Journal of Electrical Engineering and Informatics (JEEI)

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

An IoT-Enabled Monitoring System for Real-Time Water Quality Management in Catfish Aquaculture

*** Bayu Arif Ramadhan[1], Muhammad Wahyu Fauzi[2], Sekar Kinasih[3]**
[1,2]Electrical Engineering, Universitas Islam Indonesia, Yogyakarta, Indonesia
[3]Electrical Engineering, Sekolah Tinggi Teknologi Nusantara Lampung, Bandar Lampung, Indonesia
E-mail: [1]sekakinasih043@gmail.com *Corresponding Author

Article History: *Received: February, 5th 2026; Accepted: February, 27th 2026; Published: February, 28th 2026*

ABSTRACT

Water quality management is a critical factor in determining the productivity and sustainability of catfish (*Clarias sp.*) aquaculture. Conventional monitoring practices are generally manual, periodic, and inefficient, limiting farmers' ability to respond promptly to environmental changes. This study presents the design and implementation of an Internet of Things (IoT)–based water quality monitoring system for catfish ponds using an ESP8266 microcontroller, a type-K thermocouple temperature sensor, and an SEN0161 pH sensor. The proposed system enables real-time monitoring of water temperature and pH, wireless data transmission to an online database, and continuous visualization through a web-based interface. System performance was evaluated in three pond environments indoor, semi-outdoor, and outdoor during a six-hour observation period, yielding a total of 1,012 measurement data points. The results indicate that the recorded water temperature and pH values generally fall within the recommended ranges for catfish aquaculture, demonstrating stable monitoring performance across different environmental conditions. Linear regression analysis further confirms the consistency of temperature and pH trends during the monitoring period. The findings show that the developed system is capable of providing reliable real-time water quality information and can support data-driven pond management while reducing dependence on manual measurements. Despite its effectiveness, the system's performance is influenced by internet connectivity and is currently limited to temperature and pH parameters. Future work may focus on extending monitoring duration, improving communication reliability, and integrating additional water quality indicators to enhance system comprehensiveness.

Keywords: *internet of things; water quality monitoring; catfish aquaculture; esp8266; smart aquaculture systems*

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

INTRODUCTION

Catfish (*Clarias sp.*) aquaculture represents one of the most strategic freshwater farming sectors contributing to food security and economic development in Indonesia. The increasing demand for catfish, particularly in urban areas, necessitates more efficient and sustainable aquaculture management practices. However, the success of catfish farming is highly dependent on aquatic environmental quality, especially water temperature and acidity (pH), which directly influence fish metabolism, growth performance, and survival rates (Boyd, 2020; Badiola et al., 2018).

Poor water quality management can induce physiological stress, reduce feeding activity, and increase disease susceptibility, ultimately leading to decreased productivity. Previous studies have reported that optimal growth conditions for catfish occur at water temperatures ranging from 25 to 30 °C and pH values between 6.5 and 8.0, while deviations from these ranges may significantly impair production performance (El-Sayed, 2019; Effendi et al., 2016). These findings are consistent with the Indonesian National Standard SNI 6484.3:2014, which specifies recommended water quality parameters for catfish seed production, as well as international guidelines issued by the Food and Agriculture Organization (FAO) for sustainable aquaculture management (FAO, 2017).

In practice, water quality monitoring in catfish ponds is still predominantly conducted using manual and periodic measurements. Such conventional approaches are inherently limited, as they do not provide continuous or real-time information, thereby delaying the detection of unfavorable environmental changes. Consequently, farmers often experience difficulties in implementing timely corrective actions, particularly in intensive aquaculture systems where water quality fluctuations may occur rapidly (Ahmed et al., 2021).

The advancement of Internet of Things (IoT) technology offers a promising solution to these challenges. IoT enables the integration of sensors, microcontrollers, and communication networks to perform real-time environmental monitoring and transmit data over the internet with minimal human intervention (Gubbi et al., 2019). The application of IoT-based systems in aquaculture has been shown to enhance operational efficiency, reduce labor requirements, and support data-driven decision-making processes (Li et al., 2020; Tzounis et al., 2017).

