

Internet of Things (IoT)-Based Water Quality Monitoring System Design for Tilapia Fish Farming Ponds

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Article History:

Submitted: 06-09-2025

Accepted: 10-09-2025

Published: 17-09-2025

Keywords:

Blynk; IoT; water quality; nodeMCU ESP32; pH sensor temperature sensor; turbidity sensor.

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ABSTRACT

This study aimed to develop an Internet of Things (IoT)-based water quality monitoring system for tilapia cultivation ponds at Varel Collection. Farmers previously monitored pond water manually, which was often neglected due to their agricultural activities, leading to poor water conditions and negative impacts on fish growth. To overcome this issue, a prototype system was designed to enable real-time monitoring of water parameters using IoT technology integrated with the Blynk platform.

The research applied a Research and Development (R&D) approach with a Prototype method. The system was built using NodeMCU ESP32 as the main microcontroller, integrated with several sensors including a pH sensor, DS18B20 temperature sensor, and a turbidity sensor to measure water quality parameters. Data from these sensors are processed and transmitted to the Blynk application, allowing farmers to remotely monitor pond conditions via the internet. Supporting tools included Fritzting for design, Arduino IDE for programming, and hardware components such as adapters, jumper cables, and enclosures.

Evaluation by three experts indicated that the system achieved an average feasibility index of 95.93%, categorized as “very good.” These findings show that the IoT-based monitoring system is functional, feasible for aquaculture use, and has strong potential for further development in real-time water quality management.

INTRODUCTION

Indonesia, with a water area of approximately 5.8 million km², holds tremendous potential for the development of its fisheries sector. This resource plays a vital role in food security, economic growth, and community welfare. Among various freshwater fish commodities, tilapia is one of the most widely cultivated due to its high economic value, fast growth, adaptability, and consumer preference. According to the Ministry of Marine Affairs and Fisheries, tilapia production in 2015 reached 592,365 tons with an average annual production of 197,455 tons and a growth rate of 22.75%. These figures underline the strategic importance of freshwater aquaculture in providing affordable animal protein, creating employment opportunities, and increasing household income Wahid et al. (2023).

Indonesia's fisheries sector consists of capture and aquaculture activities. Capture fisheries are conducted in seas, rivers, and lakes, while aquaculture is carried out in controlled environments such as ponds, reservoirs, and farms. Major freshwater aquaculture commodities include carp, tilapia, catfish, Mozambique tilapia, and gourami Prasetya et al. (2022).

In tilapia farming, water quality is a critical factor for success. Tilapia requires an optimal temperature of 24–32 °C, sufficient dissolved oxygen, proper waste management, and balanced nutrition. However, aquaculture practices in Indonesia remain largely manual, leading to challenges such as delayed feeding, inefficient monitoring, and limited technical knowledge, which reduce productivity Fahmi et al. (2020).

Another issue is unstable pond water quality, particularly in terms of pH and temperature, which directly affect fish survival. Extreme pH levels may cause culture failure, while unsuitable temperatures increase mortality. Continuous monitoring is therefore essential Deidy (2021). Unfortunately, traditional monitoring methods restrict farmers' ability to detect changes promptly, often resulting in delayed responses.

The Internet of Things (IoT) has been introduced as a solution to these problems. IoT-based systems allow continuous real-time monitoring of key parameters such as temperature, pH, and turbidity. Data can be accessed via digital platforms, enabling timely decision-making Nursobah et al. (2022). Recent advancements in wireless technology have further enhanced IoT adoption in aquaculture, as sensors can connect to mobile devices, allowing farmers to track pond conditions anytime, thus improving efficiency and productivity Dimas et al., (2024).

In Mulyorejo Village, North Luwu Regency, South Sulawesi, tilapia farming still faces inefficiencies. Common problems include improper stocking density, poor pond maintenance, overfeeding, and the absence of aeration or automated systems. These factors contribute to low productivity and high mortality, while limited resources hinder



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effective monitoring.

