CHAPTER I

INTRODUCTION

1.1 Research Background

Nile tilapia (Oreochromis niloticus) is one of the leading freshwater aquaculture commodities with high economic value and continuously increasing market demand. This is supported by its excellent nutritional content, particularly its protein composition, essential amino acids, and fatty acids beneficial to human health. Nile tilapia contains complete essential amino acids and unsaturated fatty acids such as omega-6 and omega-9, providing substantial potential as a high-quality protein source to support national food security (Rieuwpassa et al., 2022).

As the demand for Nile tilapia increases, an aquaculture system capable of efficiently and sustainably boosting productivity is required. One of the widely applied technologies today is the biofloc system. Biofloc technology utilizes microbial activity to process organic waste from uneaten feed and fish feces into microbial aggregates (flocs) that can be reused as a natural feed source. This system is known to be environmentally friendly as it minimizes water usage and reduces aquatic pollution (McCusker et al., 2023; Minaz et al., 2024).

Despite its numerous advantages, the biofloc system faces challenges in water quality management. High fish stocking densities and floc biomass can trigger a decline in water quality, such as pH fluctuations, temperature changes, and increased concentrations of dissolved compounds that potentially endanger the fish. Failure to monitor and control water quality parameters in the biofloc system can cause physiological stress, decreased appetite, and even fish mortality, making water quality management a highly crucial aspect for the success of biofloc aquaculture (Khanjani et al., 2024).

In a biofloc system, water quality stability affects not only the cultured fish but also the activity of heterotrophic microorganisms, which are the core of the system. Microbial dynamics in biofloc are heavily influenced by the physical and chemical conditions of the water, particularly temperature, acidity (pH), and the accumulation of dissolved solids (De Schryver et al., 2008; McCusker et al., 2023). Temperature plays a role in regulating the metabolic rates of both microorganisms and fish, thus temperature fluctuations can affect nitrogen conversion efficiency and the growth of Nile tilapia (Yao et al., 2013). The pH value affects the balance of nitrogenous compounds, especially the proportion of toxic unionized ammonia (NH_3), as well as the stability of biological processes in the pond (Martins et al., 2019). Meanwhile, Total Dissolved Solids (TDS) reflects the accumulation level of microbial biomass and metabolic compounds in the biofloc system, thereby serving as an indirect indicator of floc dynamics and dissolved solid density in the pond (Gurung et al., 2025). Therefore, monitoring these three parameters is essential because they simultaneously represent the stability of the biofloc system from the thermal, chemical, and dissolved solid dynamics aspects that affect fish health and the pond's microbiological balance. These conditions indicate that water quality management in biofloc systems requires monitoring that is not only accurate but also continuous and responsive to environmental parameter changes.

To overcome these issues, a water quality monitoring system capable of operating continuously and in real-time is required. Internet of Things (IoT) technology offers a solution through the integration of sensors, microcontrollers, and communication networks to automatically collect and transmit environmental data (Rejeb et al., 2022). IoT enables water quality monitoring processes to be conducted systematically without relying on manual measurements, allowing farmers to obtain pond condition information in real-time.

However, water quality monitoring data alone is insufficient without a decision-making method capable of handling the uncertainty of environmental parameter values. Hence, a computational approach that can process temperature, pH, and Total Dissolved Solids (TDS) data into easily understandable water quality information is needed. Fuzzy logic was chosen because it can represent ambiguous and non-crisp environmental conditions into linguistic rules, allowing it to determine biofloc water quality conditions through a structured rule-based evaluation. The integration of the IoT system with the fuzzy logic method is expected to assist farmers in monitoring and controlling the water quality of Nile tilapia biofloc ponds with a structured and data-driven computational approach.

The dynamic characteristics of the biofloc system, involving complex interactions between microorganisms and fish, cause water quality conditions to not always remain within strict boundaries (De Schryver et al., 2008; Khanjani et al., 2024). Minor changes in temperature, pH, or dissolved solid accumulation can significantly impact system balance, yet they cannot always be rigidly classified as "good" or "bad" conditions. Single-threshold-based approaches often fail to represent the gradual transitional conditions occurring in biological systems like biofloc. Therefore, a decision-making model capable of flexibly accommodating the uncertainty and variation in water quality parameter values is required. Fuzzy logic is known for its ability to represent uncertainty through a linguistic approach and handle continuous and non-crisp data, making it more suitable for dynamic environmental systems (Saatchi, 2024; Zadeh, 1965; Zimmermann, 2010). In this context, the application of fuzzy logic becomes relevant for modeling water quality conditions based on a combination of several interacting parameters.