Several previous studies have developed IoT-based water quality monitoring systems using various platforms and sensors, including Wi-Fi-enabled microcontrollers such as the ESP8266. These systems generally focus on acquiring temperature and pH data and visualizing the measurements through online platforms (Zhou et al., 2018; Rahman et al., 2020). Nevertheless, challenges remain with respect to sensor accuracy, calibration reliability, data transmission stability, and the integration of monitoring functions with automated control mechanisms under different pond environmental conditions (Islam et al., 2021; Kumar & Rani, 2022).

Addressing these research gaps, there is a need for a well-calibrated, real-time water quality monitoring system that can be reliably implemented across various pond

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

configurations, including indoor, semi-outdoor, and outdoor systems. Therefore, this study aims to design and implement an IoT-based water quality monitoring system for catfish ponds using an ESP8266 microcontroller, a type-K thermocouple temperature sensor, and an SEN0161 pH sensor. The proposed system is expected to continuously monitor temperature and pH parameters, store measurement data in an online database, and present real-time information via a web server, thereby supporting effective, accurate, and standards-compliant water quality management in catfish aquaculture.

RESEARCH METHODS

This study adopts a design and implementation research approach to develop an Internet of Things (IoT)–based water quality monitoring system for catfish ponds. This approach is widely applied in sensor- and network-based engineering research to ensure system replicability and measurable performance evaluation (Tzounis et al., 2017).

Research Object and Parameters

The research object comprises catfish (*Clarias sp.*) aquaculture ponds under three environmental conditions: indoor, semi-outdoor, and outdoor ponds. The monitored water quality parameters include:

1. Water temperature (°C), measured using a type-K thermocouple sensor.
2. Water acidity (pH), measured using an SEN0161 pH sensor.

These parameters were selected based on aquaculture literature identifying temperature and pH as primary indicators affecting the growth and health of freshwater fish (Boyd, 2020).

Monitoring System Design

The monitoring system was designed using an ESP8266 microcontroller as the main control unit and Wi-Fi communication module. The temperature and pH sensors were integrated with the ESP8266 to perform periodic data acquisition. The measured data were subsequently transmitted via an internet connection to an online database before being visualized on a web server.

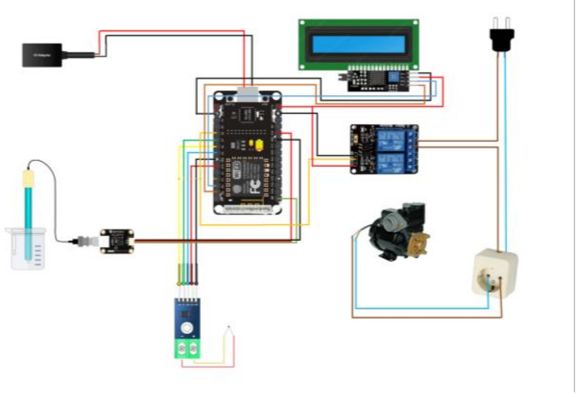

Figure 1. Schematic

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

The overall system architecture and interconnections among hardware components are illustrated in Figure 1 (Schematic). This architecture aligns with IoT-based aquaculture monitoring frameworks that integrate sensors, microcontrollers, and cloud platforms for real-time data management (Li et al., 2020).

Sensor Calibration Procedure

Prior to system operation, a sensor calibration process was conducted to ensure measurement accuracy. The temperature sensor was calibrated by comparing thermocouple readings with a glass thermometer, while the pH sensor was calibrated using a digital pH meter as the reference instrument. The calibration procedure is shown in Figure 2.

Figure 2. The calibration procedure

$$RMSE = \frac{\sqrt{\sum_{i=1}^{N}(T_{i,p}-T_{i,s})^2}}{1} \quad (1)$$

$$RSME = \sqrt{\frac{(39-39{,}50)^2}{1}} \quad (2)$$

$$RSME = 0{,}25 \quad (3)$$

$$RSME = \sqrt{\frac{(8{,}42-8{,}33)^2}{1}} \quad (4)$$

$$RSME = 0{,}008 \quad (5)$$

Measurement error was evaluated using the Root Mean Square Error (RMSE) method, as expressed in Equations (1)–(5). RMSE is commonly applied in sensor-based monitoring studies to assess the deviation between sensor measurements and reference values, where lower RMSE values indicate higher measurement accuracy (Islam et al., 2021).