Varel Collection, an aquaculture enterprise established in 2023 in the same village, cultivates tilapia, catfish, pomfret, and koi. However, water quality monitoring remains manual, with key parameters such as temperature and pH measured using time-consuming and often inaccurate methods. This leads to delayed responses, poor water management, and high mortality, resulting in financial losses.

To overcome these challenges, this study develops an IoT-based water quality monitoring system for tilapia ponds. The system integrates sensors to measure temperature, pH, and turbidity, providing accurate real-time data accessible via smartphones through the Blynk platform. This innovation is expected to improve management efficiency, enhance water quality control, and support the sustainable development of tilapia aquaculture in Indonesia

LITERATURE REVIEW

Several recent studies have explored the application of Internet of Things (IoT) in aquaculture water quality monitoring. Efendi (2020) designed a smart system capable of automatically monitoring pond parameters such as temperature and pH, with real-time data accessible via Blynk and integrated notifications for abnormal conditions. Similarly, Nursobah et al. (2022) developed a telemetry prototype for tilapia ponds using NodeMCU, pH and temperature sensors, and Cayenne My Device, enabling real-time measurements that facilitate freshwater aquaculture management.

Expanding the monitored parameters, Fatimah et al. (2024) proposed a system that includes dissolved oxygen alongside temperature and pH, providing automated alerts when values deviate from acceptable ranges. Dimas et al. (2024) further improved system scope by integrating turbidity sensors, delivering real-time water quality data with automated notifications through digital platforms. Meanwhile, Erlillah et al. (2022) demonstrated that IoT-based designs can comprehensively monitor temperature, pH, and dissolved oxygen, supporting better decision-making in tilapia farming.

In addition, although focusing on agriculture, Wahid et al. (2023) highlighted the effectiveness of NodeMCU ESP32 and Blynk integration for real-time automation, a concept highly adaptable to aquaculture. Collectively, these studies indicate a growing trend toward more holistic IoT-based monitoring systems. Susanto et al. (2021) However, most remain limited by narrow parameter coverage or less user-friendly interfaces. Therefore, there is still a research gap in developing an integrated system that combines key parameters—such as temperature, pH, dissolved oxygen, and turbidity—into a single, accessible platform tailored for small-scale fish farmers.

METHOD

This study employed the Research and Development (R&D) approach, which focuses on producing a functional product while testing its efficiency and effectiveness in real implementation. R&D serves as a bridge between basic and applied research, ensuring that the developed system not only fulfills theoretical expectations but also addresses practical challenges in aquaculture Okpatrioka (2023).

The development process adopted the prototype method, which emphasizes creating an early system model that can be iteratively tested, refined, and validated before full implementation Siswidiyanto et al., (2020). The prototyping cycle consisted of four stages: requirements gathering, design, prototype construction, and evaluation.

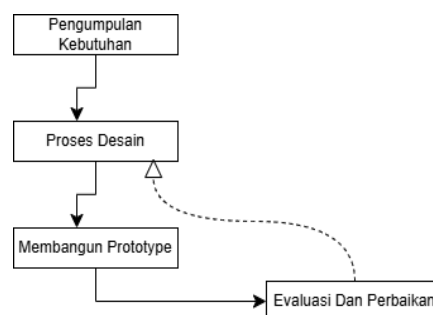


Fig. 1 Prototype Method Stages

Data Collection (Requirements Gathering)

Data were obtained through three complementary methods:

Observation at Varel Collection fish farm in Muliyorejo Village, Luwu Utara, to identify current practices and problems in water quality monitoring. The study noted that pH, temperature, and turbidity were not regularly monitored, leading to fish mortality and reduced yields.

Interviews with the farm owner revealed reliance on manual water checks using indicator papers, with no automation in place. This confirmed the necessity of a real-time IoT-based monitoring solution.

