IoT-Enabled Water Quality Monitoring for Safe Fish Cage Placement in Talisay, Batangas

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ABSTRACT

This study develops an IoT-enabled system to monitor and mitigate fish kills caused by low dissolved oxygen (DO) levels in Taal Lake, Talisay, Batangas. Advanced sensors measure critical water parameters—temperature, pH, and DO—providing real-time data to fish cage operators for optimal aquaculture management. The system is designed to aid decision-making by offering continuous monitoring and early warnings when water quality deteriorates.

Data from interviews with the Municipal Head of Agriculture and local fish farmers shaped the system's design, ensuring its relevance to real-world aquaculture challenges. The system integrates a decision-support algorithm that triggers automated notifications when predefined water quality thresholds are breached, enabling timely interventions. Implemented with wireless communication and cloud storage, the system allows remote access to water quality data, improving operational efficiency.

Validated against Bureau of Fisheries and Aquatic Resources (BFAR) standards, the system demonstrated high accuracy and predictive capabilities, helping farmers prevent fish kills, enhance sustainability, and improve food security and market stability. Despite challenges such as internet connectivity limitations and environmental disruptions, the system proved to be a reliable tool for real-time water quality monitoring, contributing to the advancement of smart aquaculture practices.

1. 0 INTRODUCTION

1.1 Background of the Project

Taal Lake, a vital resource for local aquaculture, experiences fish kills primarily due to sulfur upwelling. This phenomenon occurs when a significant drop in water temperature, combined with strong northeastern winds, triggers the release of hydrogen sulfide (H_2S)—a toxic gas with a characteristic rotten egg odor. The Bureau of Fisheries and Aquatic Resources (BFAR) in Calabarzon has reported dissolved oxygen (DO) levels ranging from 0.07 to 0.46 mg/L and hydrogen sulfide levels between 0.03 and 0.55 mg/L, both of which fall far below optimal thresholds for sustaining aquatic life. This natural event, which typically occurs from November to February, severely disrupts aquaculture operations, leading to economic losses, compromised food security, and market instability.

The success of tilapia fish cage farming in Taal Lake has attracted widespread investment in the industry. However, the recurrence of mass fish mortality events has resulted in substantial economic losses, jeopardizing small-scale and commercial fish farmers. In one recent fish kill incident, over 109 metric tons of tilapia perished, amounting to a financial loss of PHP 3 million (Cabico, 2022). This vulnerability necessitates the integration of advanced water quality monitoring technologies to enhance the resilience of aquaculture operations.

Parameter	Standard/Acceptable Level
Dissolved Oxygen (DO), mg/L (S)	>5.0mg/L*
Temperature, °C (S)	25°C-31°C*
Temperature, °C (M)	
Temperature, °C (B)	
pH, (S)	6.5-9*

* DAO 2016-08; S - Surface; M - Middle; B – Bottom

Table 1.1 Water Quality Standards

Table 1.1 illustrates the water quality standards for maintaining a healthy aquatic environment. The table lists the acceptable levels for various parameters critical to water quality.

These standards, outlined in DAO 2016-08, provide guidelines to ensure the water remains conducive to the fish habitat, which is particularly relevant in monitoring water quality for safe fish cage locations. If any of these parameters consistently fall outside the acceptable levels, it signals the need to relocate the fish cage to a better location with suitable water quality conditions.

1.2 Objective of the Project

The primary objective of this system is to design a water quality monitoring device to mitigate fish kills in Taal Lake, Talisay, Batangas. This device will use sensors to measure the lake's water temperature, pH level, and dissolved oxygen, providing real-time data that personnel can monitor. The specific objectives are:

- To determine the measuring sensors for water temperature, pH, and dissolved oxygen levels.
- To analyze the water condition based on the collected data.
- To implement a system that allows personnel to monitor real-time parameter values.
- To evaluate the measurement accuracy of the device.
- To check the water quality at different fish cages by manually placing the device to monitor the conditions of the water.

