JAIIT *(Journal of Advances in Information and Industrial Technology)*
Vol. 7, No. 2 Nov 2025, ISSN 2716-1935, E-ISSN 2716-1927

IoT-Based Water Quality Monitoring System to Enhance Sustainability and Business Performance in Koi Fish Cultivation

Sugiarto*1), Isna Nugraha2), Tresna Maulana Fahrudin3), Azza Rizqina4) Keisya Agvenia5).
1,4) Department of Digital Business, UPN Veteran Jawa Timur, Indonesia
2) Department of Industrial Engineering, UPN Veteran Jawa Timur, Indonesia
3) Department of Information and Communication Systems, Okayama University, Japan
1*sugiarto.if@upnjatim.ac.id, 2isna.nugraha.ti@upnjatim.ac.id, 3tresnamf@s.okayama-u.ac.jp,
423084010039@student.upnjatim.ac.id 523084010045@student.upnjatim.ac.id

ARTICLE INFO

Article history:
Received 31 October 2025
Revised 5 November 2025
Accepted 27 November 2025
Available online 29 November 2024

Keywords:
Business Performance
Internet of Things
Koi Fish Cultivation
Smart Aquaculture
Sustainability
Water Quality Monitoring

ABSTRACT

Water quality is a critical factor that determines the survival and productivity of koi fish cultivation. Fluctuations in key parameters, such as pH, dissolved oxygen (DO), total dissolved solids (TDS), and turbidity, can induce stress and lead to mass fish mortality, resulting in substantial financial losses for farmers. This study proposes an IoT-based water quality monitoring system designed to enhance both environmental sustainability and business performance in koi aquaculture. The system integrates four sensors (pH, DO, TDS, and turbidity) connected to an ESP32 microcontroller, which transmits real-time data via Wi-Fi to cloud platforms (Firebase and Blynk). A dedicated dashboard provides continuous monitoring, historical trend visualization, and real-time alerts when parameter thresholds are exceeded. The prototype was validated in an operational koi pond and achieved an average accuracy of 96.5%. User testing involving 10 koi farmers showed an 89% satisfaction rate, demonstrating the system's practicality and usability. Economically, the solution reduced manual monitoring costs by 40%, water replacement volume by 25%, and increased fish survival rates by 12%. These results indicate that IoT implementation in aquaculture not only improves environmental control but also increases operational efficiency and overall profitability, contributing to sustainable, data-driven aquaculture practices.

1. Introduction

Koi fish (Cyprinus carpio) cultivation has become one of the most profitable segments in ornamental aquaculture, especially in Asian countries such as Indonesia and Japan. Growing international demand driven by aesthetic value and cultural significance has encouraged many breeders to transition from conventional aquaculture practices toward more modern, data-driven systems[1]. Despite its economic potential, small- and medium-scale koi farmers continue to face persistent production challenges, particularly those caused by fluctuations in water quality parameters that directly influence fish health, growth, and survival rates. Key environmental indicators—pH, dissolved oxygen (DO), total dissolved solids (TDS), and turbidity—must remain within optimal thresholds; deviations can induce stress, compromise immune function, and increase disease susceptibility, ultimately resulting in significant economic losses [2]. Traditional monitoring methods, which rely on manual measurements using water test kits, are time-consuming and prone to human error. These limitations often delay farmers' responses to sudden environmental changes, thereby increasing financial and operational risks. Recent advancements in Internet of Things (IoT) technologies offer promising solutions by enabling continuous, automated monitoring using integrated sensors that transmit real-time data to cloud platforms for analysis and decision support. Through IoT-enabled dashboards and mobile applications, farmers can remotely supervise their ponds and respond promptly to environmental shifts[3]. Beyond reactive monitoring, IoT systems also support predictive and preventive aquaculture management, helping farmers take corrective action before water quality reaches harmful levels.

From a business perspective, IoT adoption can reduce operational costs by automating data collection, minimizing labor requirements, and lowering fish mortality rates—all of which contribute to improved profitability and long-term business resilience. IoT-generated data also provides strategic insights for optimizing feeding schedules, adjusting aeration routines, and improving resource allocation [4]. From an environmental sustainability standpoint, IoT systems promote responsible aquaculture by reducing resource waste, minimizing water use, and supporting more efficient energy consumption.

Several previous studies have explored IoT applications in aquaculture, focusing primarily on the integration of sensors to measure parameters such as temperature, pH, and oxygen concentration [5]. However, most existing systems emphasize technological implementation alone and rarely examine the broader impact of IoT on business performance, operational efficiency, and economic sustainability. Furthermore, prior research often evaluates only partial parameter sets or laboratory-scale environments, limiting their applicability to real-world koi farming. Thus, a clear research gap exists in developing and evaluating an IoT-based water quality monitoring system that integrates environmental sensing with measurable business outcomes for small- and medium-scale koi aquaculture. In response to this gap, the present study proposes an integrated IoT-based water quality monitoring system designed to enhance environmental stability, business performance, and long-term sustainability in koi cultivation [6]. The system utilizes pH, DO, TDS, and turbidity sensors connected to an ESP32 microcontroller, with real-time data transmitted to cloud platforms (Blynk and Firebase) for monitoring, visualization, and alert notifications [7].

The objective of this research is to (1) design and implement a real-time IoT monitoring system for koi aquaculture, (2) evaluate its accuracy, responsiveness, and usability under real-world farming conditions, and (3) assess its impact on operational efficiency, cost reduction, and overall business performance.