Literature Review of previous studies, books, and journals on IoT, aquaculture practices, and water quality



parameters, which provided theoretical foundations for system design.

System Design

Based on collected data, the system was designed to integrate ESP32 with pH, temperature, and turbidity sensors, supported by the Blynk platform for real-time monitoring. The design outlined both functional requirements (accurate data sensing, remote accessibility, automated alerts) and non-functional requirements (hardware specifications, software platforms, and supporting equipment). A flowchart was created to represent the overall process, from sensor data acquisition to notification delivery.

Prototype Development

The prototype was constructed using defined hardware and software specifications. Each component—ESP32, sensors, baseboard, and mobile application—was configured to replicate real operational conditions. The prototype served as a tangible model, enabling iterative improvements based on user feedback and design validation.

Evaluation and Refinement

Evaluation consisted of two methods:

System Testing (Black Box Testing) to verify that all system functions operated correctly without analyzing internal code structures. Input–output accuracy, sensor responsiveness, and notification delivery were tested.

Expert Review, in which aquaculture and IoT specialists assessed system functionality, accuracy, and reliability. Feedback from this stage guided necessary refinements to enhance performance and ensure alignment with practical needs.

Research Location and Timeline

The research was conducted at Varel Collection, Muliyorejo Village, Luwu Utara Regency, South Sulawesi, over three months (February–April 2025). Data collection took three weeks, followed by two weeks of system design, three weeks of prototype construction, and one month of evaluation and refinement.

Through this structured and chronological methodology, the study ensured that data collection was comprehensive, system design was evidence-based, prototype development was systematic, and evaluation was both technical and expert-driven. The methodology guarantees that the resulting IoT-based water quality monitoring system is functional, reliable, and ready for practical application in tilapia aquaculture.

RESULT

Data Collection

Observation

Observations were conducted directly at the fish farming site to identify the main problems in the tilapia cultivation process. The results showed that the farming methods had not yet been optimized. Issues identified included high fish density, poorly maintained pond conditions, and excessive feeding. In addition, water quality monitoring was still carried out manually, without measuring instruments capable of recording accurate data to support analysis or decision-making.

Interview

Interviews were conducted with the owner of the Varel Collection fish farming business. The information obtained revealed that parameters such as temperature and pH were not measured regularly. A decline in water quality was often noticed too late, after the fish had already experienced stress, and water replacement was rarely carried out. This indicates the need for technology that can continuously and in real-time monitor water quality parameters such as temperature, pH, and turbidity, allowing farmers to take corrective action promptly.

Literature Review

The literature reviewed includes books, scientific journals, and theses relevant to microcontrollers, water quality sensors, and the implementation of the Internet of Things in monitoring systems. This study provided the necessary references for designing an automatic, technology-based water quality monitoring device for fish ponds.

Design Process

The design process aims to analyze the current system and develop a new system design that is more efficient and adaptive.



Current System

The fish farming system at Varel Collection is still carried out manually. The process begins with pond filling, seed stocking, and feeding twice a day. Water quality is assessed only through visual observations of fish behavior, such as surfacing to the water's surface. Supporting tools, such as thermometers or pH test papers, are used in a limited manner. If the water is considered poor, partial replacement is done manually. This process heavily relies on the farmer's intuition and carries the risk of delayed handling, which can negatively impact fish growth.

Proposed System

Based on field findings, this study proposes an Internet of Things (IoT)-based water quality monitoring system to enhance efficiency and accuracy in aquaculture. The system utilizes an ESP32 microcontroller connected to Wi-Fi and integrates three sensors: a pH sensor to measure acidity, a DS18B20 temperature sensor to monitor water temperature, and a turbidity sensor to assess clarity. Once powered, the ESP32 automatically connects to the network and processes sensor data against predefined thresholds. Alerts are generated via the Blynk application if pH drops below 6.5 or exceeds 8.5, temperature falls outside 24–32 °C, or turbidity is below 50 NTU or above 100 NTU. Real-time data visualization enables farmers to take immediate corrective action, thereby reducing fish mortality risks, improving aquaculture quality, and supporting modern, technology-driven practices.

