson or Spearman correlation coefficients. Fuzzy logic methods will then be applied to analyse the relationship between environmental variables and disease symptoms, as well as to diagnose diseases based on environmental parameters and observed symptoms.

Optionally, predictive models can be developed to forecast future environmental conditions or diagnose disease in Sumatran fish. The results of the analyses will be validated by comparing predictions from the models with observational data and then interpreted to gain a better understanding of the factors affecting Sumatran fish health. Conclusions and implications of the findings of this study will be discussed, along with suggestions for further research or practical applications based on the findings and limitations of the study. The analysis of this data, it is expected that valuable insights will be gained into the environmental conditions and health of Sumatran fish, as well as the effectiveness of fuzzy logic solutions in controlling the environment and diagnosing diseases in Sumatran fish.

Literature Studies

Literature studies is the collection of data derived from some readings or some research that has been done, the data obtained is secondary data produced by experts so that the truth can be accounted for. Data on the value of water quality parameters can be seen as follows:

1. Temperature Input Variable

Shown in Table 1. The temperature input set is divided into 3 different variables, namely low with a membership degree of 18-22°C, normal with a membership degree of 22-28°C, and high with a membership degree of 28-32°C. Temperature is a very important physical factor in water, because together with the substances or elements contained in it will determine the density of water, and together with pressure can be used to determine the density of water (Koniyo, 2020). Temperature input variables are shown below in table 1.

Table 1. Temperature Sets (°C)

No	Sets	Membership Degree (°C)
1.	Low	18-22
2.	Normal	22-28
3.	High	28-32

2. pH Input Variable

Shown in table 2. The pH input set is divided into 3 different variables, namely Acid with a membership degree of 0-6.5, neutral with a membership degree of 6.5-7.5, and alkaline with a membership degree of 7.5-14. Acid is a substance that in the water releases H⁺ ions or it can be said that H⁺ ions are carriers of acid properties. Base is a compound that can release hydroxide ions in water (OH⁻). So, OH⁻ ions are carriers of alkaline properties according to Arrhenius. The abbreviation of the word pH is "pondus Hydrogenium" (Nurhidayat, 2020). pH input variables are shown below in table 2.

Table 2. The pH sets

No	Sets	Membership Degree
1.	Acid	0-6,5
2.	Neutral	6,5-7,5
3.	Alkaline	7,5-14

3. Dissolved Oxygen Input Variable (DO)

Shown in Table 3. the dissolved oxygen input set is divided into 3 different variables, namely low with membership degrees 1-5, normal with membership degrees 5-9, and high with membership degrees 9-11. DO is dissolved oxygen used to measure the quality of water cleanliness Siskandar et al., 2022; Wiyoto et al., 2022; Anuri et al., 2023). The greater the value of the DO content shows that the better the water quality. Water with low DO is usually cloudy, smells bad, and tastes bitter due to the anaerobic degradation process that produces compounds such as sulfides, ammonia, methane, and others (Samura et al., 2018). Dissolved oxygen input variables are shown below in table 3.

Table 3. Dissolved Oxygen Sets (mg/L)

No	Sets	Membership Degree (mg/L)
1.	Low	1-5
2.	Normal	4-6
3.	High	6-9

4. Ammonia Input Variable

Shown in Table 4. the ammonia input set is divided into 3 different variables, namely Low with a membership degree of 0-0.5 mg/l, Medium with a membership degree of 0.5-1 mg/l, and High with a membership degree of 1-1.5 mg/l. Ammonia (NH₄) is a nitrogen compound (Iskandar et al. 2018). In liquid form, ammonia exists in two forms: free or unionized ammonia (NH₃) and in the form of ammonia ions (NH₄⁺) (Samura et al., 2018; Akbar, F. dan Irawan, 2023; Bahri, S. & Ridwan). Ammonia input variables are shown below in table 4.

Table 4. Ammonia sets (mg/L)

No	Sets	Membership Degree (mg/L)
1.	Low	0-0,5
2.	Medium	0,5-1
3.	High	1-1,5

RESULTS AND DISCUSSION

System Implementation

System implementation is a series of stages where the process of designing a system consisting of software and hardware that will carry out predetermined commands is carried out. System implementation is the process of implementing the system to be used as an application (Ariefianto et al., 2021). Software design is done by compiling command codes, while hardware design is done by combining several tools such as Arduino IDE as software, Expansion Board Esp 32, WIFI module, dissolved oxygen sensor (DO), temperature sensor, ammonia sensor, pH sensor, and light module. Arduino IDE is a microcontroller board with ATmega328P Processor. Arduino IDE has 14 pins, comes with USB type B connection, ICSP header and reset button (Askar MA et al., 2022). ESP32 is a microcontroller introduced by Espressif System is Successor of the ESP8266 microcontroller, ESP32 has a total of 16 I/O pins which, there are 16 pins as ADC, 2 pins as DAC, and 2 pins as input only (Putra & Almasri, 2023)

