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FUZZY SYSTEM FOR EVALUATING WATER QUALITY IN AN AQUAPONIC SYSTEM

Research paper

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Abstract (10 pt): The paper presents the implementation of a fuzzy logic-based system in the MATLAB environment, designed to evaluate environmental conditions in a fish tank and assess water quality. The system uses three main water parameters: temperature, pH, and dissolved oxygen concentration. For each parameter, membership functions are defined using three linguistic terms: Low, Optimal, and High. Based on these input variables, a fuzzy rule base is developed to evaluate the general state of the aquatic environment and provide an output value representing the suitability of the water quality conditions. The model is implemented and tested in MATLAB using fuzzy logic tools, and the obtained results allow the analysis of system behavior as the input parameters vary. The proposed approach provides a simple and flexible method for integrating multiple environmental parameters into a single assessment system.a
Key words: fuzzy logic, aquaponics, water quality, aquaculture, MATLAB.

INTRODUCTION

Fish farming in controlled systems involves monitoring the physicochemical parameters of the water. Their variations can influence the development and condition of aquatic organisms. In the case of carp, water temperature, pH and dissolved oxygen concentration are important parameters for evaluating the rearing conditions.
Fuzzy logic is suitable for evaluating such systems, as it allows the use of intermediate values and linguistic terms such as "low", "optimal" and "high". In contrast to methods based on fixed thresholds, it allows for a gradual transition between different states and the simultaneous integration of several parameters.
A fuzzy system is proposed to evaluate the environmental conditions necessary for carp farming. The model uses temperature, pH and dissolved oxygen as input variables, and the result is expressed as a level of adequacy of environmental conditions. The system is implemented and simulated in MATLAB, using membership functions and "If–Then" rules.

MATERIAL AND METHODS

Implementing and Simulating the Fuzzy System in MATLAB

For the evaluation of water quality in the aquaponic system, a system based on fuzzy logic was developed, implemented and tested in the MATLAB environment. The use of fuzzy logic is suitable for the analysis of systems in which the input parameters show continuous variations and in which the boundaries between the different states of the system cannot always be defined by fixed thresholds.
By using membership functions, the numerical values of the parameters can be represented by linguistic terms and subsequently combined by means of fuzzy rules (Rad et al., 2022).
In aquaculture systems, water quality is influenced by several physicochemical parameters, including temperature, dissolved oxygen, pH, ammonia, nitrates, and salinity. Monitoring these parameters is important because variations in environmental conditions can influence the health of aquatic organisms, feeding efficiency, growth rate, and system productivity (Abul Kashem et al., 2026).
Within the model proposed in this paper, three input parameters considered representative for evaluating the environmental conditions in the basin were selected: water temperature, pH and dissolved oxygen (DO). The reduction in the number of variables allows obtaining a fuzzy

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model that is simpler and easier to interpret, while maintaining the main information necessary for the evaluation of the water status.

Studies dedicated to aquaponic systems highlight the need for automatic monitoring and control of water quality parameters to maintain proper system operating conditions (Mustika et al., 2023).

For each input variable, three membership functions have been defined, corresponding to the linguistic terms 'Low', 'Optimal' and 'High'. The use of linguistic terms allows the numerical values of the parameters to be transformed into information that can be processed by the fuzzy system. In the case of systems based on fuzzy logic, this representation is especially useful when the input information presents uncertainty or imprecision and when it is necessary to construct a relationship between several input variables and an output variable (Rad et al., 2022).

Membership functions were entered into MATLAB for each of the three input variables. For temperature, the range of analysis was set between 0 and 35 °C, for pH between 0 and 14, and for dissolved oxygen between 0 and 15 mg/L. The partial overlap of the membership functions allows a value between two linguistic states to contribute to several fuzzy rules simultaneously, leading to a gradual transition of the system's response.

The structure of the fuzzy system is built on the basis of an "IF–THEN" rule base. The rules establish the relationship between the state of temperature, pH and dissolved oxygen and the resulting level of water quality (Bautista et al., 2022; Gustilo et al., 2014). Such an approach allows the combination of information from several inputs into a single decision.