Functional Requirements

The functional requirements of the IoT-based water quality monitoring system for tilapia ponds were designed to support fish farmers at Varel Collection in monitoring pond conditions in real time. The system must be capable of measuring three key parameters: temperature, pH, and turbidity. The pH sensor transmits data to the ESP32 microcontroller and triggers a notification via the Blynk application if the pH value exceeds 8.5, enabling farmers to immediately take corrective action. The DS18B20 temperature sensor detects temperatures above 32 °C and sends a warning through the application, while the turbidity sensor issues an alert when the value reaches 100 NTU, indicating excessive turbidity that requires intervention.

Non-Functional Requirements

The non-functional requirements cover both hardware and software components that support the system. The hardware includes an Acer Aspire 3 laptop with an Intel Celeron N4120 processor, 4 GB RAM, and 256 GB SSD; a smartphone for accessing the Blynk interface; an ESP32 microcontroller; jumper and USB cables; a pH sensor; a DS18B20 temperature sensor; a turbidity sensor; an NTC thermistor sensor; and an adapter. The software consists of the Arduino IDE for microcontroller programming and the Blynk application for sensor data visualization. The research was carried out at Varel Collection, located in Mulyorejo Village, Sukamaju Selatan Subdistrict, North Luwu Regency, South Sulawesi. This site was selected because it aligns with the operational requirements of the developed system. Device selection was also based on budget considerations and efficiency in system assembly.

Design Process

Electronic Component Design

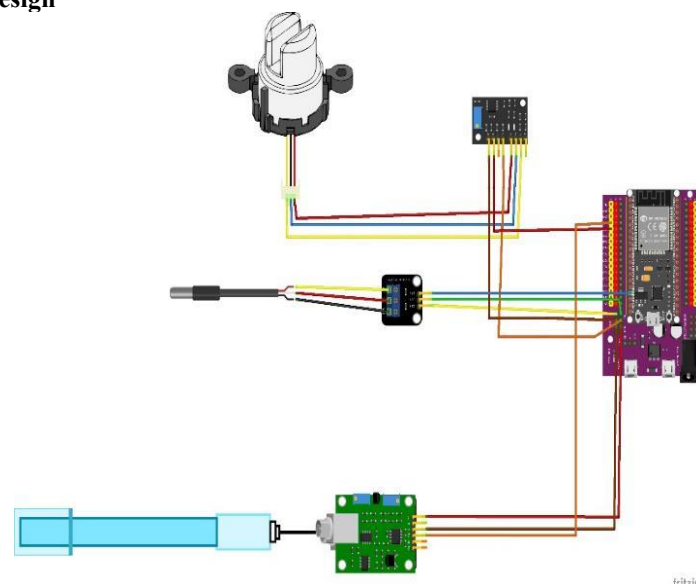


Fig. 2 Electronic Component Design

Figure 2 illustrates the circuit configuration of the device developed in this study. The circuit consists of several key components, with the NodeMCU ESP32 serving as the main controller of the system. In addition, the device integrates multiple sensors, including a pH sensor, a temperature sensor, an NTC thermistor, an ESP32 dashboard, and a turbidity sensor used to measure water clarity. Each component within the circuit plays a specific role in supporting the overall monitoring of water quality.

