



Development of an IoT-Based Fish Pond Water Quality Monitoring System

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ABSTRACT

Aquaculture has remained a critical component of global food security, especially in developing countries where fish farming serves as a key source of nutrition and income. The productivity and sustainability of fish farms are largely dependent on maintaining optimal water quality. Traditional methods of monitoring pond water quality involve manual sampling and chemical test kits, which are time-consuming, labor-intensive, and often reactive rather than proactive. To address these challenges, this study presents the development of a low-cost Internet of Things (IoT)-based system designed to monitor essential water quality parameters in real time. The developed system integrates multiple sensors—namely, temperature, dissolved oxygen (DO), ammonia, pH, and electrical conductivity (EC)—connected to a microcontroller (ESP32), which processes the data and displays it on a local LCD screen. This design eliminates the need for continuous manual testing and provides immediate, on-site access to water quality information. The device is enclosed in a waterproof housing and powered by a solar-rechargeable battery, ensuring its suitability for rural and remote aquaculture environments with limited infrastructure. Unlike many existing solutions that rely on internet connectivity for cloud-based dashboards and remote notifications, this system operates entirely offline. It is particularly beneficial for small- and medium-scale fish farmers who require affordable, standalone monitoring tools. The system enables timely intervention when parameters deviate from acceptable levels, improving fish health and farm efficiency. This work contributes a practical and scalable solution to water quality management in aquaculture and lays a foundation for future enhancements such as data logging and alert systems.

CITATION

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INTRODUCTION

Aquaculture has become an essential component of global food production, addressing the growing demand for animal protein while reducing pressure on wild fish populations. In developing countries, particularly in Africa and Southeast Asia, small-scale fish farming plays a

critical role in food security, income generation, and rural economic development (Food and Agriculture Organization [FAO], 2020). As the global population continues to rise, the importance of sustainable aquaculture practices is becoming more apparent, especially in regions facing challenges related to poverty,

malnutrition, and unemployment. The success of aquaculture operations is highly dependent on the quality of the aquatic environment. Fish are ectothermic organisms, meaning that their physiological functions are significantly influenced by external environmental conditions (Maheshwari & Singh, 2025). Key water quality parameters such as temperature, pH, dissolved oxygen (DO), ammonia concentration, and electrical conductivity (EC) must be continuously maintained within optimal thresholds to ensure healthy growth and survival. Deviations in these parameters may result in fish stress, increased susceptibility to diseases, slower growth rates, and even large-scale mortality (Boyd, 2015). Traditionally, fish farmers monitor these parameters manually using chemical test kits or by sending water samples to laboratories for analysis. Although such methods may provide accurate results, they are often labor-intensive, time-consuming, and impractical for frequent assessments (Hemal et al., 2024). In many rural farming communities, access to proper testing materials, skilled personnel, or laboratory facilities is limited. Consequently, unfavorable changes in water quality are often detected too late, resulting in preventable economic losses (Maqbool et al., 2022).

Recent advancements in the Internet of Things (IoT) have enabled automated, real-time monitoring systems in various domains, including agriculture and aquaculture. These systems utilize embedded sensors, microcontrollers, and wireless communication modules to track environmental conditions and transmit data to cloud servers or mobile applications. In aquaculture, IoT systems have been developed to monitor water quality and provide farmers with remote alerts and analytics (Zhou, Yang, & Yu, 2019). However, most of these systems are designed for urban or industrial settings and rely on stable internet connectivity and power supply, which may be unavailable in many fish farms located in rural or off-grid areas. This creates a practical challenge for smallholder fish farmers in developing countries. While sophisticated cloud-based solutions exist, they are often too expensive, complex, or infrastructure-dependent to be deployed in low-resource environments. There is a significant research and implementation gap in the development of affordable, offline, and user-friendly IoT-based monitoring systems tailored to rural aquaculture. Without such systems, fish farmers are left with limited tools to proactively manage water quality and protect their stock. To address this gap, the present study aims to develop a standalone, offline IoT-based monitoring system for fish ponds. The proposed system integrates sensors for measuring temperature, DO, ammonia, pH, and EC. It displays real-time data on a local LCD screen, thereby eliminating the need for cloud servers or mobile app integration. Powered by a rechargeable battery, with the option for solar support, the system is designed for deployment in rural environments

with limited technical infrastructure. This current study is hoped to contribute a practical and context-aware solution to the problem of environmental monitoring in aquaculture. By prioritizing affordability, accessibility, and simplicity, the system empowers small-scale fish farmers to make informed, real-time decisions regarding pond management. Ultimately, this initiative supports broader efforts toward sustainable aquaculture, improved food security, and economic resilience in underserved farming communities.