Fuzzy Logic Implementation

In the system that has been designed, fuzzy logic is used to determine the results of decisions regarding the water quality of Sumatran fish rearing so as to facilitate environmental control. Fuzzy logic is a great way to map an input space into an output space, especially for very complex systems (Kastina & Silalahi, 2016). This fuzzy logic will be run using MATLAB software. The essence of connecting MATLAB and fuzzy logic is that MATLAB acts as a computational tool for defining, processing, and applying fuzzy logic in various application. MATLAB also contains a toolbox that contains additional functions for special applications such as fuzzy sets, fuzzy rules, performing fuzzy inference, and visualizing results (Natalia, 2018) The implementation process is likely to use MATLAB programming to define the fuzzy system, input data, run fuzzy inference, and analyze the results. The displayed results show how the environmental quality is at that very moment.

Fuzzy Variable

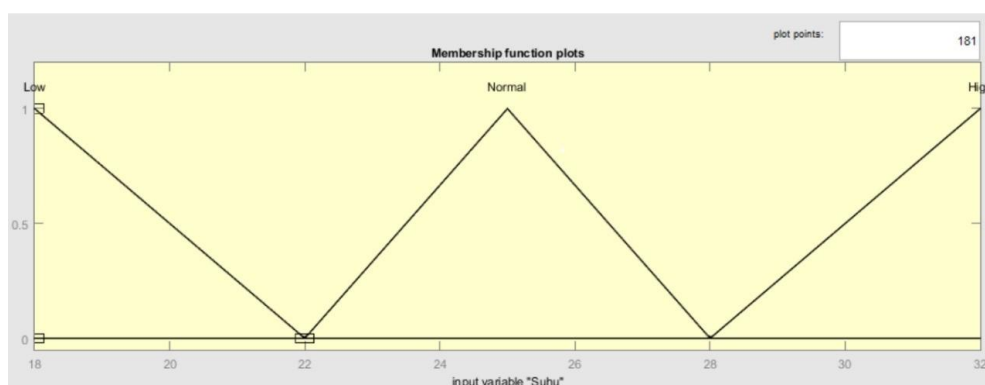


Figure 1. Temperature Variable Input

Based on Figure 1. Shows that the temperature variable has a value that ranges in the range of 18-32°C. This temperature variable is divided into 3 sets, namely, low with a membership degree of 18-22°C, normal with a membership degree of 22-28°C, and high with a membership degree of 28-32°C. All these variables will be processed using fuzzy logic.

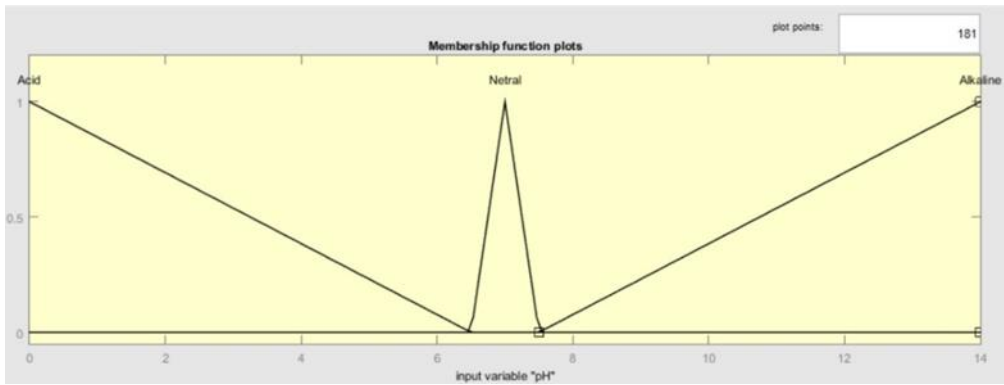


Figure 2. pH Variable Input

Based on Figure 2. shows that the pH variable has a value that ranges from 0-14. This pH variable is divided into 3 sets, namely, acid with a membership degree of 0-6.5, neutral with a membership degree of 6.5-7.5, and alkaline with a membership degree of 7.5-14. All these variables will be processed using fuzzy logic.