System Interface Design

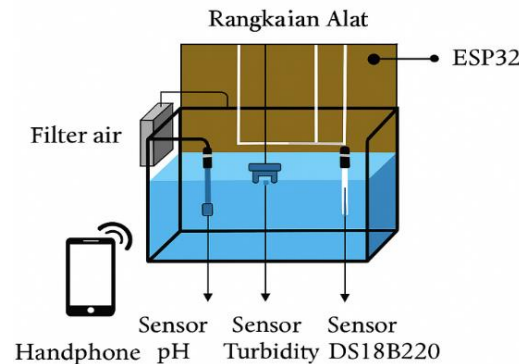


Fig. 3 System Interface Design

Figure 3 shows the prototype model developed by the authors to simulate the fish pond water quality monitoring system using IoT technology. Positioned above the aquarium is the ESP32 module as the main control unit, accompanied by a pH sensor to evaluate acidity levels, a DS18B20 temperature sensor to monitor water temperature, and a turbidity sensor to assess water clarity. A smartphone is also integrated as the device for receiving notifications.

Evaluation and Improvement System Testing

Table 1. Expert Validation Results

No	Evaluation Aspect	Indicator	Expert 1	Expert 2	Expert 3
1	Physical Design & Data Display	Prototype design compliance with construction	3	4	4
		Circuit placement inside the box is clearly visible	3	4	4
		Prototype is compact and suitable for the user environment (e.g., near water source, lab, field)	4	4	4
		Component placement (sensors, microcontroller, display, indicators) is neat and ergonomic	3	4	4
		Ports and connectors are easily accessible for maintenance	4	4	4
		Parameters such as pH, temperature, TDS, DO are clearly displayed in real-time	4	4	4
		Font size is readable under different lighting conditions	4	4	4
		Data layout is logical and not confusing	4	4	4
2	Functional Aspect	IoT device performs as expected	4	4	4
		All sensors and actuators function properly	4	4	4
		Transmitted data is accurate and consistent	4	4	4
		Device responds quickly and correctly to commands (manual/automatic)	3	4	3
		Device operates stably over an extended period	4	4	4
3	Connectivity Aspect	Communication between device and server runs smoothly	4	4	4
		No connection interruptions during testing	4	3	3
		Device handles connection disruptions effectively (auto reconnect, data buffering)	4	4	4
		Real-time data is smoothly accessible via Blynk app	4	3	3

4	Usability Aspect	User interface is easy to use	4	4	4
		Instructions are easy to understand	4	4	4
		Device can be operated by non-technical users	4	3	4
		Data is well protected (e.g., encryption)	4	4	4
5	Energy Efficiency & Durability	Device does not overheat or suffer physical damage	4	3	4
		Power consumption matches specifications	4	4	4
		Device operates under various environmental conditions (temperature, humidity)	4	4	4
		Casing is resistant to wet/damp environments (at least splash-proof)	4	3	4
		No sharp edges or exposed dangerous components	4	4	4
		Materials are strong and resistant to temperature/water	4	3	4

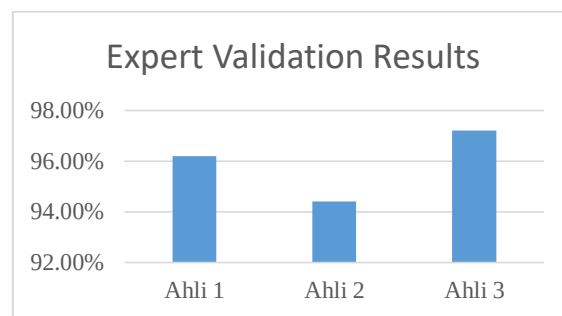


Fig. 4 Expert Validation Results Diagram

Based on the information presented in Table 6, the next step is to calculate the index value and determine the assessment interval. Referring to the formula described in the previous chapter, the obtained index value is as follows:

- Value 1 means "Very Poor"
Value 2 means "Poor"
Value 3 means "Good"
Value 4 means "Very Good"

$$\text{Index} = \frac{\text{Score obtained}}{\text{Maximum Score}} \times 100\%$$

Explanation:

Score obtained = total score achieved

Maximum score = total maximum score

Table 2. Assessment Percentage Table

Score Value	Index/Percentage	Interpretation
1	0% - 25%	Very Poor
2	26% - 50%	Poor
3	51% - 75%	Good
4	76% - 100%	Very Good