2. Literature Review

The widespread application of Internet of Things (IoT) technology has transformed various industries, including agriculture, aquaculture, manufacturing, and logistics. In aquaculture, IoT is a foundation for developing smart farming systems that allow remote control, automatic adjustment, and data-driven management. In previous studies, koi pond monitoring systems only displayed real-time sensor values but did not evaluate their accuracy performance compared to standard field equipment. This study provides a more in-depth analysis because sensor testing was conducted directly in operational koi ponds and validated using professional benchmarking tools, resulting in an average accuracy of 96.5%, increasing user confidence in the displayed data[3][2]. Several studies have used the ESP32 as a controller to read sensors and transmit data to a cloud platform. While this approach allows for online data display, most lack long-term historical storage or trend analysis that could help farmers monitor gradual changes in water quality daily. The ability to analyze patterns in environmental conditions is crucial for determining more precise, data-driven actions [8]. The systems allow farmers to control the environment in an optimal way and improve efficiency and sustainability. In this section, a general overview of current research on IoT-based water quality monitoring systems, sustainable aquaculture, and the employment of IoT technology as a tool for enhancing business performance and business resilience is provided [9].

2.1 IoT in Aquaculture Monitoring Systems

The adoption of Internet of Things (IoT) technology in aquaculture is now more critical as fish farmers face mounting challenges from environmental changes and operational inefficiency. According to [10], IoT-supported monitoring systems can be employed for continuous measurement of real-time data on key water quality parameters such as pH, dissolved oxygen, temperature, and salinity, thereby enabling proactive and adaptive management of aquaculture environments. Similarly, [11] found that the application of ESP32 microcontrollers with multi-sensor networks greatly enhances measurement accuracy and minimizes monitoring latency compared to conventional manual testing methods.

DOI: https://doi.org/10.52435/jaiit.v7i2.730

In most IoT-based aquaculture systems, sensors are the first sources of environmental data, while microcontrollers such as Arduino and ESP32 serve as gateways that push data via Wi-Fi or GSM networks to cloud platforms like Firebase, ThingSpeak, or Blynk. The platforms provide data visualization through mobile applications or web dashboards, allowing farmers to monitor conditions remotely and make timely, data-driven decisions [11].

Despite these technical innovations, the majority of existing literature remains centered on the technicalities, like sensor calibration, network reliability, and data transmission, with little contribution regarding how IoT adoption contributes to business sustainability, cost efficiency, and overall profitability in aquaculture enterprises.

2.2 Sustainability and Environmental Efficiency in Aquaculture

Currently, sustainability is an important part of aquaculture management. Aquaculture is characterized by high water and energy demands, and poor environmental management can result in pollution, habitat destruction, and fish kills. The IoT-based systems have the challenge to contribute to sustainable aquaculture through monitoring water quality in real time, minimizing resource waste, and maximizing the use of water and energy [12]. This makes it possible to detect contamination or changes in the environment in advance, reducing the use of chemical treatments and therefore contaminating the ecosystem less. Previous research has shown that IoT systems in koi aquaculture can help reduce the risk of fish mortality through structured monitoring during the quarantine process. This study confirms these findings and adds a new dimension: business impact evaluation, demonstrating a reduction in operational costs of up to 40% and a 12% increase in survival rates. Therefore, IoT implementation not only provides technical benefits but also significantly improves the economic performance of koi farmers [13]

In addition, IoT-enabled monitoring systems comply with Good Aquaculture Practice (GAP) by producing authentic and traceable data logs to foster more transparency and accountability in aquaculture. This is a useful functionality, especially for koi fish farms mainly exporting, as they need to adhere to rigorous international quality sustainability standards [14]. In the same manner, utilization of IoT technology in fish farming not only supports environmental stewardship but also can help attain several United Nations Sustainable Development Goals (SDGs), including SDG 9 (Industry, Innovation and Infrastructure) and SDG 12 (Responsible Consumption and Production) through the promotion of innovation, efficiency, and responsible utilization of aquaculture resources [15].

2.3 IoT and Business Performance Enhancement

Along with being nature-friendly, the IoT enables the improvement of fishery operations and their efficiency. Automation based on IoT enables lightning-fast work, removes work dependence, and increases data fidelity, which works as a prevention against data loss due to human mistakes. According to [9], the application of an IoT-based monitoring system can save the operating cost up to 35% by enabling automated gathering of data and predictive analysis to predict variations in the quality of water.

The fusion of IoT with digital business models is creating new start-ups and opportunities for aquaculture business scale-ups. For instance, such IoT-enabled monitoring platforms may adopt a subscription-based model (Software as a Service, SaaS), where fish farmers pay a subscription as the primary customer segment for real-time data visualization, predictive analytics, and automated alerting mechanisms. In addition, massive amounts of environmental data produced by IoT systems can be commercialized and monetized, for example, as analytical reports and decision-support systems for governments, research organizations, or environmental consultants [16].

These changes are turning aquaculture from a labour-intensive, small-scale practice to a technology-driven, data-heavy industry. Via IoT, aquaculture companies have a new potential stream of revenue and can be more efficient and sustainable, resulting in long-term competitiveness in the global market. IoT allows this and more for aquaculture companies to be more profitable and sustainable, ultimately leading their industries [3].