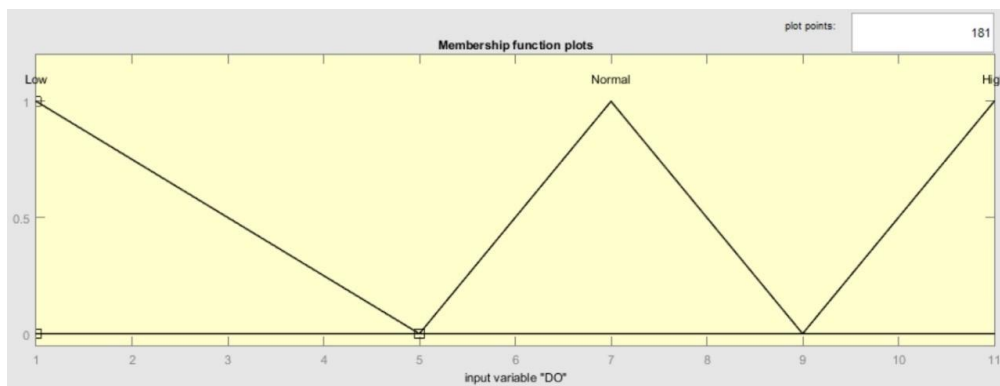


Figure 3. Dissolved oxygen Variable Input

Based on Figure 3. Shows that the DO variable has a value that ranges from 1-11 mg/l. This DO variable is divided into 3 sets, namely, low with a membership degree of 1-4 mg/l, normal with a membership degree of 4-9 mg/l, and high with a membership degree of 9-11 mg/l. All these variables will be processed using fuzzy logic.

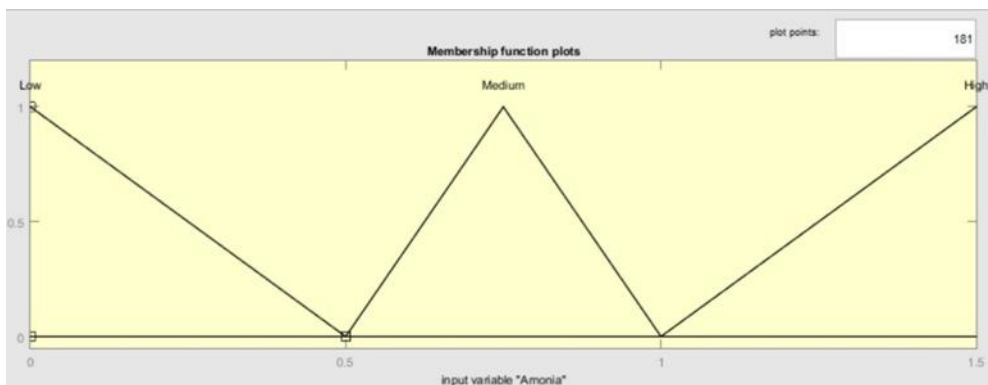


Figure 4. Ammonia Variable Input

Based on Figure 4. Shows that the ammonia variable has a value that ranges in the range of 0-1.5 mg/l. This ammonia variable is divided into 3 sets, namely, low with a membership degree of 0-0.5 mg/l, medium with a membership degree of 0.5-1 mg/l, and high with a membership degree of 1-1.5 mg/l. All these variables will be processed using fuzzy logic.

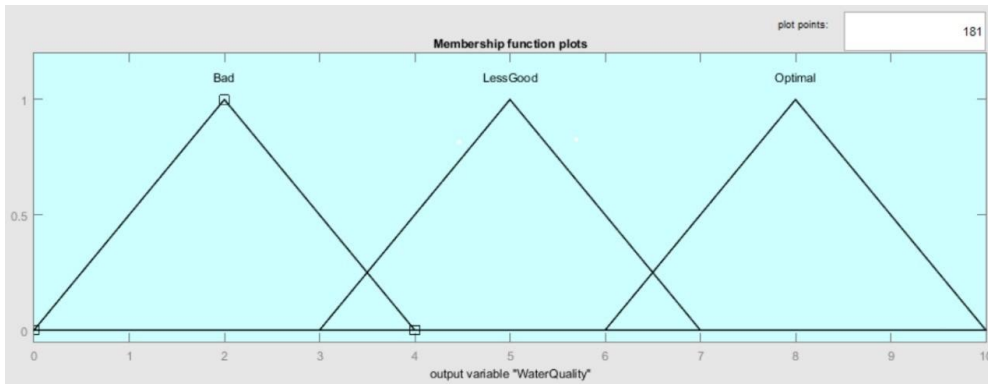


Figure 5. Water Quality Variable Input

Based on Figure 5. Shows the value of the output in the form of water quality values for Sumatran fish rearing media which are divided into 3 parts, namely bad, less good, and optimal. Bad output values range from 0-4, less good output values range from 3-7, and optimal output values range from 6-10.