Based on the evaluation carried out by three experts, Expert 1 obtained an index of 96.29%, Expert 2 achieved 94.44%, and Expert 3 obtained 97.22%. All three results fall under the "very good" category. The average index score from the three experts is 95.93%, which indicates that the proposed IoT-based water quality monitoring system for tilapia fish ponds meets the required functional aspects. Therefore, the system is considered to be in the "very good" category, making it feasible for implementation and further development

Product Trial

Table 3. Black Box Testing Results of the Water Quality Monitoring System

No	Test Component	Expected Outcome	Validator 1	Validator 2	Result
1	ESP32 Module	The module powers on and runs the program as designed	Success	Success	Achieved
		The ESP32 transmits sensor data to the IoT platform stably	Success	Success	Achieved
		The ESP32 transmits sensor data periodically to the server	Success	Success	Achieved
2	Temperature Sensor	Detects changes in water temperature accurately	Success	Success	Achieved
		Temperature data is displayed in real-time on the IoT dashboard	Success	Success	Achieved
3	Turbidity Sensor	Accurately detects water turbidity levels	Success	Success	Achieved
		Turbidity values are transmitted and displayed on the IoT system	Success	Success	Achieved
		Turbidity data is transmitted to the monitoring system without interruption	Success	Success	Achieved
4	pH Sensor	Accurately and stably reads water acidity levels	Success	Success	Achieved
		pH values are displayed periodically on the dashboard/application	Success	Success	Achieved
		Readings remain consistent when tested with water samples of different pH levels	Success	Success	Achieved

Field Testing of the Overall System Development

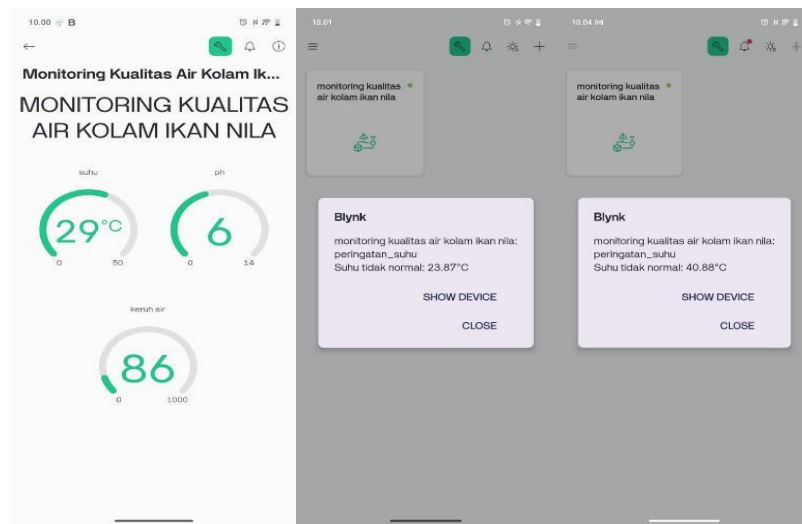


Fig 5. Temperature Sensor Testing

The temperature sensor was evaluated by immersing it in water at different temperature levels, namely cold water (ice), room temperature, and warm water. The experimental results, as presented in Fig.2, demonstrate that the sensor accurately detected variations in water temperature. Furthermore, the system was able to automatically transmit notifications to the Blynk application when the temperature exceeded the predefined threshold, thereby enabling users to take immediate corrective action.