1.3 Scope and Limitation of the Project

This research aims to develop a real-time monitoring device for fish cages and tracking water quality parameters that can lead to fish kills in Taal Lake. The device is designed to assist fish cage owners in monitoring various parameters, enabling timely and appropriate interventions. However, it is important to note the following limitations of the study:
Selected area. The system will be implemented only in specific areas of Taal Lake, allowing for targeted and efficient intervention. It does not cover the entire lake.
Water Quality Monitoring. To evaluate water quality, the system will measure specific factors, such as water temperature, pH, and dissolved oxygen levels. These critical metrics offer a thorough knowledge of the water's general health and chemical makeup.
Fish Species. This study monitors water quality parameters in fish cages populated by black carp and milkfish. It does not extend beyond these specific cages to other fish species or aquatic environments.
Battery operated. The device will be battery-operated, ensuring flexibility and ease of deployment in various locations within the designated areas of Taal Lake. However, this introduces a need for regular battery maintenance and replacement to ensure continuous operation.

2. 0 REVIEW OF RELATED WORK

2.1 Fish Kills

Fish kills have severe environmental and economic impacts, caused by factors such as low dissolved oxygen, pollution, climate change, and algal blooms (Johnson & Brown, 2017; Jones et al., 2019). They disrupt ecosystems, reduce biodiversity, and indicate underlying environmental stress (AFS, 2019).

Research in Mediterranean and Australian rivers has shown that fish kills peak during warm months and are linked to nutrient pollution and oxygen depletion (Water Research, 2019; NSW DPI, 2019).

Incidents in Lake Taal and Lake Buhi have highlighted the effects of natural events like overturns and human activities like poor lake management (Bestari et al., 2020; Nieves et al., 2020).

In the Philippines, fisherfolk in Laguna Lake report fewer native fish due to fish kills, invasive species, and poor water conditions (Mendoza et al., 2022). Similarly, a study in Europe found pollution from a failed treatment plant significantly altered fish communities (Wasilewska, 2023).

2.2 Water Quality

Lakes like Taal face declining water quality due to unregulated aquaculture, nutrient buildup, and poor enforcement of regulations (Medallon & Garcia, 2021; de Leon et al., 2024).

Effective monitoring is crucial, but traditional methods are limited. New technologies using Arduino-compatible sensors improve real-time data collection (Demetillo et al., 2019).

In Maninjau Lake, significant water quality changes followed a major fish kill, stressing the importance of continuous monitoring (Jasalesma et al., 2023).

Recent models combining weather and water data have achieved over 90% accuracy in predicting fish deaths, aiding resource management and sustainability (Chen & Ting, 2024).

3.0 METHODOLOGY

This section presents the theoretical foundation, design methodology, simulation, implementation, and testing of the IoT-Enabled Water Quality Monitoring System. The goal is to ensure accurate, real-time monitoring of pH levels, dissolved oxygen (DO), and temperature to reduce fish kills in Taal Lake.

3.1 Design and Simulation

The system integrates sensors, a microcontroller, and wireless communication to enable real-time water quality monitoring. It consists of four stages: input (pH, DO, and temperature sensors), processing (Arduino Uno), communication (ESP32 to Firebase), and output (LCD, mobile app, and cloud storage). The DFRobot pH sensor operates at 3.3–5V with ±0.1 pH accuracy; the DO sensor includes temperature compensation and ±10 mg/L accuracy; and the DS18B20 temperature sensor uses one-wire communication with ±0.5°C accuracy.

The circuit calculations for the system involve several key equations. The Nernst equation is used to calculate pH values, while the Winkler titration method is applied to measure dissolved oxygen concentration. Additionally, a temperature compensation formula is employed to adjust dissolved oxygen readings based on varying water temperatures.

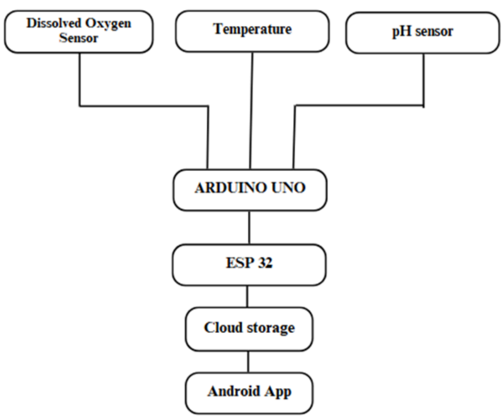

Fig. 2.1 System Block Diagram

Figure 2.1 shows the proposed system block diagram, illustrating its implementation. The different hardware parts are connected to the microcontroller. Furthermore, the entire system will be solar powered. Wire connector cables will be used to link the temperature, pH level, and dissolved oxygen sensors to the microcontroller. The processed data is then safely sent via secure protocols to a cloud-based server. The Android app is linked to the cloud server. The real-time monitoring will be shown on the Android app.