2.4 Conceptual Framework

Based on the reviewed literature, the current study adopts an integrated conceptual framework that has three main pillars:

a. Technological Innovation (IoT Infrastructure): Multi-sensor node deployment and cloud integration for real-time data collection and analysis.
b. Sustainability Impact: Improved environmental monitoring and resource management through automated surveillance.
c. Business Performance: Profit improvement and productivity gain through cost reduction, risk minimization, and digitalization of aquaculture procedures.

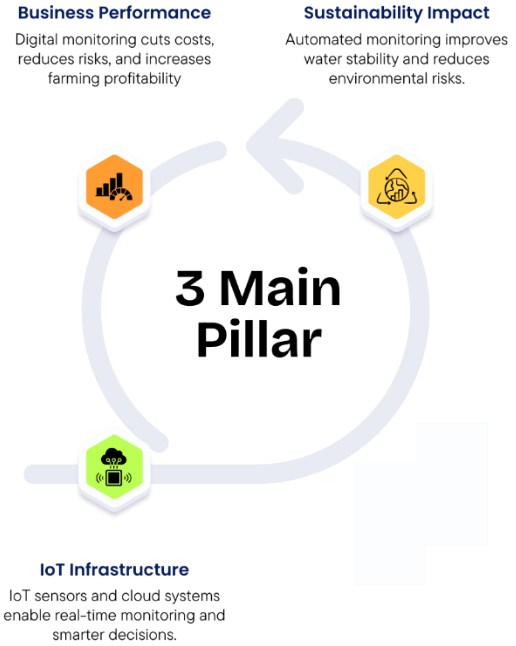

Figure 1. Three Main Pillars Conceptual Framework

The conceptual framework in Figure 1 illustrates a continuous cycle driven by three interconnected pillars: IoT Infrastructure, Sustainability Impact, and Business Performance. The cycle begins with IoT Infrastructure, where multi-sensor systems and cloud-based platforms enable real-time water quality monitoring. This technological capability produces accurate and continuous environmental data. The resulting data feeds into the second pillar, Sustainability Impact, by ensuring early detection of water quality fluctuations, improving environmental stability, and reducing resource waste. Automated monitoring supports more sustainable aquaculture practices through efficient water use, reduced chemical exposure, and optimized pond management.

Enhanced sustainability directly strengthens the third pillar, Business Performance, where farmers benefit from reduced operational costs, minimized risk of fish mortality, and improved production consistency. Increased survival rates and operational efficiency translate into higher profitability and stronger business resilience.

Finally, strengthened Business Performance reinforces further investment in IoT Infrastructure, completing the cycle. As farmers gain measurable economic benefits, they are more willing to adopt and maintain digital systems, which again supports sustainability goals and overall technological improvement. This circular relationship demonstrates how technological innovation, environmental sustainability, and economic performance continuously reinforce each other, forming a holistic and scalable model for modern, data-driven aquaculture.

3. Methodology

This study employed a hybrid qualitative-quantitative methodological design. The qualitative component involved field observations and informal interviews with koi farmers in Surabaya, aiming to identify operational issues and common challenges in water quality management. These insights informed the definition of system requirements and ensured that the proposed solution was grounded in real-world aquaculture practices. Complementing this, the quantitative component consisted of systematic prototype testing to evaluate sensor accuracy, system responsiveness, and user satisfaction.

A Prototyping development approach was adopted, as it is well-suited for Internet of Things (IoT)–based projects that demand iterative refinement, usability assessment, and rigorous technical validation. This approach facilitates continuous improvement through repetitive interaction between developers and end-users, ensuring that both functional requirements and contextual needs are adequately addressed. The overall methodology was structured into five principal phases: (1) Requirements analysis, (2) System design, (3) Prototype construction, (4) Testing and validation, and (5) Evaluation.

During the requirements analysis phase, functional system objectives and sensor specifications were formulated based on real operational needs identified from koi producers. The system design phase encompassed the conceptualization of hardware and software architecture, emphasizing modularity, interoperability, and efficient data communication. In the prototype development phase, microcontrollers, sensors, and cloud services were integrated to form a functional IoT-based monitoring system. This was followed by testing and validation, where the system's performance, stability, and measurement accuracy were examined directly in aquaculture environments. Finally, the evaluation phase assessed both the technical outcomes and the broader implications of the system in terms of business feasibility and environmental sustainability. The methodological approach bridges the gap between technological innovation and practical applicability, enabling the development of an effective, sustainable, and user-oriented smart aquaculture solution. [17].

3.1 Research Design

The research design is grounded on a qualitative-quantitative hybrid. Qualitative data were gathered through field observation and informal interviews with koi farmers to identify operational problems and water quality management issues. Quantitative evaluation was obtained through prototype testing, measuring sensor accuracy, response time of the system, and customer satisfaction [18]. This allows the system to be evaluated as a technological innovation and as a business-enabling solution.

The prototype was tested in an operational koi pond located in Kabupaten Mojokerto, East Java, owned by a local farmer who is an active member of the Agro Koi Mojokerto community. The pond has an approximate area of 15 m^2 with a depth of around 1 meter, representing the typical pond size used in small- and medium-scale koi farming. Testing was conducted over a period of two months, with data collected for 18 days per month, corresponding to six days of data-taking per week. The testing period was selected during months with stable weather conditions and no rainfall, ensuring minimal external disturbance and allowing natural environmental variations (feeding routines, aeration, and daily pond activities) to serve as the primary influencers of water quality changes.