System Operational Procedure

Following calibration, the system was operated to perform real-time water quality monitoring. The temperature and pH sensors continuously acquired data, which were then transmitted by the ESP8266 to the ThingSpeak database platform. The stored data were subsequently displayed on a web server in the form of numerical values and graphical visualizations.

Journal of Electrical Engineering and Informatics (JEEI)
Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

In addition to monitoring, the system incorporates a basic control mechanism based on a predefined threshold. When the detected water temperature exceeds 40 °C, the ESP8266 activates a relay to turn on a water pump, thereby reducing the temperature until it falls below the threshold. The complete system workflow is presented in Figure 3 (System Flowchart). This approach is consistent with IoT monitoring systems that integrate sensing and basic control functions (Kumar & Rani, 2022).

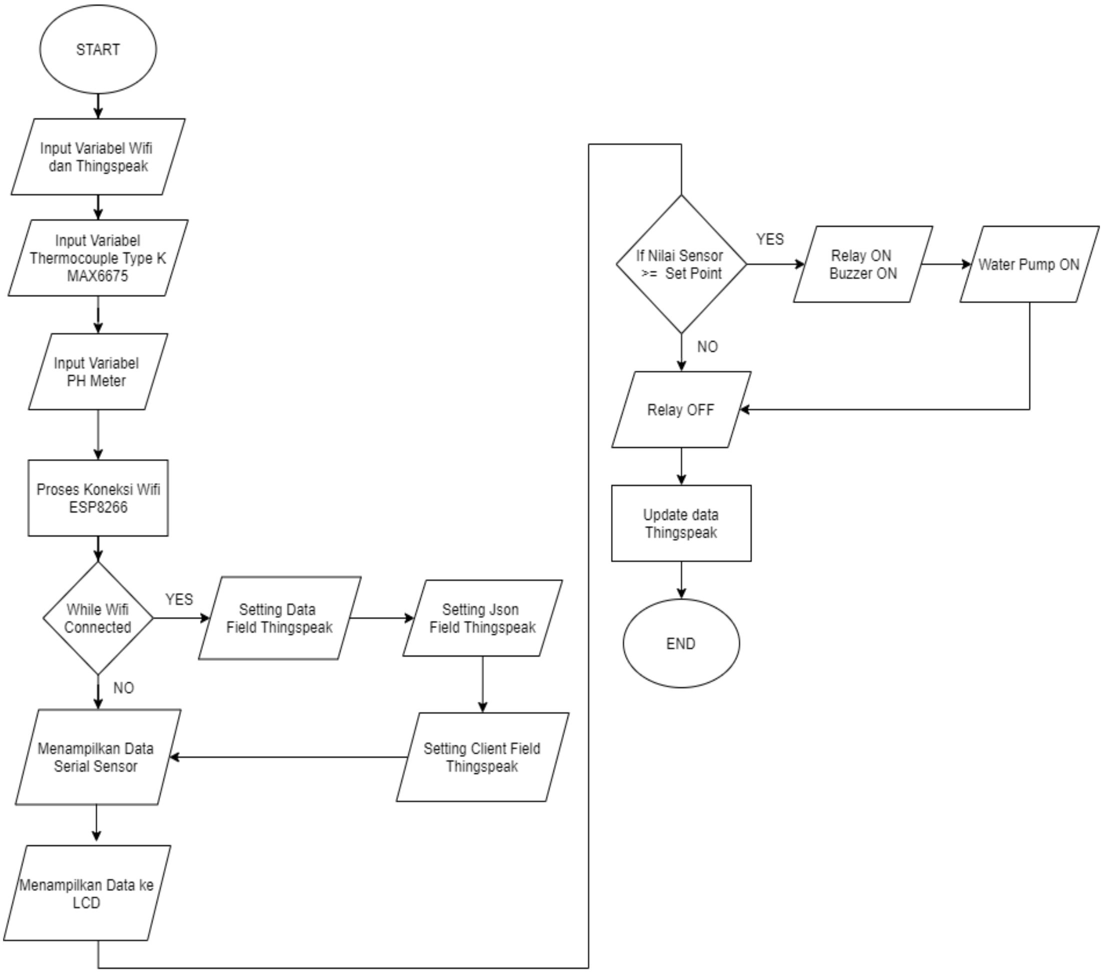

Figure 3. Flowchart System

Data Acquisition and Analysis

Data collection was conducted on 13 July 2021, from 11:00 to 16:00 WIB. A total of 1,012 measurement data points were obtained, comprising 378 data points from indoor ponds, 279 from semi-outdoor ponds, and 355 from outdoor ponds. Data analysis was performed using two main approaches:

1. Measurement error analysis, employing RMSE to evaluate sensor accuracy after calibration.
2. Trend analysis, using linear regression to examine temperature and pH variation trends during the observation period for each pond condition.

Journal of Electrical Engineering and Informatics (JEEI)
Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

The analysis results are presented in the form of graphs and linear regression equations in the Results and Discussion section.

RESULTS AND DISCUSSION

Research Result

The performance evaluation of the water quality monitoring system was conducted in catfish aquaculture ponds under three environmental conditions, namely indoor, semi-outdoor, and outdoor ponds. Data acquisition was carried out on 13 July 2021, from 11:00 to 16:00 WIB. A total of 1,012 measurement data points were collected, comprising 378 data points from indoor ponds, 279 from semi-outdoor ponds, and 355 from outdoor ponds.

Results of Indoor Pond Monitoring

The results of temperature and pH monitoring in the indoor pond are presented in Figure 4 and Figure 5. The recorded water temperature ranged from 27 to 29 °C, while the pH values were within the range of 6 to 8. The graphs indicate relatively stable temperature and pH conditions throughout the observation period.

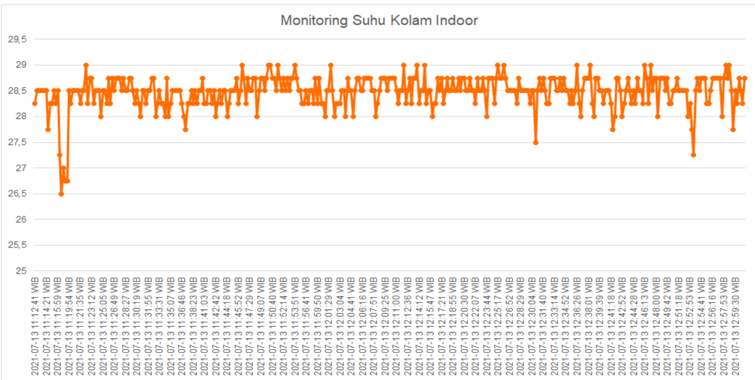

Figure 4. Monitoring Results of pH and Temperature in Indoor Pond

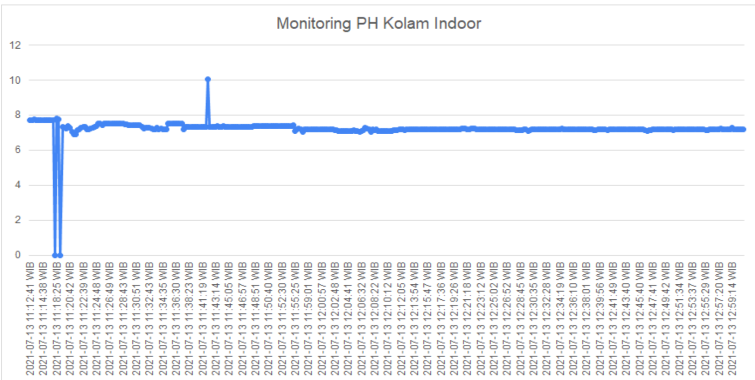

Figure 5. Monitoring Results of pH in the Indoor Pond

Several data points with zero values appear in the graphs. These values resulted from temporary internet connectivity disruptions during data acquisition, which caused certain sensor readings to fail to be transmitted to the database. In addition, a single pH reading

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

reached a value of 10, which occurred when the pH sensor was momentarily lifted above the water surface during measurement.

The linear regression results for the indoor pond are shown in Figure 6. The regression equation reflects a stable trend in both temperature and pH over the monitoring period.