Water Quality Output Variable

This system provides output that is easy for humans to understand to take corrective action on fish pond water quality (Wulandari SA et al., 2024). The output of water quality with fuzzy logic is not directly in the form of numbers, but in the form of water quality levels that can be understood by humans. This system uses the concept of (fuzzification) to convert water parameter values (for example: temperature, pH, DO, and ammonia) into fuzzy variables (for example: low, normal, high). The fuzzy variables are then processed with “if-then” rules (rule base) to get the level of water quality (for example: bad, less good, and optimal).

- Water quality level: can be a linguistic variable such as "optimal", "bad", "less good", etc.
- Level determination: depends on the rule base created. This rule base is based on the needs of the fish being cultured and the safe limits of the water parameters.
- Example: The rule "If DO is low and temperature is high then water quality is danger".

Assignment of Fuzzy Rules

The fuzzy rule base that can occur for the input variables is determined based on the set of degrees of membership of the input and output variables (Siskandar et al., 2023). Fuzzy rules are used to map some possible outputs resulting from a combination of entered parameters (Hariyanto et al., 2022). Fuzzy rules setting is shown in Figure 6.

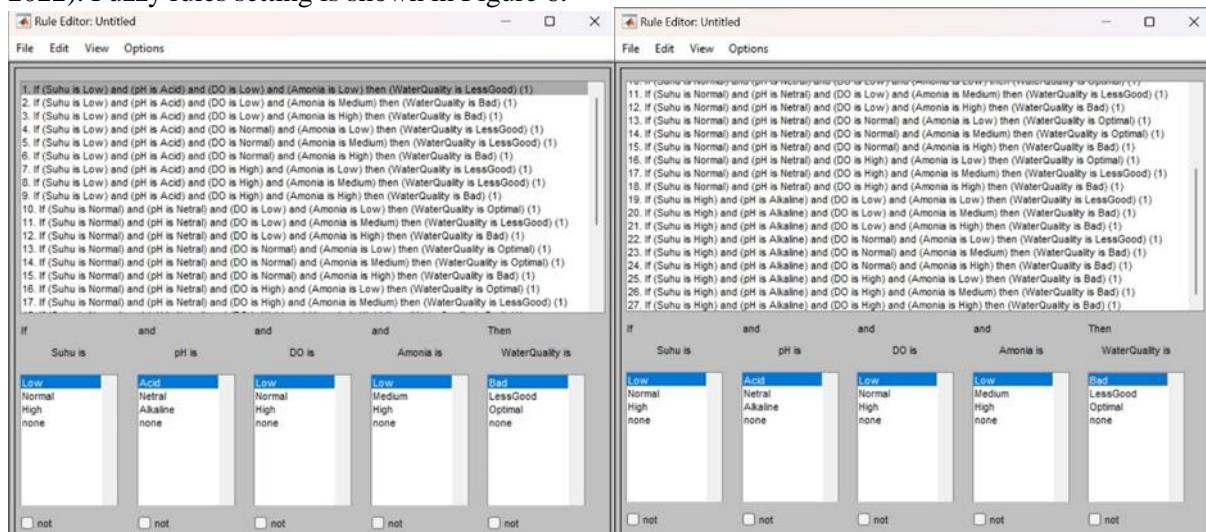


Figure 6. Establishment of Fuzzy Logic Rules

There are four stages in the fuzzy mamdani method to get the output, namely fuzzification, fuzzy rule formation, inference and defuzzification (Salim & Rahman, 2022). The fuzzification process has 4 variables, namely temperature, pH, DO, and ammonia variables. The temperature variable has 3 sets, namely good, less good and bad. The inference process is a combination of many rules based on the set data of each variable. There are 27 Fuzzy rules used in the system with "IF" and "AND" commands so as to produce "THEN". The last process is defuzzification, the defuzzification process uses the high method where each output condition variable will be sought for its largest value (MAX) (Indra et al., 2023). This fuzzy rule is designed to assess water quality based on several environmental parameters. If the water has a low temperature along with low pH, high DO, and low ammonia levels, then the water quality is categorized as good, signifying favorable conditions for aquatic life. Conversely, high temperature and pH combined with low DO and high ammonia levels indicate poor water quality, which threatens the survival of aquatic organisms. Moderate levels of temperature, pH, DO and ammonia indicate fair water quality, where some environmental parameters are within acceptable but not optimal ranges. In addition, any deviation from normal ranges in temperature, pH, DO, or ammonia indicates poor water quality, which confirms the importance of each parameter in determining overall water quality.