Literature review

FAO (2024) reported that in 2022, global aquaculture production surpassed 130 million tonnes, with close to 60 percent of that majorly for human consumption. More than 60 million people globally are involved in small-scale aquaculture as a source of livelihood with a very large percentage of this number from a handful of countries. Low-income and developing countries in Africa, Asia, the Caribbeans, and Latin America have not fully unlocked their potential in aquaculture and fisheries most likely due to the constraint of technological tools which can help them properly manage their farms and maximise production. Technology when used well, can help the farmers to better manage and monitor the entire process for better production and maximum profits (FAO & WorldFish, 2020).

IoT-based systems that are developed for monitoring and managing aquaculture leverage on sensors for data collection and monitoring of physical and chemical water quality parameters. They are also able monitor fish growth rates, detect diseases, as well as determine optimal harvest times among many other capabilities (Flores-lwasaki et al., 2025). When parameters deviate from optimal thresholds, systems can be programmed to automatically trigger actuators, such as oxygen pumps, water heaters/coolers, or feeder pumps, to adjust environmental conditions without human intervention (Agossou, 2021; Nayoun, 2024). In most cases, data collected by sensors are transmitted automatically to cloud servers via various communication protocols like Wi-Fi, MQTT, or GSM modules that allow for secure storage, management, and real-time visualization of critical data (Cusack, 2021).

IoT-based aquaculture systems are highly customizable to meet the different needs peculiar to farmers. They can range from simple monitoring and control of a single parameter (Babalola et al., 2024) to complex systems monitoring multiple parameters and fitted with actuators including heaters, water pumps, agitators, and smart feeding devices (Chiu et al., 2022). Others provide user-friendly web interfaces or mobile applications to monitor and control parameters in real-time and incorporate machine learning for predictions (Verma et al., 2024).

An automated analytics system for small scale fisheries (PeskaAS) was developed by WorldFish as an open-source, near real-time monitoring and analytics system. It was trialed and adopted in Timor-Leste and has further been adapted for use in Kenya, Mozambique, and Malawi (Tilley & Rossignoli, 2024; Bossuet, 2023). It provides a workflow for data ingestion and analysis to a decision dashboard, helping to understand fishery impacts and test technologies like Fish Aggregating Devices (FADs). The goal is to provide a publicly accessible and scalable platform for managing anonymized small-scale fisheries information, enhancing transparent governance of aquatic food systems globally (Longobardi et al., 2025).

The study by Sung et al, (2023) challenge is to figure out how to combine Internet of Things devices with Firebase's cloud data system to deliver accurate and dependable data that makes it simple for fish farmers to remotely and in real time monitor fishpond conditions. Three metrics are used in IoT aquaculture fishpond monitoring: (1) water temperature; (2) water pH; and (3) pond water turbidity level. A microprocessor and Wi-Fi module are integrated with temperature, pH, and turbidity sensors in Internet of Things devices. The Wi-Fi module transmits sensor reading data to the Firebase cloud, where end users can access it instantly through an Android-based mobile app. The results show that (1) the IoT-based aquaculture monitoring system device has a low error rate in turbidity, pH, and temperature measurements, with percentages of 9.78%, 1.94%, and 1.75%, respectively. The three components' combined average inaccuracy is 4.49%; (2) IoT-based systems are 94.21% more cost-effective than labor-based systems in cost analysis. Fish cultivators who help provide an IoT-based aquaculture monitoring system that generates reliable data, is accurate, simple to set up, and is reasonably priced can benefit greatly from the technology's ability to monitor fish pond conditions in real-time and remotely using Firebase.

A wide range of water quality metrics, such as temperature, pH, DO, ammonia, turbidity, and salinity, are listed by the National Standardization Agency (SNI, 2016). In order to help farmers monitor and maintain the water in their fish ponds, the research by (Anggraini et al, 2024) was developing a system that blends the idea of the Internet of Things (IoT) with the cultivation of catfish in tarpaulin ponds. With the help of an Android Telegram bot, the system that will be developed will be able to continuously monitor and manage the water quality of fish ponds without requiring users to physically visit the site. Starting with the fish pond water, which is used as research material, temperature, pH, TDS, and ultrasonic sensors are inserted to measure the water's quality. The ESP32 then receives signals from all of the sensors, processes the data, and controls relays based on the results of sensor measurements or commands from the Telegram bot. For instance, it determines when to open or close a solenoid valve based on water level or other water quality parameters.

Anggraini et al, (2024) created a system that makes use of device connectivity to gather data from sensing devices about fish pond monitoring and send it to a distant server for analysis in order to make management decisions. In this study, we propose an Internet of Things (IoT) smart pond solution that offers real-time and continuous pond monitoring. Temperature, pH, dissolved oxygen (DO), total dissolved solids (TDS), and salinity are the five main environmental characteristics that the system measures in order to assess the quality of the water. In order to ensure effective pond management, the Internet of Things (IoT) system also incorporates the creation of an Android mobile application that enables users to monitor their pond remotely. With its easy-to-use interface, the program assists the farmer in tracking sensor readings, managing the fish production cycle, recording the feeding schedule, while maintaining track on the health of fish from various ponds.