3.2 Requirement Analysis

The analysis of requirements was conducted to identify major functional and non-functional requirements of the IoT monitoring system:

a. Functional requirements include continuous monitoring of pH, DO, TDS, and turbidity, cloud streaming of real-time data, web dashboard visualization, and automated alerts raised when parameters exceed thresholds.
b. Non-functional requirements are system reliability, low power usage, scalability of multi-pond monitoring, and friendly interfaces for small-scale farmers.

Optimal thresholds for water quality were set according to koi fish breeding standards:

a. pH: 6.8–8.0
b. Dissolved Oxygen (DO): >5 mg/L
c. Total Dissolved Solids (TDS): <500 ppm
d. Turbidity: <50 NTU

These sensors were connected to an ESP32 microcontroller, which transmitted real-time data to cloud platforms (Firebase and Blynk) via Wi-Fi. Data were captured at 30-second intervals, producing high-frequency environmental records that allowed for accurate assessment of daily fluctuations in water quality. Threshold-based alerts were configured to notify users when any parameter exceeded acceptable koi health standards. This enabled continuous monitoring capable of detecting abrupt environmental changes.

3.3 System Architecture

The proposed system architecture consists of three interconnected layers that work together to enable continuous environmental monitoring, cloud-based data processing, and user-level decision support in koi fish aquaculture. Figure 2 illustrates the overall system flow from sensor acquisition to application interaction.

a. Sensing Layer (Distributed Sensor Nodes)
The sensing layer is deployed directly in the fishpond and consists of four primary water-quality sensors: pH, dissolved oxygen (DO), turbidity, and total dissolved solids (TDS). These sensors continuously capture real-time environmental parameters and transmit raw data to the microcontroller through wired interfaces. This layer represents the physical interaction with the aquatic environment and forms the foundation of the monitoring framework.

b. Processing and Communication Layer (Microcontroller Gateway)
Sensor signals are processed through a microcontroller gateway consisting of ESP32 (as the main communication module) and Arduino UNO (for sensor stabilization and interfacing). The ESP32 handles Wi-Fi connectivity and transmits sensor data to the cloud using lightweight communication protocols (HTTP/MQTT). This layer performs preliminary data handling and acts as the bridge between the physical sensing system and cloud infrastructure.

c. Cloud Layer (Centralized Data Processing and Analytics)
Upon transmission, the data is stored in a cloud database using Firebase Realtime Database, enabling persistent time-series storage. The cloud layer integrates several processing components, including:

i. Data cleaning, to filter noise and remove incorrect readings.
ii. Data analytics, to identify trends and performance deviations.
iii. Machine learning prediction, used for anomaly detection and early warning.
iv. Visualization modules, generating charts and insights for users.

These cloud functions enable higher-level computation, long-term monitoring, and automated decision support.

DOI: https://doi.org/10.52435/jaiit.v7i2.730

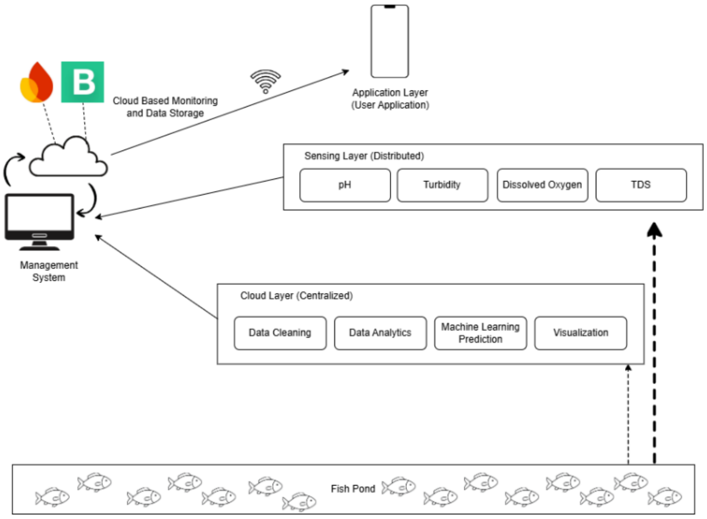

Figure 2. IoT System Architecture for Water Quality Monitoring

d. Application Layer (User Interface – Mobile and Web Dashboard)
   The processed data is visualized through Blynk and a custom-built web dashboard, which provides users with real-time indicators, historical charts, environmental alerts, and system status reports. The mobile application layer allows farmers to access pond information remotely, ensuring fast response to environmental fluctuations and simplifying farm management.

Sensor nodes feed the microcontroller, the microcontroller forwards data to cloud storage, cloud processing modules analyze and visualize the data, and users access the results via mobile/web applications. This architecture establishes a vertically integrated IoT ecosystem that supports real-time monitoring, predictive analytics, and informed decision-making for sustainable koi aquaculture.

3.4 Business and Sustainability Evaluation

To complement technical analysis, cost-benefit analysis was conducted to establish the potential business value of the system. Results indicated that the cost of operational monitoring was cut by 40% through the reduced frequency of manual water testing. The system also optimized the efficiency of resources, with a reduction of unnecessary replacement of water by up to 25%. From an environmental sustainability perspective, the system improves sustainable aquaculture through the reduction of chemical usage, improving the control of oxygenation, and ensuring compliance with environmental regulations [7], [14].