$y = 0{,}4624x - 5{,}9493$ ....(6)

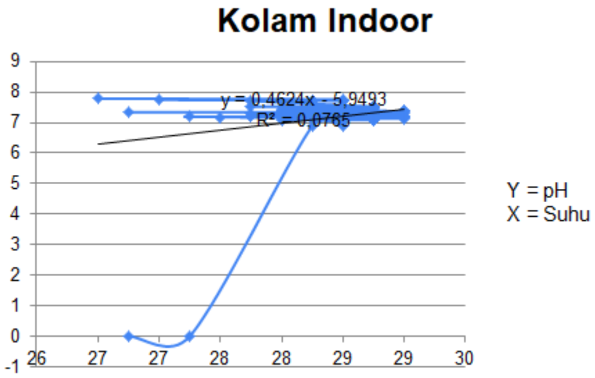

Figure 6. Linear Regression Results of the Indoor Pond

Results of Semi-Outdoor Pond Monitoring

The temperature and pH monitoring results for the semi-outdoor pond are illustrated in Figure 7 and Figure 8. The measured water temperature ranged from 27 to 29 °C, while pH values were observed within the range of 6 to 8. The graphical trends demonstrate that temperature and pH fluctuations in the semi-outdoor pond remained within acceptable limits for catfish cultivation.

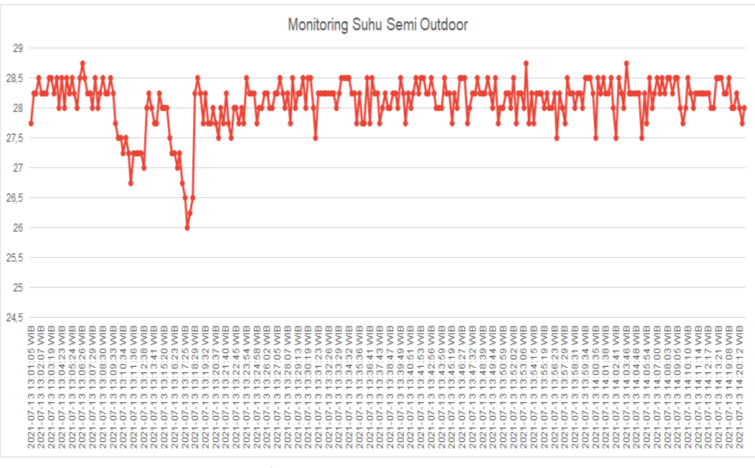

Figure 7. Monitoring Results of pH and Temperature in the Semi-Outdoor Pond

Journal of Electrical Engineering and Informatics (JEEI)
Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

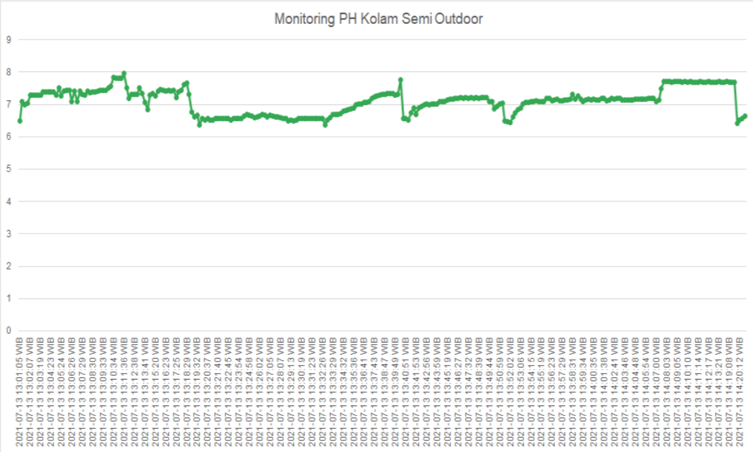

Figure 8. Monitoring Results of pH in the Semi-Outdoor Pond

The linear regression analysis for the semi-outdoor pond is presented in Figure 9. The regression results indicate that the variations in temperature and pH did not exhibit significant deviations during the observation period.