Defuzzification

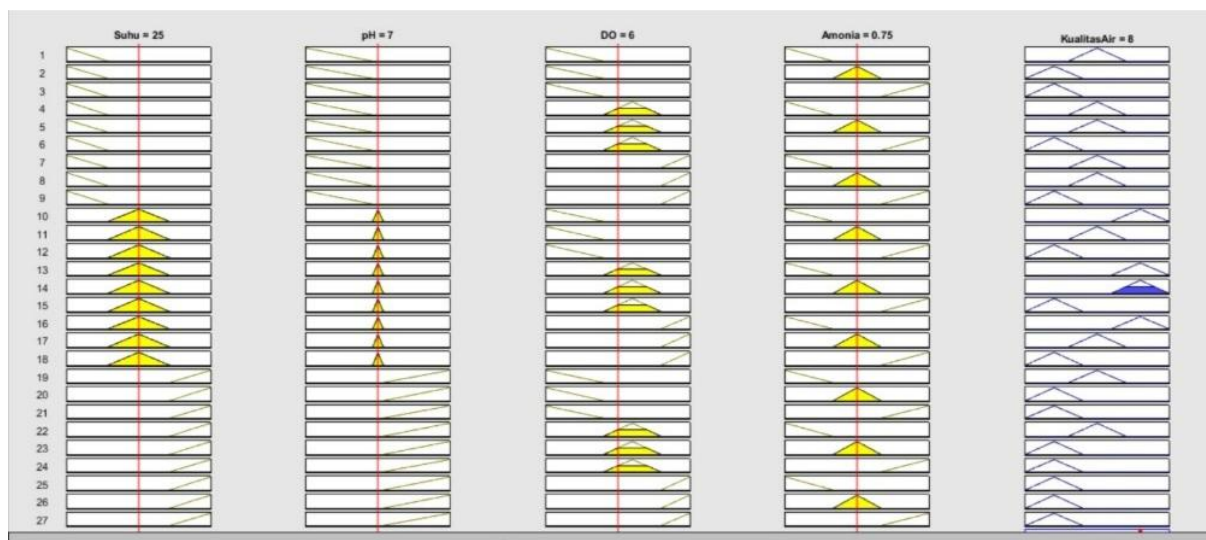


Figure 7. Defuzzification

Defuzzification shown in figure 7 above. Defuzzification is the process of converting the value of each fuzzy parameter into real numbers (Huda, 2017). The parameters for determining water quality will previously be made into a rule that has been verified by an expert to produce an output. Defuzzification is an affirmation process by converting the fuzzy output value into a firmer (crisp) value in accordance with the predetermined sets. The input of the defuzzification process is a fuzzy set obtained from the composition of fuzzy rules, while the resulting output is a number in the domain of the fuzzy set (Daniawan & Hermawan, 2023). Defuzzification is done with a firm input value of temperature value at 25°C, pH value at 7, DO value at 6, and ammonia at 0.75 mg/l. The results of the fuzzy logic simulation with the mamdani method with the values of several variables above obtained an index of the water quality value of Sumatran fish rearing media of 8, or entering into optimal conditions. In addition, any deviation from normal ranges in temperature, pH, DO, or ammonia indicates poor water quality, which confirms water quality plays an important role for life and development of biota freshwater biota, especially pH and dissolved oxygen dissolved (Kulla et al., 2020).

Surfaces Fuzzy Logic

The following is the result of the surfaces display of the water quality output rules that have been determined in the rule setting process shown in figure 8.