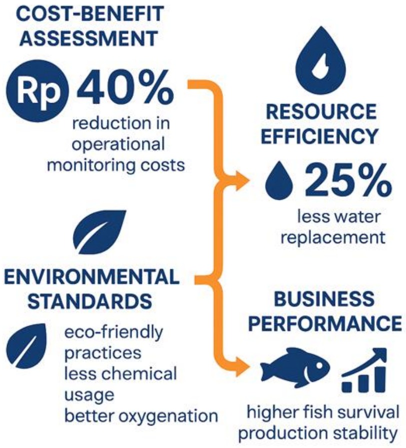

Figure 3. Cost-Benefit and Sustainability Impact of the IoT-Based Water Quality Monitoring

The overall system improvements lead to a deep impact on business performance in koi fish farming, as seen in Figure 3. By enabling the support of more stable water conditions and real-time environmental control, the IoT-based monitoring system effectively reduces fish mortality rates and improves uniform growth rates across production cycles [19]. This kind of consistency derived from regular water quality monitoring translates into more stable and reliable production levels, enabling farmers to plan activities and resource utilization more effectively. The predictability in operations reduces financial risks and minimizes vulnerabilities to environmental uncertainties that work to destabilize koi fish farming. Apart from this, mortality reduction of fish and prevention of growth irregularities caused by poor water conditions have the immediate effect of higher productivity and improved profit margins.

In the broader business context, such improvements are not only near-term cost savings but the foundation for economic resiliency in aquaculture businesses. With the leverage of real-time data and automatic decision support, farmers enjoy more accurate control over production cycles and the potential to make data-driven decisions about feeding schedules, aeration control, and water replacement procedures. In the long term, this technological integration enhances business sustainability overall, allowing small and medium-scale koi farming enterprises to be more profitable and competitive while adhering to environmentally sound methods.

3.5 Evaluation Metrics

The system was evaluated through three quantitative metrics:

a. Sensor Accuracy
   Accuracy was measured by comparing IoT sensor readings with reference measurements using certified water-testing tools.
b. System Responsiveness
   Response time was calculated as the latency between the moment a parameter was detected by the sensors and its appearance on the cloud dashboard.
c. User Satisfaction
   Ten koi farmers participated in a structured usability test, evaluating the clarity, usability, and practicality of the system dashboard and alert features. This methodology provides a comprehensive basis for evaluating the system’s technological performance and its potential to enhance environmental stability, operational efficiency, and business outcomes in koi aquaculture.

4. Results and Discussions

This section outlines some of the results of the research conducted. But not all the results of the research should be discussed in this section. Only some of the important research results. The results that are interesting must be explained elaborately. Previous research only emphasized the automation of feeding in koi ponds, while this research expands the IoT function by monitoring pH, DO, TDS, and turbidity while analyzing their impact on business efficiency and improving business performance [20]. Discussion can also be provided by comparing the results obtained with the previous research results. To help writers in explaining research results, tables and figures can be used in this section.

4.1 System Implementation

The system prototype was effectively implemented, developed, and deployed in a real-world setting for growing koi fish located in Surabaya, Indonesia. The implementation site was selected to assess the performance of the system under natural pond conditions where temperature, turbidity, and dissolved oxygen levels fluctuate naturally. The IoT-based monitoring system accommodates four fundamental water quality sensors: pH, dissolved oxygen (DO), total dissolved solids (TDS), and turbidity, which are all vital for aquatic ecosystem health parameters. The sensors were interfaced with an ESP32 microcontroller, which is the central processing unit responsible for data acquisition, preprocessing, and wireless transfer, as mentioned in Table 1.

Table 1. Testing Conditions and Data Collection Framework

Component	Description
Research Location	Koi pond located in Mojokerto Regency, owned by a local farmer affiliated with the Agro Koi Mojokerto community
Pond Size	Approximately 15 m² with a depth of about 1 meter
Data Collection Schedule	18 days per month (6 days per week)
Environmental Conditions	Clear weather, no rainfall during the observation period
Measured Parameters	pH, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Turbidity
Data Sampling Interval	Every 30 seconds
Hardware Components	ESP32 microcontroller, pH sensor, DO sensor, TDS sensor, turbidity sensor
Cloud Platforms	Firebase and Blynk
Evaluation Methods	Sensor accuracy assessment, system responsiveness analysis, and user satisfaction survey
Number of Respondents	10 koi farmers
Purpose of Testing	To evaluate the effectiveness of the IoT monitoring system in enhancing environmental stability and business performance in koi aquaculture

The ESP32 was chosen considering its dual-core architecture, low power consumption, and built-in Wi-Fi capabilities, rendering it highly suitable for continuous real-time monitoring applications in aquaculture. Readings of the sensors were taken at periodic intervals and delivered to a cloud-based database, where the readings were graphically represented using the dashboard interface implemented. The deployment procedure ensured the operational feasibility of the system and validated that all sensor components worked as expected under field conditions.