In fuzzy control applications, the rules and control structure can be adapted to changing operating conditions, and the behavior of the system can be verified by simulation (Popa et al., 2022).

An example of a rule used in the model is: "IF temperature is Optimal AND pH is Optimal AND dissolved oxygen is Optimal THEN water quality is Optimal". Similarly, rules can be defined for situations where one or more parameters are in the low or high range. Thus, the system can provide an overall assessment of water quality based on the combination of the monitored parameters. The fuzzy model is then simulated in MATLAB for different combinations of input parameters.

The simulation allows the observation of the change in the system output when the temperature, pH or concentration of dissolved oxygen are changed. The use of simulation is an important step in verifying the behavior of a fuzzy system before an eventual practical implementation, a method also used in the development of fuzzy control systems for engineering applications (Popa et al., 2022).

The graphical representation of the response surfaces allows the simultaneous influence of two input variables on the output variable to be analyzed. In the case of the proposed system, these representations can highlight how the combination of temperature and dissolved oxygen or that of pH and dissolved oxygen influences the final assessment of water quality. This approach facilitates the interpretation of the model's behavior and the identification of areas where changing parameters causes significant changes in the fuzzy output. In a practical application, the fuzzy system can represent an intermediate step between the acquisition of data from the sensors and the automatic control system.

The measured data in real time can be transmitted to the fuzzy model, and its result can be used to signal an improper condition or to control equipment such as pumps and aeration systems. In intelligent aquaponics systems, automating the control of water parameters can help to manage operating conditions more efficiently (Mustika et al., 2023; You et al., 2021).

The choice of parameters used in the model is also supported by previous studies on aquaponic systems. The analysis of the water parameters in an aquaponic system highlights the importance of monitoring the characteristics of the water for maintaining the proper operating conditions of the system (Alexuță & Bălaș, 2023). In this context, the integration of the monitored parameters into a fuzzy model allows the transition from the simple measurement of the values to an automatic and interpretable assessment of the state of the system.

Therefore, the implementation in MATLAB provides the possibility to experimentally verify the fuzzy system structure, membership functions, and rule base before integration into a real aquaponics system. The model can later be extended by introducing additional parameters, modifying membership functions, or connecting to data from sensors. The use of computational models for water quality analysis and classification is also a current direction in the development of modern aquaculture monitoring systems (Abul Kashem et al., 2026).

Definition of Input and Output Variables

Table 1. *Parameters and linguistic levels of the fuzzy system.*

Parameter (Unit)	Domain	Low(L)	Optimal(O)	High(H)
Water temperature (°C)	0–35	0–22	14–30	22–35
pH	0–14	0–7	5–9	7–14
Dissolved oxygen (mg/L)	0–15	0–5	2–8	5–15
Water Quality (%)	0–100	0–50	25–75	50–100

The fuzzy system uses three input parameters: water temperature, pH, and dissolved oxygen (DO). Each parameter is described by three linguistic levels: Low, Optimal, and High. The output variable, Water Quality, is also divided into three linguistic levels. The parameter ranges were chosen so that the membership functions overlap, with adjacent linguistic sets intersecting at a membership degree of 0.5. This approach ensures a gradual transition between linguistic levels and avoids sudden changes in the fuzzy system's response. The defined ranges were later implemented in MATLAB using triangular and trapezoidal membership functions.

In aquaponic systems, maintaining water parameters at appropriate intervals is an important condition for the proper development of aquatic organisms and plants. pH control can be achieved through systems based on fuzzy logic, which allow control actions to be adapted to continuous variations in environmental parameters. Rahayu et al. (2021) presented a pH control and water recirculation system in an aquaponic system, using a Mamdani-type fuzzy regulator. The results of this type of approach highlight the possibility of using fuzzy logic for the automatic management of water quality parameters in aquaponic systems.