The primary challenge in the study by Agus Suwardono et al, (2024) is that improper water quality and temperature conditions might either kill or stunt catfish growth, which would be detrimental to the farming industry's bottom line. Their method lacks real-time temperature control, the manual method of water quality monitoring in catfish ponds is thought to be less effective.

With an emphasis on real-time temperature control, this study intends to develop and deploy an Internet of Things (IoT)-based water quality monitoring system in catfish farming ponds. Catfish cultivation ponds are the subject of this experimental study. IoT-based system testing was used to gather data, and descriptive analysis was used to assess how well the system maintained pool temperatures between 28°C and 32°C. The study's findings demonstrate how effectively the ESP32 microcontroller and DS18B20 sensor work together to monitor the water temperature in real time in an Internet of Things-based catfish farm monitoring system. Users may keep an eye on farm conditions from anywhere at any time because to this system's ability to wirelessly communicate data to a web or application-based monitoring platform. The potential for revolutionizing aquaculture management, particularly catfish farming, is demonstrated by the consequences of research on Internet of Things-based catfish farm monitoring employing an ESP32 microcontroller and DS18B20 sensors.

MATERIALS AND METHODS

System Design

The system architecture comprises a microcontroller (ESP32), which interfaces with multiple water quality sensors. The ESP32 was selected for its analog input support and power efficiency, although its Wi-Fi capability was not used in this project. An LCD screen (16x2) is connected to the microcontroller to provide real-time data display as seen in Figure 1.

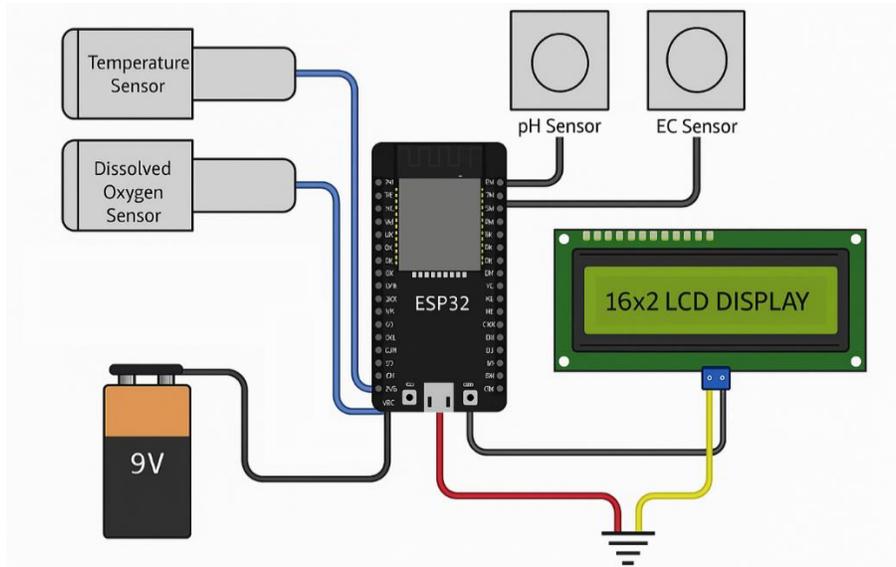


Figure 1: Fish pond water quality monitoring system design

Sensor Integration

The following sensors were used:

DS18B20 – The DS18B20 Temperature Sensor(Figure 2), is a flexible and stable temperature sensing device built for

use in harsh conditions. This sensor, which comes with a stainless steel probe, is perfect for applications that need accurate temperature readings in liquids, gasses, or other difficult situations. It is simple to interface with microcontrollers and other digital devices since it makes use of the 1-Wire digital communication protocol.



Figure 2: DS18B20 Temperature Sensor

Source: <https://hub360.com.ng/product/ds18b20-waterproof-temperature-sensor/>

pH Sensor – pH sensor is an important tool for measuring pH and is commonly used in water quality monitoring. This type of sensor (Figure 3), is capable of measuring alkalinity and acidity in water and other solutions. When used

properly, pH sensors can help fish farmers to monitor water quality and take necessary steps to maintain the correct pH levels in their fish ponds.



Figure 3: pH Sensor Kit

Source: <https://wiki.seeedstudio.com/Grove-PH-Sensor-kit/>

TDS Sensor: The Total Dissolved Solids (TDS) Meter, as seen in Figure 4, is a device used for measuring the concentration of dissolved solids, minerals and metals in

water. It provides a quick and reliable way to assess water quality by measuring the conductivity of the water, which correlates to the amount of dissolved ions present.