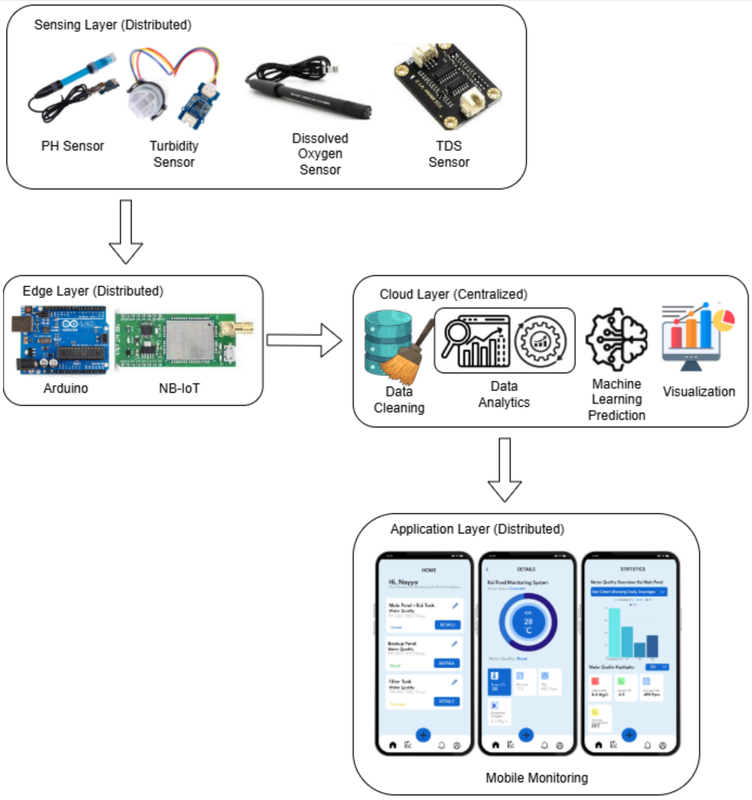

Figure 4. Prototype of the IoT-based Water Quality Monitoring System

The system continuously monitored the water parameters and transmitted data every 30 seconds via Wi-Fi to the Firebase Realtime Database, as given in Figure 4. Real-time data visualization, numeric readings, past plots, and automated alerting across threshold values were conveyed through the Blynk mobile app and an in-house developed web dashboard. The user interface of the dashboard was kept simple in order to enable farmers to view water status and receive warnings directly from smartphones [4]. Preliminary testing ensured that the interface enhanced user responsiveness and response time to sudden environmental variations efficiently.

4.2 Sensor Accuracy Testing

An intense sensor validation and calibration procedure was performed to ensure the accuracy and reliability of the developed system. Those readings from the IoT-based monitoring system were then compared with comparative industry-calibrated reference measurements. Those sensors included a HANNA pH meter and a YSI dissolved oxygen (DO) meter because these specific instruments have an established record of being highly accurate and stable when implemented in water quality measurement. The sensors had to go through various trials of measurement under the same environmental conditions to minimize variability and maximize data consistency.

Before conducting the usability testing with koi farmers, this study first reviewed and synthesized findings from previous research related to IoT-based water quality monitoring in aquaculture. The purpose of this step was to establish a comparative foundation, identify performance benchmarks, and understand common limitations in earlier systems. Several studies reported the use of sensor networks, cloud platforms, and mobile dashboards; however, their accuracy levels, sensor configurations, and user adoption rates varied significantly. To provide a clear reference point, the results of prior research are summarized in the following table, highlighting key parameters such as sensor types, accuracy, data transmission intervals, and overall system performance.

DOI: https://doi.org/10.52435/jaiit.v7i2.730

Table 2. Comparative Analysis of Previous IoT Aquaculture Monitoring Research

Reference Data	Year	Accuracy	Interval	Parameter
Lekswina, F., & Widjaja, D. (2021). **Title** IoT-based Two-Level Feeding System for Koi Fish Pond. IOP Conference Series: Materials Science and Engineering,	2021	90-93%	30-60 sec	Temperature, Water Level
Leadtree, W., & Needs, W. C. (2025). **Title** MITOR : Koi Fish Pond Monitoring System Using IoT.	2025	92-95%	60 sec	pH, Temperature, DO
Baldovino, R. G., Magallanes, F. N., Santos, E. J. C., Conti, K. D., & Sia, P. D. L. (2024). **Title** Smart IoT-based Feeder System for Koi Fish (Cyprinus rubrofuscus) Aquaculture. Proceedings of the 9th International Conference on Mechatronics Engineering,	2024	91-94%	60 sec	Temperature, Water Level, Feeding Actuation
Andiyansyah, R. N., Setyawati, O., & Hario Partiansyah, F. (2024). **Title** IoT-Based Water Quality Monitoring System for Koi Fish Quarantine.	2024	90-94%	30-60 sec	Temperature, pH, TDS

The calibration process involved measuring simultaneous readings from the reference devices and the IoT sensors and then calculating the deviation to determine the measurement accuracy as provided in Table 2. The data of each parameter, pH, DO, TDS, and turbidity, were compared to determine the level of precision of the IoT sensors. The comparative outcomes, shown in Table 3, show that all the sensors were within acceptable accuracy ranges for aquaculture applications, confirming the system's capability to provide good real-time monitoring under koi fish aquaculture conditions.