$y = -0{,}1035x + 10{,}009$ ....(7)

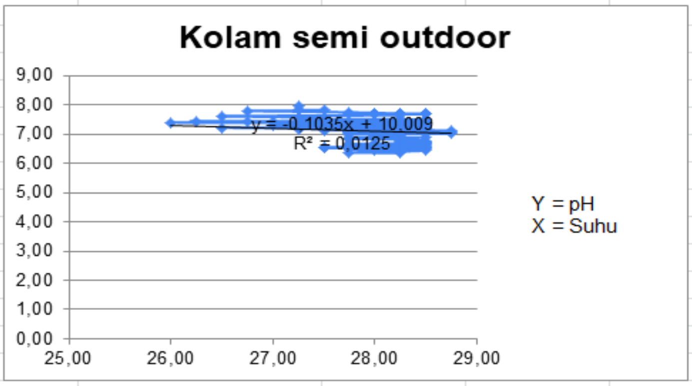

Figure 9. Linear Regression Results of the Semi-Outdoor Pond

Results of Outdoor Pond Monitoring

The monitoring results for the outdoor pond are shown in Figure 10 and Figure 11. The recorded water temperature ranged from 26 to 29 °C, while pH values were observed within the range of 5.5 to 8. Compared to the indoor and semi-outdoor ponds, the outdoor pond exhibited slightly greater variability, particularly in pH values.

Journal of Electrical Engineering and Informatics (JEEI)
Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

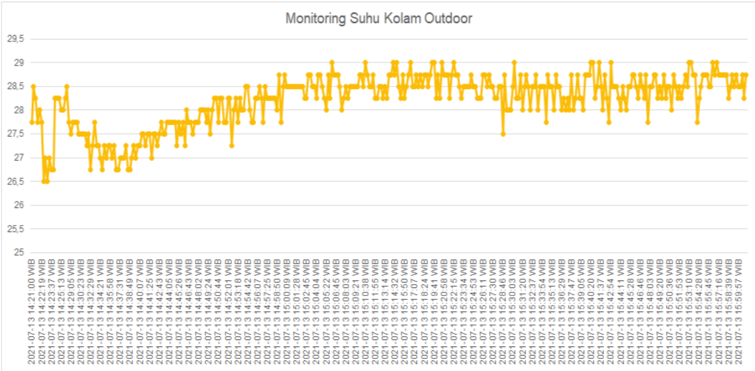

Figure 10. Monitoring Results of pH and Temperature in the Outdoor Pond

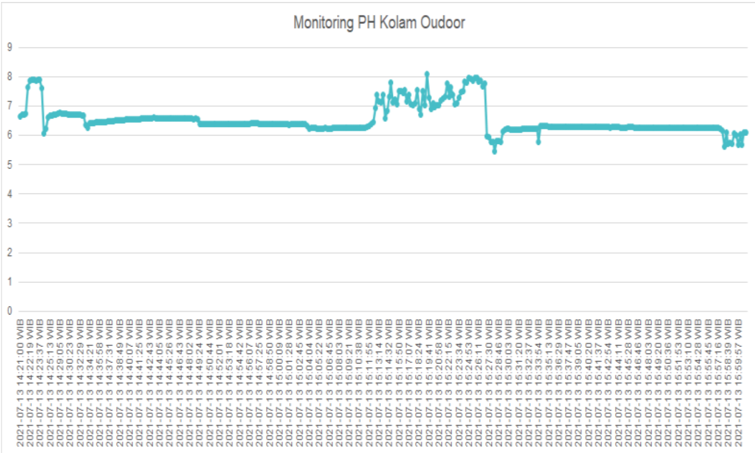

Figure 11. Monitoring Results of pH in the Outdoor Pond

The linear regression results for the outdoor pond are provided in Figure 12. The regression analysis shows that temperature and pH trends remained generally stable throughout the monitoring duration.