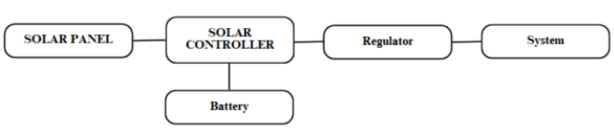

Fig. 2.2 Power Supply Block Diagram

Figure 2.2 shows the power supply's block diagram. The solar panel, solar controller, and battery are connected to supply the system. The solar panel converts sunlight into DC electricity, which the solar controller regulates to prevent overcharging or deep discharge of the battery. The battery stores excess energy for use when sunlight is unavailable. The system ensures efficient energy capture, storage, and supply to connected devices.

3.2 Implementation

The implementation phase focuses on constructing the physical design of the monitoring system, ensuring reliable data collection and transmission. The process begins with component selection, where suitable sensors and microcontrollers are chosen based on their accuracy and compatibility. Next, the circuit design and PCB layout are developed for precise schematic representation and printed circuit board fabrication.

The firmware for the microcontrollers is programmed using Arduino IDE, enabling real-time data processing and transmission to Firebase. A mobile application is also developed allowing users to remotely access water quality data.

The schematic design consists of an analog pH and DO sensor connected to Arduino analog pins, a DS18B20 temperature sensor using one-wire communication, and an ESP32 module for wireless data transmission. The system is powered by a 12V battery with solar charging, ensuring continuous operation even in remote areas.

ESP 32	160mA
Arduino Uno (microcontroller)	100mA
DS18B20 (temperature sensor)	1mA * 3 = 3mA
DFRobot (pH sensor)	5mA
DFRobot (dissolved oxygen sensor)	5mA
Total	273mA

Table 2.1 Power Consumption

Table 2.1 presents the power consumption of individual components in the IoT-enabled water quality monitoring system. The ESP32 module, responsible for wireless communication, consumes 160mA, while the Arduino Uno microcontroller requires 100mA. The DS18B20 temperature sensor, operating with three units, contributes a total of 3mA. Additionally, the DFRobot pH sensor and dissolved oxygen sensor each consume 5mA. The total system power consumption amounts to 273mA, ensuring efficient energy usage while maintaining real-time monitoring capabilities.

Component	Specification	Calculation	Result
Load Power Demand	1.365W	Daily Energy = Power * 24	1.365W * 24h = 32.76Wh/day
Solar Panel Power	25W	Daily Output = 25W * 5h	125Wh/day
Efficiency Losses	30% (due to controller, temperature, etc.)	Usable Output = 125Wh * 0.7	87.5Wh/day
Battery Capacity	12V, 12Ah	Battery Capacity = 12V * 12Ah	144Wh/day
Autonomy (Backup)	Duration without sunlight	144Wh/32.76Wh per day	4.4 days

Table 2.2 Power Consumption Computation

The system consumes 32.76Wh of energy per day, while the solar panel produces 125Wh per day under five peak sun hours, providing more than three times the energy required. After powering the load, excess energy is stored in a battery with a capacity of 144Wh. This allows the battery to supply power for over 4 days (144Wh ÷ 32.76Wh) without recharge, ensuring reliable energy availability even during periods of low sunlight.

The solar energy system is well-designed to meet daily energy needs, with a sufficient buffer to store excess energy. The battery provides reliable power backup, ensuring continuous operation even during cloudy or overcast days.

3.3 Testing

The system undergoes rigorous testing to ensure it meets the required objectives. The functional testing phase involves calibrating the sensors. The microcontroller processing is tested to verify that sensor data is correctly converted and transmitted. Additionally, wireless communication is validated by checking Firebase Cloud Storage.

Field testing is conducted in Taal Lake, where the system is deployed in multiple locations to collect real-time water quality data. The collected sensor readings are compared with measurements taken by BFAR (Bureau of Fisheries and Aquatic Resources) instruments to assess accuracy.