Table 3. Comparison of IoT Sensor Readings with Reference Instruments

Parameter	Standard Value	IoT Reading	Deviation	Accuracy (%)
pH	7.20	7.12	0.08	98.9
DO (mg/L)	6.50	6.25	0.25	96.1
TDS (ppm)	480	500	20	95.8
Turbidity (NTU)	45	47.2	2.2	95.1
Average	—	—	—	**96.5**

The findings from the user evaluation that yielded an 89% overall satisfaction rate validate that the system designed is highly user-friendly and most compatible with the operational tendencies of small-scale koi fish farmers. The easy-to-use interface and easy-to-access dashboard design resulted in a satisfactory user experience, minimizing the learning process for first-time users. Participants responded that the real-time alert was particularly helpful, as it provided immediate warning when water parameters shifted outside optimal ranges [1]. This enabled farmers to intervene, for instance by readjusting aeration or performing a partial water change, and prevent any potential stress or mortality in the fish. The combination of real-time responsiveness and usability confirms that the IoT-based system is effectively achieving pragmatic decision-making in aquaculture management and augmenting farmers' trust in the adoption of digital technology [21].

4.3 User Acceptance Testing

It conducted a usability test involving 10 koi farmers as respondents. The test utilized a Likert-scale questionnaire (1–5) for evaluating five criteria: ease of use, interface design, reading accuracy, responsiveness to alerts, and perceived usefulness. The result can be seen in Table 4.

Table 4. User Acceptance Test Results

Evaluation Aspect	Average Score	Percentage (%)
Ease of Use	4.5	90
Interface Design	4.3	86
Accuracy of Readings	4.4	88
Alert Responsiveness	4.6	92
Perceived Usefulness	4.5	90
Overall Satisfaction	4.46	89%

The overall user satisfaction rate of 89% demonstrates that the system is user-friendly and convenient for daily usage in small-scale koi fish farms. Farmers were particularly satisfied with the real-time notification system because it allowed them to take immediate remedial actions when the water quality deteriorated.

4.4 Impact on Sustainability and Business Performance

The use of the IoT-based water quality monitoring system has demonstrated high potential in increasing both environmental sustainability and business productivity in koi fish farming operations.

From the perspective of environmental sustainability:

a. Real-time data monitoring enables more precise control of water quality, avoiding overuse of water and chemical treatments.
b. The system is more resource efficient, with 25% fewer water changes, and a resulting weekly saving of around 500 liters per pond.
c. Stable environmental parameters have achieved a 12% increase in fish survival in one cultivation cycle.

From a business performance perspective:

a. The need for manual water quality testing — previously done twice a day — has been minimized to once every other day, thus saving 40% in labor.
b. Higher survival rates and more reliable growth patterns have boosted farmers' income by approximately 15–18% in each production cycle.

c. The archival of historical water quality data aids in strategic business management, enabling more accurate planning, prediction, and decision-making using data analytics. The summary can be seen in Table 5.

Table 5. Summary of Business and Sustainability Impact

Indicator	Before IoT	After IoT	Improvement (%)
Labor Time for Monitoring	60 min/day	35 min/day	41.7
Water Replacement Volume	2,000 L/week	1,500 L/week	25.0
Fish Survival Rate	85%	95%	11.8
Average Revenue per Cycle	IDR 4.5M	IDR 5.3M	17.8

These results suggest a direct positive effect of IoT adoption on corporate sustainability through cost reduction, risk mitigation, and the overall productivity enhancement in the case of aquaculture firms. Moreover, since the system's gathered data are real-time, they can also constitute a critical input to feed predictive models that automate feeding and filtration systems, leading to efficiency improvements and long-term optimization of operations.

4. Conclusion

This study successfully designed and validated an integrated IoT-based water quality monitoring system to address critical challenges in small and medium-scale Koi fish cultivation. The implementation, centered around an ESP32 microcontroller and four key sensors (pH, DO, TDS, and turbidity), proved technologically robust, achieving an average sensor accuracy of 96.5% and a high user satisfaction rate of 89% among participating farmers. These results confirm that the system provides a reliable, user-friendly, and responsive platform for continuous environmental surveillance, effectively mitigating the risks associated with manual and delayed water quality assessments.

Crucially, the system demonstrates a tangible positive impact on both environmental sustainability and business performance, linking technological adoption directly to measurable economic outcomes. From a sustainability perspective, precise monitoring led to enhanced resource efficiency, specifically reducing water replacement volume by 25% and ensuring stable environmental parameters. From a business standpoint, the system generated significant productivity gains and cost reduction, including a 40% decrease in manual monitoring costs and a 12% increase in fish survival rates. These improvements, translating to an increase in average revenue per cycle, establish a clear case for adopting data-driven aquaculture practices as a foundation for long-term profitability, resilience, and adherence to environmental stewardship principles.

References

[1] S. Muslimin, Y. Wijanarko, and N. A. Z. Bibrosi, "Real-time Fishpond Water Temperature Monitoring with Internet of Things (IoT) Technology," *J. Teknol. Inf. dan Pendidik.*, vol. 17, no. 2, pp. 315–328, 2024, doi: 10.24036/jtip.v17i2.824.

[2] W. Leadtree and W. C. Needs, "MITOR : Jurnal Teknik Elektro," pp. 39–46, 2025.

[3] O. A. Nasir and S. Mumtazah, "IoT-Based Monitoring of Aquaculture System," *MATTER Int. J. Sci. Technol.*, vol. 6, no. 1, pp. 113–137, 2020, doi: 10.20319/mijst.2020.61.113137.

[4] C. H. Chen, Y. C. Wu, J. X. Zhang, and Y. H. Chen, "IoT-Based Fish Farm Water Quality Monitoring System," *Sensors*, vol. 22, no. 17, 2022, doi: 10.3390/s22176700.