$$y = -0,0852\,x + 8,9332 \qquad (8)$$

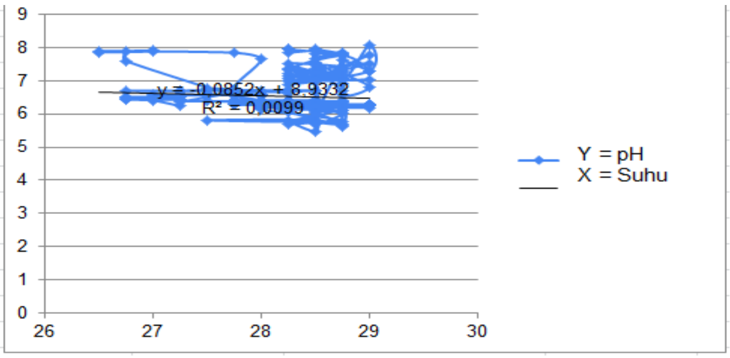

Figure 12. Linear Regression Results of the Outdoor Pond

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

Summary of Monitoring Results

Overall, the monitoring results demonstrate that the developed system was capable of continuously measuring water temperature and pH across all three pond conditions. The recorded temperature and pH values in the indoor, semi-outdoor, and outdoor ponds largely fell within the recommended ranges for catfish aquaculture. Although several data anomalies were observed due to technical factors during data acquisition, the system consistently captured and transmitted water quality parameters during the monitoring period.

Discussion

The results demonstrate that the proposed Internet of Things (IoT)–based water quality monitoring system is capable of continuously monitoring temperature and pH in catfish ponds under indoor, semi-outdoor, and outdoor conditions. Across all pond types, the measured temperature and pH values generally fell within the recommended ranges for catfish aquaculture, namely 25–30 °C for temperature and pH 6.5–8.0, as reported in aquaculture literature and water quality standards (Boyd, 2020; El-Sayed, 2019).

The relative stability observed in the monitoring graphs and linear regression trends indicates that the system can reliably capture real-time environmental conditions. From a physiological perspective, maintaining stable temperature and pH is essential for sustaining metabolic balance in fish, as excessive fluctuations may induce stress responses and reduce survival rates (Badiola et al., 2018). Therefore, the system's capability to record continuous trends in temperature and pH constitutes a critical feature for data-driven aquaculture management.

Differences in monitoring characteristics among indoor, semi-outdoor, and outdoor ponds further highlight the influence of environmental exposure on water quality. Outdoor ponds exhibited greater variability in pH compared with indoor and semi-outdoor ponds. Theoretically, this can be attributed to direct exposure to external factors such as solar radiation, rainfall, and air–water interactions, which affect the chemical dynamics of pond water (Ahmed et al., 2021). This observation is consistent with previous studies reporting higher water quality fluctuations in open ponds than in enclosed or semi-enclosed systems (Li et al., 2020).

Data anomalies, including zero values and occasional pH readings exceeding optimal limits, should not be interpreted as system failures but rather as consequences of technical conditions during data acquisition. Temporary internet connectivity disruptions resulted in incomplete data transmission to the database, while elevated pH readings occurred when the pH sensor was momentarily lifted above the water surface. Similar issues have been reported in prior IoT-based aquaculture monitoring studies, where network reliability and sensor positioning are recognized as critical factors influencing data accuracy (Islam et al., 2021).

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

In comparison with previous research, the system developed in this study demonstrates performance consistent with ESP8266-based IoT monitoring systems reported by Zhou et al. (2018) and Rahman et al. (2020), particularly in terms of real-time acquisition and online visualization of temperature and pH data. However, the present study extends existing work by evaluating system performance across three different pond environments, thereby providing a more comprehensive assessment of monitoring reliability under varying aquaculture conditions.

From a practical standpoint, the proposed monitoring system has the potential to assist catfish farmers in conducting continuous water quality supervision without relying on repetitive manual measurements. Real-time access to temperature and pH information enables timely corrective actions when deviations from optimal conditions occur, thereby improving pond management efficiency and reducing the risk of production losses. From a theoretical perspective, these findings further support the effectiveness of IoT integration in aquaculture as a foundation for precision farming and data-driven decision-making (Tzounis et al., 2017; Kumar & Rani, 2022).

Despite these contributions, several limitations should be acknowledged. First, the data collection period was relatively short and may not fully represent seasonal variations in water quality. Second, system performance remains dependent on internet connectivity, which can affect data completeness. Third, the monitored parameters were limited to temperature and pH; future studies could incorporate additional indicators such as dissolved oxygen and turbidity to enhance system comprehensiveness.

CONCLUSION

This study successfully designed and implemented an Internet of Things (IoT)–based water quality monitoring system for catfish ponds using an ESP8266 microcontroller, a type-K thermocouple temperature sensor, and an SEN0161 pH sensor. The developed system is capable of performing real-time monitoring of water temperature and pH, storing measurement data in an online database, and continuously presenting the information through a web server.