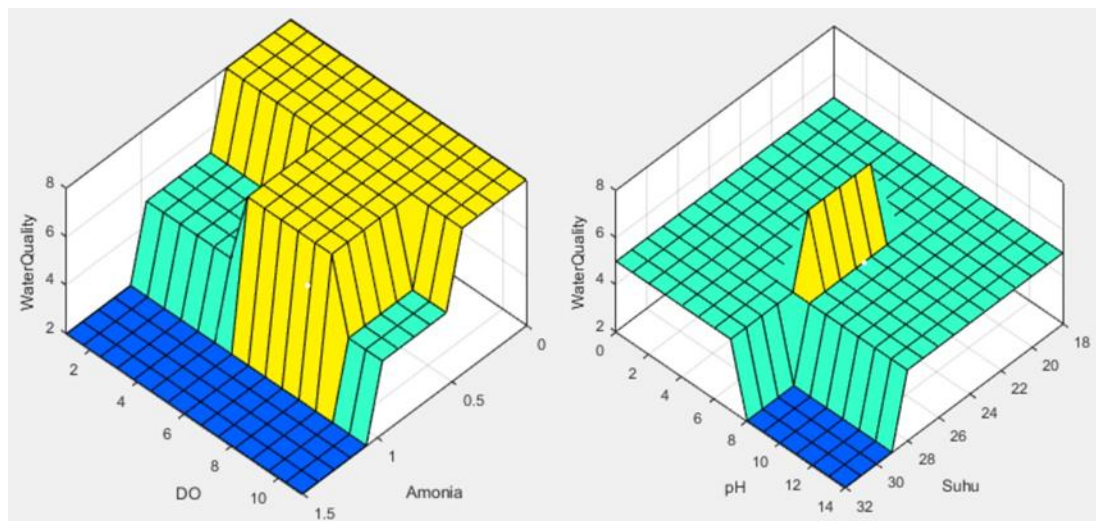


Figure 8. Surface In Fuzzy Logic

Based on Figure 8. above, it can be seen that there are differences in the output results of water quality seen from several measured parameters. It can be seen in the picture that there are fluctuations in water quality caused by the different conditions of each parameter. This surface can make it easier to see the output of several possibilities.

Correlation between Water Quality and Disease in Sumatran Fish *Puntius tetrazona*

Sumatran fish is an endangered fish that has been protected and monitored by the government in natural waters. In its maintenance, this fish is often attacked by disease, so it is important to understand the relationship between water quality and disease. The cause of disease can be caused by fungi, bacteria, and parasites. This is closely related to the water quality of the culture medium. The examples are as follows:

- IF High Temperature and Low DO THEN Fish Disease: Bacterial: Hot water temperatures and low dissolved oxygen levels can accelerate the growth of pathogenic bacteria.
- IF High Temperature and High Ammonia THEN Risk of Fish Disease: Bacterial Increased: The combination of high temperature and high ammonia levels can exacerbate stress in fish and increase the risk of bacterial infection.
- IF High Temperature and Low DO THEN Fish Disease: Bacterial: Hot water temperatures and low dissolved oxygen levels can accelerate the growth of pathogenic bacteria.
- IF High Temperature and High Ammonia THEN Risk of Fish Disease: Bacterial Increased: The combination of high temperature and high ammonia levels can exacerbate stress in fish and increase the risk of bacterial infection.
- IF High Ammonia THEN Fish Disease: Parasites: High ammonia levels can damage the gills of fish, making them more susceptible to parasites.
- IF pH Neutral and Temperature Normal and DO Moderate and Ammonia Low THEN Risk of Fish Disease: Low Parasite: Ideal water conditions (neutral pH, normal temperature, moderate DO, and low ammonia) can help maintain fish health and minimize the risk of parasites.

Water quality is the state and nature of the physical, chemical and biological properties of a body of water compared to the eligibility standards for certain requirements, such as water quality for fisheries, agriculture and drinking water, hospitals, industry and so on. For the development of the fishing industry according to increase production is limited by several factors, namely limited water, land and environmental pollution.

Water quality affects the health and resistance of Sumatran fish to a disease because it is a place for fish to develop. This is caused by pathogens, viral parasites, and fungi that pollute the pond. Water As a medium for raising fish, its quality must always be considered. Good water quality management cannot be done separately. Water quality parameters such as temperature, oxygen content, turbidity, color, pH, hardness, carbon dioxide content, ammonia, nitrite and nitrate are interrelated. If the value of a parameter is known to be suboptimal, it is certain that the value of other parameters is also suboptimal. The limiting parameter that has the greatest influence on fish farming is DO (oxygen content). Low oxygen levels can cause water temperature to increase. High temperature in the pond can reduce the pH value and make the pond atmosphere more acidic. Under these conditions, pathogens are more likely to attack fish, which can cause mass fish mortality if left untreated (Wulansari et al., 2022)

CONCLUSION

Based on the explanation above, it can be concluded that this research aims to design an environmental control system and diagnosis of disease in fish in Sumatran fish containers using fuzzy logic-based controllers. This research develops a fuzzy logic-based system to control water quality and diagnose diseases of Sumatran fish *Puntius tetrazona*. The use of fuzzy logic methods in monitoring the water quality of Sumatran fish rearing media makes it easier to make decisions so that fish are not attacked by disease and fish diagnostics can be carried out.