1.2 Problem Identification

Based on the previously described background, several issues focused on in this research can be identified as follows:

a) Water quality monitoring in biofloc-based Nile tilapia aquaculture is still largely conducted manually and periodically, making it incapable of detecting water quality parameter changes rapidly and in real-time.
b) Unmonitored changes in water quality parameters, such as temperature, pH, and Total Dissolved Solids (TDS), potentially lead to suboptimal environmental conditions, thereby increasing the risk of physiological stress and fish mortality.
c) The absence of an automated water quality data recording and storage system makes it difficult to access and utilize historical data for evaluating the condition of the biofloc ponds.
d) The determination of water quality conditions is generally still based on subjective observations or simple thresholds, thus lacking the capability to represent dynamic and non-crisp water quality conditions.
e) The lack of an automated decision-making system that integrates water quality data causes pond water management processes, such as water quality control actions, to still rely on farmers' manual interventions.

1.3 Research Questions

Based on the problem identification outlined above, the research questions in this study are as follows:

a) How to design an Internet of Things (IoT)-based water quality monitoring system capable of conducting real-time monitoring of temperature, pH, and Total Dissolved Solids (TDS) parameters in biofloc-based Nile tilapia aquaculture?
b) How to process the water quality parameter data obtained from the monitoring system using the fuzzy logic method to determine the water quality conditions of the biofloc pond?
c) How to present the monitoring and water quality determination results informatively to assist farmers in making water quality management decisions?

1.4 Research Limitations

To ensure this research remains focused and aligned with the established objectives, the scope of the study is limited as follows:

a) This research focuses on a water quality monitoring system in biofloc-based Nile tilapia aquaculture, observing water quality parameters that include temperature, pH, and Total Dissolved Solids (TDS).
b) The water quality monitoring system is developed using an Internet of Things (IoT) approach to conduct real-time and continuous water condition monitoring.
c) The fuzzy logic method utilized in this research is the Mamdani Fuzzy Inference System (FIS), which functions to determine water quality conditions based on temperature, pH, and TDS parameters.

d) The testing and validation of the Mamdani fuzzy logic model are conducted offline using software (Python programming language) by utilizing historical water quality datasets previously acquired from the aquaculture ponds.

e) This research does not discuss other water quality parameters outside of temperature, pH, and TDS, such as dissolved oxygen (DO), ammonia, nitrite, or nitrate.

f) The developed system does not encompass long-term predictive analysis or machine learning; rather, it is limited to determining water quality conditions based on actual acquired data.

g) The use of the ultrasonic sensor (JSN-SR04T) in this system is strictly limited to measuring the water surface level to determine the mechanical crisp threshold boundaries for draining and filling the pond. The water level data is not integrated as an input variable in the Mamdani fuzzy logic processing.

h) The system testing is strictly confined to a controlled simulation environment. It has not been deployed continuously in a fully dynamic, real-world biofloc ecosystem encompassing full harvest cycles and continuous natural environmental stressors.

1.5 Research Objectives

Based on the formulated research questions, the objectives of this study are as follows:

a) To design an Internet of Things (IoT)-based water quality monitoring system capable of conducting real-time monitoring of temperature, pH, and Total Dissolved Solids (TDS) parameters in biofloc-based Nile tilapia aquaculture.

b) To describe the implementation of the Mamdani fuzzy logic method in processing water quality parameter data to determine the water quality conditions of the biofloc pond through a structured rule-based evaluation.

c) To produce a water quality monitoring system capable of presenting water quality condition information informatively as a basis for decision-making in biofloc pond management.

1.6 Research Significances

This research is expected to provide both theoretical and practical significances, outlined as follows:

a) Theoretical Significances

This research contributes to the scientific development in the field of Computer Science, specifically in the application of the Internet of Things (IoT) and fuzzy logic as a decision-making method in environmental monitoring systems. The results of this study can serve as a reference for future research examining sensor data processing and fuzzy logic-based decision-making systems in aquaculture or other environmental sectors.

b) Practical Significances

1) For the Researcher: This research provides experience in designing and developing IoT-based monitoring systems and applying fuzzy logic as a data processing and decision-making method. Furthermore, it enhances computational analysis and problem-solving skills applied to real-world problems in the aquaculture sector.

2) For Nile Tilapia Farmers: The developed system is designed as a foundational tool that has the potential to assist farmers in monitoring biofloc pond water

quality in real-time. By generating clearer information on water quality conditions, it is expected that in future field implementations, farmers can utilize this decision-support data to make more precise pond management decisions, thereby maintaining the stability of the aquaculture environment and minimizing the risks of physiological stress.

3) For Dago Engineering: The prototype developed in this research provides a validated computational and hardware blueprint that can serve as a foundational asset for the company's Research and Development (R&D) division. It specifically enriches Dago Engineering's technology portfolio in the smart aquaculture sector, offering a tested Mamdani fuzzy logic framework that can be further scaled and integrated into their future commercial IoT products.
4) For the Community: This research offers insights into the utilization of IoT technology and fuzzy logic in supporting more modern and efficient aquaculture practices. Additionally, the findings are expected to serve as an educational tool for the community to understand biofloc aquaculture systems and the application of digital technology in the fisheries sector.