Experimental evaluation conducted in indoor, semi-outdoor, and outdoor ponds indicates that the measured temperature and pH values generally fall within the recommended ranges for catfish aquaculture. These results confirm that the system provides adequate measurement performance and can reliably represent pond water quality across different cultivation environments.

The primary contribution of this study lies in the implementation of a calibrated IoT-based monitoring system evaluated under multiple pond conditions, offering a more comprehensive assessment of system performance than single-environment testing. From a practical perspective, the system has the potential to assist catfish farmers in conducting continuous water quality supervision, reducing reliance on manual measurements, and enabling faster, data-driven decision making.

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

Nevertheless, several limitations should be acknowledged. The data collection period was relatively short, and system performance remains dependent on internet connectivity. In addition, the monitored water quality parameters were limited to temperature and pH. Future research is therefore recommended to extend the monitoring duration, enhance communication reliability, and incorporate additional parameters—such as dissolved oxygen and turbidity—to improve the completeness and accuracy of the monitoring system.

REFERENCES

Ahmed, N., Thompson, S., & Glaser, M. (2021). Transforming aquaculture food systems: Sustainability, resilience, and innovation. *Food Policy, 101*, 102048. https://doi.org/10.1016/j.foodpol.2021.102048

Badiola, M., Mendiola, D., & Bostock, J. (2018). Recirculating aquaculture systems (RAS) analysis: Main issues on management and future challenges. *Aquacultural Engineering, 51*, 26–35. https://doi.org/10.1016/j.aquaeng.2018.10.003

Boyd, C. E. (2020). Water quality: An introduction. *Aquaculture, 528*, 735561. https://doi.org/10.1016/j.aquaculture.2020.735561

Effendi, H., Romanto, & Wardiatno, Y. (2016). Water quality status of rivers in Indonesia. *Procedia Environmental Sciences, 33*, 181–189. https://doi.org/10.1016/j.proenv.2016.03.070

El-Sayed, A.-F. M. (2019). *Tilapia culture* (2nd ed.). Academic Press.

Food and Agriculture Organization of the United Nations. (2017). *Aquaculture development: Water quality management*. FAO Fisheries and Aquaculture Technical Paper.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2019). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems, 29*(7), 1645–1660. https://doi.org/10.1016/j.future.2013.01.010

Islam, M. S., Rahman, M. M., & Ahmed, S. (2021). Sensor calibration and data reliability issues in IoT-based environmental monitoring systems. *IEEE Sensors Journal, 21*(14), 15678–15687. https://doi.org/10.1109/JSEN.2021.3072104

Kumar, P., & Rani, M. (2022). IoT-based smart aquaculture monitoring and control system: A review. *Journal of Ambient Intelligence and Humanized Computing, 13*, 3821–3836. https://doi.org/10.1007/s12652-021-03391-8

Li, L., Zhang, Q., & Huang, D. (2020). A review of imaging techniques for plant phenotyping. *Sensors, 20*(9), 2578. https://doi.org/10.3390/s20092578

Rahman, M. A., Islam, M. S., & Ahmed, M. (2020). Development of IoT-based smart aquaculture monitoring system. *International Journal of Advanced Computer Science and Applications, 11*(4), 386–392.

Tzounis, A., Katsoulas, N., Bartzanas, T., & Kittas, C. (2017). Internet of Things in agriculture, recent advances and future challenges. *Biosystems Engineering, 164*, 31–48. https://doi.org/10.1016/j.biosystemseng.2017.09.007

Vol. 1, No. 1, February (2026), pp. 33-45 | p-ISSN: xxxx-xxxx, e-ISSN: xxxx-xxxx
doi: https://doi.org/xxx.xxx

Zhou, J., Li, D., & Wang, Z. (2018). Design of an intelligent aquaculture monitoring system based on IoT. *IEEE Access,* *6*, 48507–48517. https://doi.org/10.1109/ACCESS.2018.2866841

Standar Nasional Indonesia. (2014). *SNI 6484.3:2014 Produksi benih ikan lele (Clarias sp.).* Badan Standardisasi Nasional.