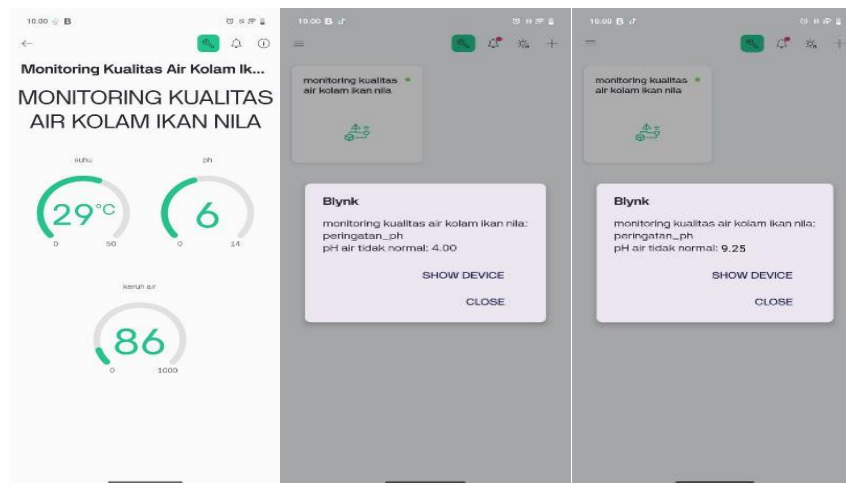


Fig 6. pH Sensor Testing

The pH sensor was tested by immersing it in water samples with varying acidity levels, namely acidic, neutral, and alkaline conditions. The objective of this test was to verify the accuracy and consistency of sensor readings across different environments. The experimental results, as shown in Fig. 3, demonstrate that the pH sensor successfully measured pH values in accordance with the characteristics of each sample. Furthermore, the system was configured to automatically transmit notifications through the Blynk application whenever the pH value exceeded the defined threshold, enabling users to promptly respond to real-time changes in water quality.

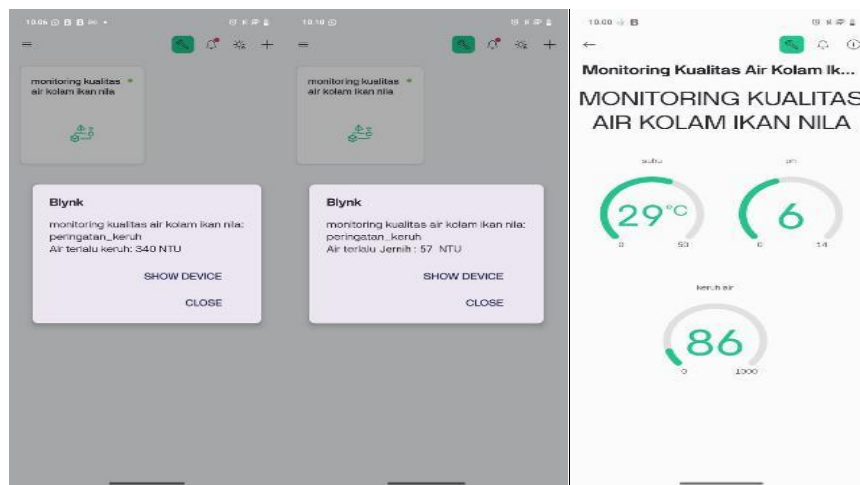


Fig 7. Turbidity Sensor Testing

The turbidity sensor was evaluated by immersing it in clear water, moderately turbid water, and highly turbid water to assess the accuracy of its measurements. The results, as illustrated in Fig. 4, demonstrate that the sensor was capable of accurately detecting variations in turbidity levels. In addition, the system was designed to automatically transmit notifications to the Blynk application when the turbidity value exceeded the predefined threshold, thereby enabling users to respond promptly to unfavorable water conditions.