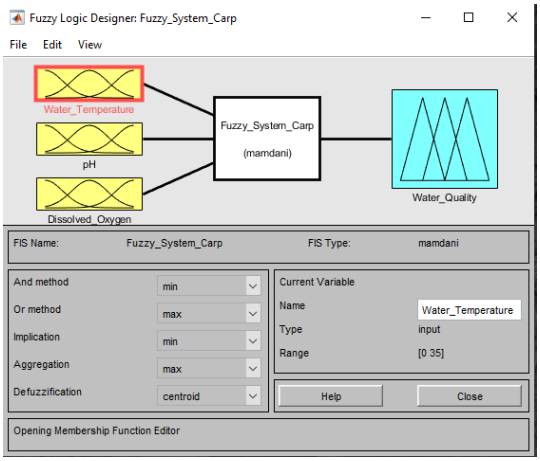


Fig. 1. *Fuzzy System Interface*

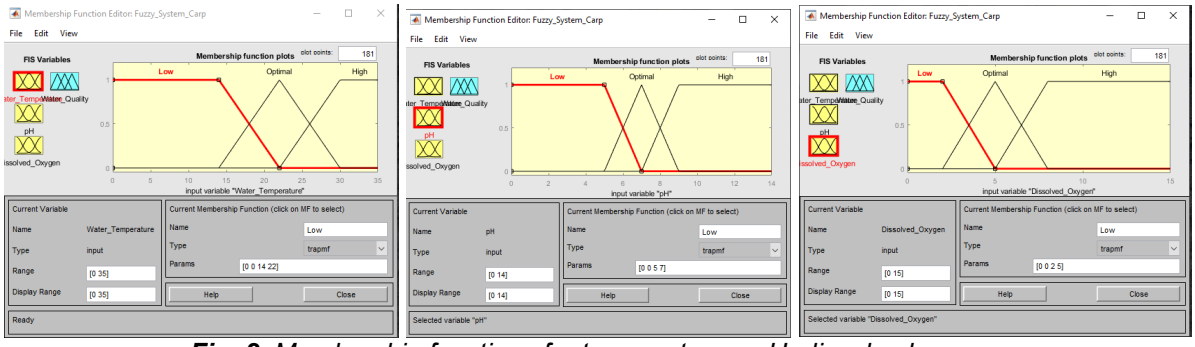


Fig. 2. *Membership functions for temperatures, pH, dissolved oxygen*

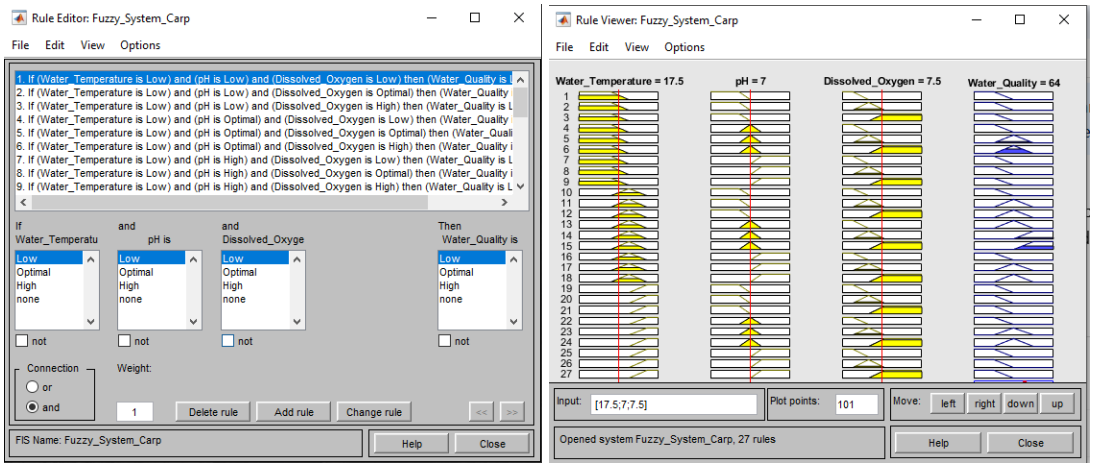


Fig. 3. *Rule base, graphical visualization of the rule base*

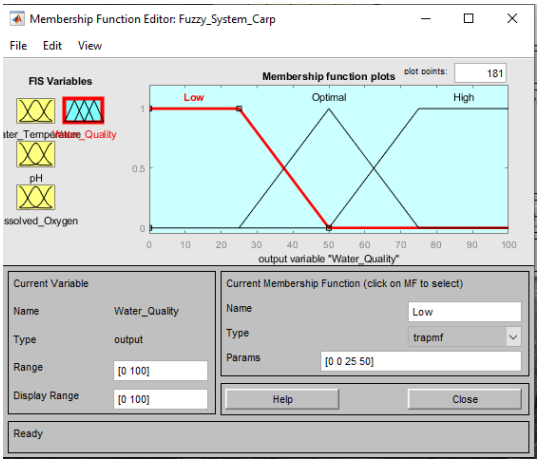


Fig. 4. *Interpretation of water quality in percentages*

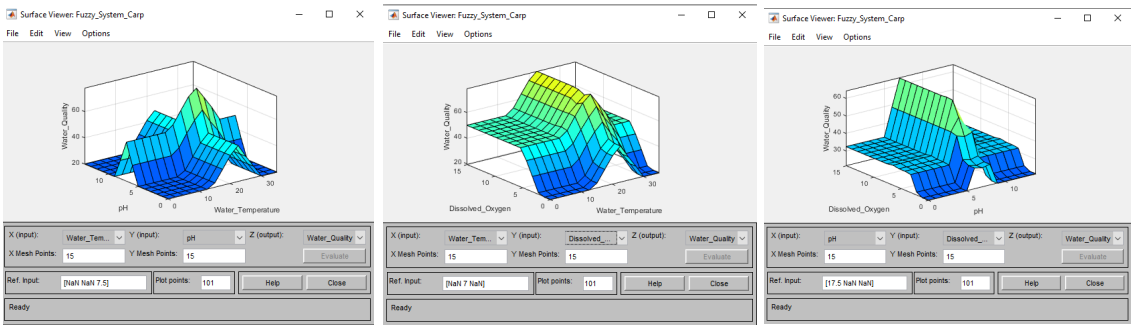


Fig. 5. *Visualization of the control surface according to selected parameters.*

RESULTS AND DISCUSSION

The simulation of the fuzzy system performed in MATLAB demonstrated the possibility of automatic evaluation of the water quality in an aquaponic system based on important physicochemical parameters. The system uses three input variables, namely water temperature, pH and dissolved oxygen concentration, and the result is expressed by the output variable Water Quality, defined on a scale from 0 to 100.

The system was tested using a water temperature of 22 °C, a pH of 7.2, and a dissolved oxygen concentration of 6 mg/L. These values are processed by the membership functions defined for each variable and are then evaluated via the fuzzy rule base. Since the input values can belong to several fuzzy sets simultaneously, the system allows for a gradual interpretation of the water status, as opposed to a strict classification based on fixed limits.

The Water Quality result should be interpreted as a fuzzy index: values close to 0 indicate low water quality, values in the central area indicate an intermediate or optimal state, and values close to 100 indicate high quality according to the rules defined in the model. Thus, the output is not a direct physical measurement, but an estimate obtained by combining the input parameters.

The simulation confirms that the fuzzy system can simultaneously integrate several parameters and transform the numerical information into an easy-to-interpret assessment of the water status. The model can form the basis for the further development of a real-time monitoring system, by connecting temperature, pH and dissolved oxygen sensors to an acquisition and control system.

The proposed fuzzy model can be further extended by integrating sensors for real-time measurement of water parameters and using an IoT-like platform for data transmission and processing. Such a development would allow the transition from simulation performed in MATLAB to a real-time monitoring and control system. Nagothu et al. (2025) presented an approach based on fuzzy logic and IoT technologies for monitoring and maintaining water quality parameters in aquaculture, using parameters such as temperature, pH, and dissolved oxygen, and allowing automatic control of some equipment, such as aerators and pumps. This approach supports the possibility of further developing the proposed model towards a practical automatic monitoring and control application (Nagothu et al., 2025).