[5] P. Erawati, D. Prasti, and T. B. Kriswinarso, "Internet of Things (IoT) -Based Water Quality Monitoring System Design for Tilapia Fish Farming Ponds," vol. 5, no. 2, pp. 860–869, 2025.

[6] A. Fitriansyah, Alfirman, R. A. Nugroho, S. Meitarice, and Sukamto, "Water Quality Monitoring and Control System for Fish Farmers Based on Internet of Things," *Ing. des Syst. d'Information*, vol. 29, no. 3, pp. 1107–1113, 2024, doi: 10.18280/isi.290328.

[7] K. Kairbekov, D. Sarsenov, and Z. Kairbekova, "Design and Implementation of a Low-Cost Water Quality Monitoring System for Aquaculture in Indonesia," *Int. Conf. Eng. Sci.*, no. 1, 2024,

[Online]. Available: https://prosiding.aritekin.or.id/index.php/ICONFES

[8] I. Ketut, A. Enriko, R. Pratiwi, W. P. Tjiptoyuda, and F. N. Gustiyana, "Implementation Internet Of Things For Monitoring Water Quality System of Koi Fish Ponds," *J. Appl. Inf. Commun. Technol.*, vol. 9, no. 1, pp. 280–286, 2024.

[9] P. S. T, M. Archana, and A. Bhuvana, "Modernizing Aquaculture by Improving Water Factors using IoT," vol. 10, no. 12, pp. 32–34, 2022.

[10] A. F. Choiri, "IoT-Based Water Quality Monitoring System for Fish Ponds Using Fuzzy Inference Method," *J. Teknol. Inf. Dan Terap. (J-TIT*, vol. 11, no. 2, pp. 2580–2291, 2024, [Online]. Available: https://doi.org/10/25047/jtit.v11i2.5794

[11] A. H. Ahmad, N. I. M.Yanis, M. N. Nur Irawan, R. Munadi, and N. Fitriyanti, "Water Quality Monitoring and Control System in Koi Fish Cultivation Based on Internet-of-Things (IoT)," *J. Rekayasa Elektr.*, vol. 21, no. 1, pp. 19–26, 2025, doi: 10.17529/jre.v21i1.40760.

[12] D. Rosandi, J. Junaidi, D. K. Apriyanto, and A. Surtono, "Design of Water Quality Monitoring System for Koi Fish Farming Using NodeMCU ESP32 and Blynk Application Based on Internet of Things," *J. List. Instrumentasi, dan Elektron. Terap.*, vol. 4, no. 1, 2023, doi: 10.22146/juliet.v4i1.83131.

[13] R. N. Andiyansyah, O. Setyawati, and F. Hario Partiansyah, "IoT-Based Water Quality Monitoring System for Koi Fish Quarantine," *J. EECCIS (Electrics, Electron. Commun. Control. Informatics, Syst.*, vol. 18, no. 3, pp. 92–99, 2024, doi: 10.21776/jeeccis.v18i3.1751.

[14] A. H. Abdullah, S. Sudin, F. S. Ahmad Saad, M. K. Ali Hassan, K. A. Abdul Khalid, and J. Zainol Abidin, "Water Quality Analysis for the Sustainability of Aquaculture Industry using IoT and Big Data," *ASEAN Artif. Intell. J.*, vol. 1, no. 1, pp. 34–45, 2025, doi: 10.37934/aaij.1.1.3445.

[15] T. N. Son, L. T. Hoan, N. C. Cuong, P. Van Minh, and R. Van Hoa, "Remote Monitoring and Control of Poultry Farm based on IoT Technology," *SSRG Int. J. Electr. Electron. Eng.*, vol. 7, no. 10, pp. 12–15, 2020, doi: 10.14445/23488379/IJEEE-V7I10P102.

[16] M. Alselek, J. M. Alcaraz-Calero, J. Segura-Garcia, and Q. Wang, "Water IoT Monitoring System for Aquaponics Health and Fishery Applications," *Sensors*, vol. 22, no. 19, pp. 1–20, 2022, doi: 10.3390/s22197679.

[17] M. G. Dayaday and C. S. Namoco, "An Innovative Real-Time Water Quality Monitoring System for Aquaculture Application," *ARPN J. Eng. Appl. Sci.*, vol. 16, no. 24, pp. 2737–2740, 2021.

[18] K. Hayati, F. A. Pratikno, P. Gesan, P. Anwar, and H. Susantiningdyah, "G-Tech : Jurnal Teknologi Terapan Optimizing Water Quality in Carp Farming through an IoT-based Dissolved," vol. 9, no. 4, pp. 2132–2140, 2025.

[19] R. Eso, H. T. Mokui, A. Arman, L. Safiuddin, and H. Husein, "Water Quality Monitoring System Based on the Internet of Things (IoT) for Vannamei Shrimp Farming," *ComTech Comput. Math. Eng. Appl.*, vol. 15, no. 1, pp. 53–63, 2024, doi: 10.21512/comtech.v15i1.10657.

[20] F. Lekswina and D. Widjaja, "IoT-based Two Levels Feeding System for Koi Fish Pond," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1115, no. 1, p. 012051, 2021, doi: 10.1088/1757-899x/1115/1/012051.

[21] J. Junaedi and H. Ki, "Smart Aquarium with IoT based as Monitoring in Fish Farming," *bit-Tech*, vol. 4, no. 3, pp. 116–122, 2022, doi: 10.32877/bt.v4i3.441.