REFERENCES

- Akbar, M. F., & Irawan, D. (2023). Sistem Kontrol Kualitas Air Tambak Udang Berbasis Fuzzy Logic Fuzzy Logic Based Shrimp Pond Water Quality Control System. *Jurnal Riset Rekayasa Elektro*, 5(1): 23-32
- Anuri, M., & Islamadina, R. (2023). Analisis Kualitas Air Bersih Dengan Logika Fuzzy Mamdani. *Jurnal Pendidikan Teknologi informasi*, 7(2):126-135.
- Ariefianto, D., Sasmito, A. P., & Wahid, A. (2021). Pemanfaatan Metode Fuzzy Untuk Budidaya Ikan Tombro Bebrasis Iot (Internet of Thing). *Jurnal Mahasiswa Teknik Informatika*, 5(1): 138-145
- Askar, A. M., Susanto E., Wibowo, A. S. (2022). Sistem Pengendalian Pakan Dan Monitoring Kualitas Air Akuarium Otomatis Automatic Aquarium Feed Control and Water Quality Monitoring System. *E-Proceeding of Engineering*, 9(2): 273-280
- Bahri, S., Ridwan. Monitoring dan Pengaturan Oksigen Terlarut untuk Menjaga Kualitas Air pada Budidaya Udang *Vannamei* Berbasis Logika Fuzzy. *RESISTOR (Elektronika Kendali Telekomunikasi Tenaga Listrik Komputer*, 4(2): 111-120
- Biondo, M. V., & Burki, R. P. (2020). A systematic review of the ornamental fish trade with emphasis on coral reef fishes—an impossible task. *Animals*, Vol. 10, hlm. 1–21. MDPI AG. <https://doi.org/10.3390/ani10112014>
- Cholilulloh, M., & Syauqy, D., Tibyani. (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. Diambil dari <http://j-ptiik.ub.ac.id>
- Haque, M. D. D., Sriani. (2023). Penerapan Logika Fuzzy Mamdani untuk Optimasi Persediaan Stok Makanan Hewan. *KLIK: Kajian Ilmiah Informatika dan Komputer*, 4(1): 427-437. <https://doi.org/10.30865/klik.v4i1.1160>
- Hariyanto, M. D., Adiputra, D., Rasmana, S. T. (2022). Desain Dan Analisa E-Fishery Urban Fish Farming Untuk Mengendalikan Kualitas Air Kolam Menggunakan Algoritma Fuzzy. *Journal of Computer, Electronic, and Telecommunication*, 2(2): 1-14. <https://doi.org/10.52435/complete.v2i2.179>
- Huda, R. N. (2017). Sistem Pakan Fuzy Penentuan Kesesuaian Jenis Ikan Berdasarkan Kualitas Air. (Undergraduate thesis, Institut Pertanian Bogor)
- Kadir, S. F. (2019). Mobile Iot (Internet Of Things) Untuk Pemantauan Kualitas Air Habitat Ikan Hias Pada Akuarium Menggunakan Metode Logika Fuzzy. *Jurnal Mahasiswa Teknik Informatika*, 3(1): 298-305.