CONCLUSION

The present study demonstrated the development and simulation of a fuzzy logic system for evaluating water quality in an aquaponic system intended for carp farming. The proposed model uses three main water quality parameters as inputs: water temperature, pH, and dissolved oxygen concentration. Each input variable was represented by three linguistic levels, namely Low, Optimal, and High, using triangular and trapezoidal membership functions with overlapping regions. The fuzzy inference system was implemented in MATLAB using a Mamdani-type architecture and a rule base designed to combine the three input parameters into a single Water Quality output. The overlapping membership functions, with adjacent sets intersecting at a membership degree of 0.5, provide a gradual transition between different water quality conditions and reduce abrupt changes in the system response.

The simulation demonstrated that the proposed approach can combine several water parameters and provide an easily interpretable assessment of the overall condition of the aquatic environment. The response surfaces generated in MATLAB also allow the influence of different combinations of input parameters on the final output to be analyzed.

The proposed model represents a preliminary computational solution that can be further developed by incorporating additional parameters, such as ammonia, nitrite, turbidity, or salinity, and by connecting the fuzzy system to real-time sensor measurements. In a practical implementation, the resulting assessment could also be used as an input for automatic control of aeration, water circulation, or other equipment. Therefore, the developed fuzzy model

provides a flexible basis for future development of intelligent monitoring and control systems for aquaponic and aquaculture applications.

REFERENCES

Abul Kashem, M., Hasan Shuvo, M., Mustary, S., Mithun Ali, M., Ullah, N., Delwar Hossain, M., ... and Uddin, J. (2026). A Fuzzy-Logic and Machine Learning-Based Framework for Water Quality Index Classification in Extensive and Intensive Aquaculture Systems. Engineering Reports, 8(6), e70839.

Alexuță, D., & Bălaș, M. M. (2023). The Study of Water Parameters in an Aquaponic System. In XIII International Conference – Industrial Engineering and Environmental Protection (IIZS 2023), p. 468.

Bautista, M. G. A. C., Palconit, M. G. B., Rosales, M. A., Concepcion II, R. S., Bandala, A. A., Dadios, E. P., & Duarte, B. (2022). Fuzzy logic-based adaptive aquaculture water monitoring system based on instantaneous limnological parameters. *Journal of Advanced Computational Intelligence and Intelligent Informatics*, *26*(6), 937-943.

Gustilo, R. C., Dadios, E. P., Calilung, E., & Lim, L. A. G. (2014). Neuro-fuzzy control techniques for optimal water quality index in a small scale Tiger prawn aquaculture setup. *Journal of Advanced Computational Intelligence and Intelligent Informatics*, *18*(5), 805-811.

Mustika, I. W., Najib, F., & Yusriadi, Y. (2023, August). Fuzzy Logic-Based Automatic Water Quality Control System in Smart Aquaponics. In 2023 10th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE) (pp. 425–430). IEEE.

Nagothu, S. K., Bindu Sri, P., Anitha, G., Vincent, S., & Kumar, O. P. (2025). Advancing aquaculture: fuzzy logic-based water quality monitoring and maintenance system for precision aquaculture. *Aquaculture International*, *33*(1), 32.

Popa, M., Alexuta, D., & Balas, V. E. (2022). Fuzzy-Interpolative Control of Temperatures for the Intelligent Rooftop Greenhouse. Journal of Intelligent & Fuzzy Systems, 43(2), 1793–1797.

Rad, D., Rad, G., Maier, R., Demeter, E., Dicu, A., Popa, M., ... Mărineanu, V. D. (2022). A Fuzzy Logic Modelling Approach on Psychological Data. Journal of Intelligent & Fuzzy Systems, 43(2), 1727–1737.

Rahayu, L. P., Al Kindhi, B., Pradika, C. D., Adhim, F. I., Priananda, C. W., Musthofa, A., ... and Istiqomah, F. (2021, December). Design of pH control system and water recirculation in aquaponic cultivation using Mamdani fuzzy logic control. In 2021 International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation (ICAMIMIA) (pp. 287-292). IEEE.

You, G., Xu, B., Su, H., Zhang, S., Pan, J., Hou, X., ... and Ding, R. (2021). Evaluation of aquaculture water quality based on improved fuzzy comprehensive evaluation method. *Water*, *13*(8), 1019.