Figure 4: TDS Sensor Kit

Source: <https://wiki.seeedstudio.com/Grove-TDS-Sensor/>

The sensors were inserted into the pond to to obtain reading over the duration of the experiment. Sensor data was read and processed sequentially by the microcontroller.

Data Display

All sensor values were displayed in a readable format on the LCD screen. The screen refreshed automatically every few seconds, cycling through the latest readings. This allowed the fish farmer to manually check and record the readings as needed.

Power Supply and Housing

The system was powered using a 12V rechargeable battery, supported by a small solar panel to ensure uninterrupted operation. All components were enclosed in a waterproof casing to withstand the pond environment.

RESULTS AND DISCUSSION

System Testing

The device was tested to ensure that it was able to monitor readings correctly as depicted in Figure 5. It successfully

captured and displayed real-time sensor readings, with an update frequency of approximately every 10 seconds. Water samples from the pond were also collected and

tested in a standard laboratory as a benchmark. Table 1 below summarizes typical readings obtained during the monitoring period of six months.



Figure 5: Monitoring device being tested



Figure 6: LCD view of sensor readings

Table 1: Sample Sensor Readings from the System

Parameter	Observed Range	Average Value	Recommended Range*	Status
Temperature (°C)	19 – 30	24.2	26 - 30	Slightly Low
pH	7.0 – 9.8	8.9	6.5 – 8.5	Above Ideal
TDS (mg/L)	210 – 460	327	20–1,000	Within Range

*Based on Boyd (2015)

Discussion

The observed readings from the IoT-based fish pond monitoring system provided valuable insights into the water quality parameters essential for effective aquaculture management. Three key parameters—temperature, pH, and total dissolved solids (TDS)—were monitored to assess the suitability of the pond environment for freshwater fish culture. The temperature ranged from 19°C to 30°C, with an average value of 24.2°C. Although the upper limit falls within the recommended range of 26°C to 30°C for most tropical freshwater species such as catfish and tilapia, the average value is slightly below optimal. Cooler temperatures, particularly those dipping to 19°C, may slow down fish metabolism, reduce feed intake, and weaken immune responses. The lower temperatures observed during the monitoring period were a reflection of the cold harmattan season at the commencement of the experiment which impacted the feed intake and growth of the fish. However, as measures like pond shading and surrounding environment were put in place to regulate the temperatures to optimal levels, a noticeable improvement was observed in the feeding and growth of the fish. Due to the nature of the water and the high photosynthetic activity in the environment, the recorded pH values varied from 7.0 to 9.8, with an average of 8.9, exceeding the ideal range of 6.5 to 8.5. Elevated pH levels, especially those nearing 10, may lead to increased ammonia toxicity, which may not be safe for fish health. In order to regulate this, a

flow through was implemented for regular water exchange while reducing vegetative cover within the area. The TDS readings were within acceptable limits, ranging from 210 mg/L to 460 mg/L, with an average of 327 mg/L. This falls well within the safe range of 20 mg/L to 1,000 mg/L and indicates a healthy concentration of dissolved minerals and nutrients essential for fish growth. Consistent TDS levels support effective osmoregulation and contribute to overall water quality stability. A constant water quality monitoring system such as the one developed in this study is very helpful for fish farmers as it provides them with real-time information which will enable them to take informed decisions at the right time that will lead to proper management of their farms and high yields and profits.

. These findings demonstrate the usefulness of real-time water quality monitoring using low-cost IoT systems in identifying deviations from optimal conditions and enabling prompt corrective actions for sustainable aquaculture practices.

CONCLUSION

This study successfully developed and implemented an IoT-based water quality monitoring system for fish ponds, using an ESP32 microcontroller integrated with a temperature sensor, pH sensor, dissolved oxygen sensor, and electrical conductivity (EC) sensor. The system was designed to continuously measure and display critical

environmental parameters on an LCD screen, providing fish farmers with real-time insights into pond conditions without the need for cloud-based data storage or internet connectivity.

The observed results revealed important trends in water quality. While the total dissolved solids (TDS) remained within the recommended range, the temperature values occasionally dropped below optimal levels, and pH readings exceeded the ideal threshold. These findings highlight the importance of continuous monitoring to detect fluctuations that may adversely affect fish health and productivity. The elevated pH levels, in particular, pose risks such as increased ammonia toxicity, which were managed through improved water management practices like flow through and control of photosynthetic activity in the environment.

Overall, the system demonstrated the potential of low-cost, sensor-based solutions in supporting efficient and sustainable aquaculture operations. By enabling early detection of unfavorable conditions, the monitoring system empowers fish farmers to take timely corrective measures, thereby reducing mortality, improving growth rates, and ensuring better yield. Future improvements could include the integration of automated alerts, solar power support, and a data logging feature for long-term trend analysis.

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