- Kastina, M., & Silalahi, M. (2016). Logika Fuzzy Metode Mamdani Dalam Sistem Keputusan Fuzzy Produksi Menggunakan Matlab. *Logika Fuzzy Metode Mamdani Dalam Sistem Keputusan Fuzzy Produksi Menggunakan Matlab Jurnal Ilmu Komputer* (Vol. 1): 171-181
- Koniyo, Y. (2020). Analisis Kualitas Air Pada Lokasi Budidaya Ikan Air Tawar Di Kecamatan Suwawa Tengah. *Jurnal Technopreneur (JTech)*, 8(1): 52–58. <https://doi.org/10.30869/jtech.v8i1.527>
- Kulla, O. L. S., Yuliana, E., & Supriyono, E. (2020). Analisis Kualitas Air dan Kualitas Lingkungan untuk Budidaya Ikan di Danau Laimadat, Nusa Tenggara Timur. *PELAGICUS: Jurnal IPTEK Terapan Perikanan dan Kelautan*, 1(3), 135. <https://doi.org/10.15578/plgc.v1i3.9290>
- Kurniawan, F., Maulana, Y. Z., & Christianti, R. F. (2022). Sistem Kendali Level Ketinggian Air Berbasis Fuzzy Control Menggunakan Simulink. *Jurnal Ilmiah Elektronika*, 21(1): 17-30
- Natalia, R. C. (2018). Implementasi Fuzzy Logic Dalam Menentukan Jumlah Produksi Meubel Di Kawasan Ruko Botania. (Undergraduate thesis, Universitas Putra Batam)
- Nugraha, A. I., Rosita, Y. D., & Ardiantoro, L. (2023). Prototipe Smart Akuarium Berbasis Iot Dengan Pemanfaatan Esp32. *APPLIED SCIENCE, ENGINEERING, AND TECHNOLOGY*, 2(1): 36-42
- Nurhidayat, R. (2020). Pengendalian Kualitas Air Pada Budidaya Ikan Lele Jenis Mutiara. *Jurnal Ilmiah Mahasiswa Kendali dan Listrik*, 1(2): 42-50. <https://doi.org/10.33365/jimel.v1i1>
- Putra, B. M. J., Almasri. (2023). Sistem Keamanan Kotak Amal Uang Dengan Terintegrasi Telegram Berbasis Mikrokontroler ESP32. *Jurnal Pendidikan Tambusai*, 6(2): 16834-16844
- Rananda, A. I., Windarti, Putra, R. M. (2020). Morfometrik dan Meristik Ikan Sumatra (Puntius hexazona) di Perairan Umum Sekitar FPK Universitas Riau dan Hulu Sungai Sibam. *Jurnal Sumberdaya dan Lingkungan Akuatik*, 1(1): 18-28
- Salim, A. N., & Rahman, A. (2022). Implementasi Fuzzy-Mamdani untuk Pengendalian Suhu dan Kekeruhan Air Aquascape Berbasis IoT. *Jurnal Algoritme*, 2(2), 159–169.
- Samura, A., Kurniawan, W., & Setyawan, G. E. (2018). Sistem Kontrol dan Monitoring Kualitas Air Tambak Udang Windu Dengan Metode Fuzzy Logic Control Menggunakan Mikrokontroler NI myRIO. *Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer*, 2(9): 2644-2653. <https://www.researchgate.net/publication/3247r20714>
- Siskandar, R., Fadhil, M. A., Kusumah, B. R., Irmansyah, I., & Irzaman, I. (2020). Internet Of Things: Automatic Plant Watering System Using Android. *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, 9(4), 297. <https://doi.org/10.23960/jtep-1.v9i4.297-310>
- Siskandar, R., Wiyoto, W., Hendriana, A., Ekasari, J., Kusumah, B. R., Halim, G., & Nugraha, I. J. (2022). Automated Redox Monitoring System (ARMS): An Instrument for Measuring Dissolved Oxygen Levels Using a Potential Redox Sensor (ORP) in a Prototype of Shrimp Farming Pond with an Internet-Based Monitoring System. *Journal of Aquaculture and Fish Health*, 11(2), 238–246. <https://doi.org/10.20473/jafh.v11i2.31487>
- Siskandar, R., Wiyoto, W., Santosa, S. H., Hidayat, A. P., Kusumah, B. R., & Darmawan, M. D. M. (2023). Prediction of Freshwater Fish Disease Severity Based on Fuzzy Logic Approach, Arduino IDE and Proteus ISIS. *Universal Journal of Agricultural Research*, 11(6), 1089–1101. <https://doi.org/10.13189/ujar.2023.110616>
- Wiyoto, W., Hendriana, A., Siskandar, R., Mashita, N., Mahendra, T., Cahyo, A. D., Ekasari, J. (2022). Analysis of water and sediment quality in Pacific white leg shrimp *Litopenaeus vannamei* culture with different sediment redox potential. *Jurnal Akuakultur Indonesia*, 21(1), 59–67. <https://doi.org/10.19027/jai.21.1.59-67>
- Wulandari, S. A., Sucipto, A., Rosyady, A. F., Ardana, M. D. R., Cahyono, O. D. P., Khomarudin, A. N., Korespondesi, P. (2024). Rancang Bangun Sistem Monitoring Kualitas Air Untuk Mendeteksi Keadaan Tidak Normal atau Penyakit Pada Tambak Ikan Mujaer Menggunakan Fuzzy Logic Mamdani Berbasis Mobile. *Technologica*, 3(1): 42–54.

- Wulansari, K., Razak, A., Hamka, J., Tawar, A., & Barat-Indonesia, S. (2022). Pengaruh Suhu Terhadap Pertumbuhan Ikan Lele Sangkuriang (*Clarias Gariepinus*) Dan Ikan Lele Dumbo (*Clarias Gariepinus X Clarias Fiscus*). *Konservasi Hayati*, 18(1), 31–39. Diambil dari <https://ejournal.unib.ac.id/index.php/hayati/>
- Yazid, A., Kusumawati, I., & Febriliana, R. (2023). Prototipe Sistem Monitoring Suhu, Ketinggian Air, dan Kontrol Otomatis pada Budidaya Ikan dalam Ember Berbasis IoT. *Journal of Advances in Information and Industrial Technology*, 5(2). <https://doi.org/10.52435/jaiit.v5i2.371>
- Yulmaini. (2015). Penggunaan Metode Fuzzy Inference System (FIS) Mamdani dalam Pemilihan Peminatan Mahasiswa Untuk Tugas Akhir. *Jurnal Informatika*, 15(1): 10-23