Overall Field Testing of the Prototype Box

Table 4. Field Testing Results

Day/Date	Time	pH	pH Status	Temperature	Temperature Status	Turbidity (NTU)	Turbidity Status
Friday, June 13, 2025	07:15	6.4	Normal	22°C	Low (<24°C)	70	Normal
	09:35	6.8	Normal	25°C	Normal	98	Normal
	13:10	7.2	Normal	28°C	Normal	104	High (>100 NTU)
	15:42	8.2	Normal	28°C	Normal	108	High (>100)

Saturday, June 14, 2025	23:45	7.9	Normal	26°C	Normal	90	NTU)
	06:20	8.6	Alkaline (>8.5)	26°C	Normal	110	Normal
	08:15	8.5	Normal	26°C	Normal	150	High (>100 NTU)
	10:10	4.0	Acidic (<6.5)	24°C	Normal	274	High (>100 NTU)
	14:32	4.0	Acidic (<6.5)	24°C	Normal	119	High (>100 NTU)
	17:23	5.0	Acidic (<6.5)	26°C	Normal	115	High (>100 NTU)
	20:03	6.4	Acidic (<6.5)	26°C	Normal	115	High (>100 NTU)
	22:10	6.4	Acidic (<6.5)	25°C	Normal	120	High (>100 NTU)
	23:56	6.8	Normal	23°C	Low (<24°C)	120	High (>100 NTU)
Sunday, June 15, 2025	05:15	6.9	Normal	26°C	Normal	122	High (>100 NTU)
	09:00	6.9	Normal	26°C	Normal	130	High (>100 NTU)
	12:05	9.6	Alkaline (>8.5)	25°C	Normal	90	Normal
	14:15	7.5	Normal	25°C	Normal	92	Normal
	19:08	8.7	Alkaline (>8.5)	26°C	Normal	92	Normal
	22:04	8.2	Normal	26°C	Normal	100	Normal
	22:46	8.2	Normal	24°C	Normal	115	High (>100 NTU)

Based on field testing conducted at the Nile tilapia cultivation site of Varel Collection, Mulyorejo Village, the optimal water quality parameters were identified at pH 6.5–8.5, temperature 24–32 °C, and turbidity 50–100 NTU. However, the observations revealed significant variations. The pH value decreased to as low as 4.0 due to the accumulation of waste and leftover feed, which triggered the nitrification process. Conversely, the pH reached 9.6 as a result of using alkaline water sources. Water temperature was also recorded to drop to 22 °C due to weather conditions, while turbidity levels exceeded 100 NTU and even reached 274 NTU, primarily caused by microorganism growth and the use of organic materials such as kapatang leaves. Although artificial pond systems in this area typically employ aerators, the stabilization of water quality requires up to one month, during which the natural microbial ecosystem in the pond is established.

DISCUSSION

This study successfully developed an Internet of Things (IoT)-based water quality monitoring system for tilapia ponds, integrating pH, temperature, and turbidity sensors with real-time monitoring via the Blynk application. The system proved effective in enhancing accuracy, efficiency, and responsiveness compared to manual methods, with expert evaluation results showing a feasibility index of 95.93% categorized as “very good.”

From a practical perspective, the system provides tilapia farmers with a reliable and user-friendly tool to continuously monitor pond conditions, reduce the risk of fish mortality, and improve aquaculture productivity. It also supports better decision-making in water management by delivering timely alerts directly to mobile devices.

From an academic perspective, this research advances the application of IoT in aquaculture by integrating multiple critical parameters into one platform. It also lays the groundwork for further studies to enhance system functionality by incorporating dissolved oxygen sensors, automated aeration control, and advanced data analytics for predictive management.

In conclusion, the proposed system not only addresses the limitations of manual monitoring but also contributes to sustainable and technology-driven aquaculture practices in Indonesia.

CONCLUSION

This study successfully designed and implemented an IoT-based water quality monitoring system for tilapia aquaculture ponds, integrating pH, temperature, and turbidity sensors with the ESP32 microcontroller and Blynk application. The system enables real-time and remote monitoring, improves efficiency compared to manual methods, and has been validated through expert assessment and black box testing. Long-term use demonstrated positive impacts on pond management and sustainability. Future development should include additional sensors such as dissolved oxygen (DO) and aerators to enhance accuracy and comprehensiveness, along with technical training for farmers to ensure optimal utilization and long-term adoption in aquaculture practices.

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