The data analysis and evaluation phase involve calculating the mean absolute error (MAE) to determine sensor accuracy. The system is also tested for its ability to generate threshold alerts, which notify users when water parameters exceed safe levels.

4.0 RESULTS AND DISCUSSION

Sampaloc					
Date/ Time	**DO** (mg/L)	**pH**	**Temp (°C)** (1-meter)	**Temp (°C)** (2-meter)	**Temp (°C)** (3-meter)
Dec 14, 2024 | 8:45 am	5.64	8.72	30.5	27.1	26.1
Dec 14, 2024 | 6:52 pm	5.38	8.05	30.8	26.2	28.5
Dec 15, 2024 | 9:47 am	5.24	8.11	31.8	30.1	26.0
Dec 15, 2024 | 7:08 pm	5.11	8.72	30.8	26.2	29.6
Dec 20, 2024 | 9:03am	5.32	8.63	30.8	28.2	27.8
Dec 20, 2024 | 5:36 pm	4.04	8.68	30.2	27.3	25.9
Dec 21, 2024 | 8:27 am	5.24	8.49	32.0	29.5	28.7
Dec 21, 2024 | 6:18 pm	5.37	8.09	31.6	27.9	26.5
Dec 22, 2024 | 6:34 am	5.24	8.49	32.0	29.5	28.7
Dec 22, 2024 | 6:48 pm	5.55	8.87	31.3	28.1	27.2
Jan 03, 2025 | 2: 38pm	5.99	8.76	30.8	28.7	26.5

Table 3.1 Test Results

Table 3.1 illustrates the actual results of the system on different time periods, showcasing its capability to display and analyze the recorded data during the implementation phase of the project.

Fig. 3.2 In-application Test Results

Figure 3.2 illustrates the in-application test results, showcasing real-time data collected during system operation. It provides insights into the system's accuracy, responsiveness, and overall performance under actual deployment conditions.

The prototype was implemented, integrating real-time monitoring, and a GUI based on a Firebase application. The system displays key water quality parameters, including Dissolved Oxygen, Temperature (measured at the bottom, middle, and surface), and pH levels. Additionally, the system highlights the set ranges for each parameter, providing real-time feedback if the recorded data falls below or exceeds the specified thresholds. This ensures that users can quickly identify deviations and monitor water quality effectively. Figures 5.4 illustrate the actual results of the system, showcasing its capability to display and analyze recorded data during the implementation phase of the project.

The data that was collected is from different time periods. There are two pieces of data presented for each day of the testing period. The parameters' values are recorded in a table and its appropriateness to the applicable range of values can be differentiated by their font color, where black font means that the recorded value is within the range for aquaculture, and red font if it is above or below the range.

Sampaloc (Testing with BFAR)					
	DO (mg/L)	pH	Temp (1m)	Temp (2m)	Temp (3m)
Faith Colleges	4.92	7.3	28.5 °C	28.3 °C	27.6 °C
BFAR	4.96	7.1	27.8 °C	–	–

Table 3.3 Test Results with BFAR

Table 3.3 illustrates the data gathered during the joint water quality testing with BFAR to ensure the device's reliability and verify precision.

The measuring instrument used by BFAR for the actual water quality values is the ProDSS Multiparameter. The reliability and precision of the ProDSS Multiparameter play a critical role in verifying the system's measurements throughout the implementation process.

Once the data is gathered, a comparison with ProDSS readings enables the calculation of the percentage error and average percentage error, ensuring the developed system adheres to the high accuracy standards set by the instrument. This process ultimately reinforces confidence in the system's ability to provide accurate, consistent, and trustworthy water quality monitoring results.

Margin error = Actual value -Measured Value

Equation 3.1 Margin of Error

The formula to compute the margin of error is equation 3.1, while its average is simply the summation of all margins of error divided by the total number of time intervals.

Parameter	Faith Colleges (Measured)	BFAR (Actual)	Margin of Error
DO	4.92 mg/L	4.96 mg/L	±0.04 mg/L
pH	7.3	7.1	±0.2
Temp (1m)	28.5°C	27.8°C	±0.7°C
Temp (2m)	28.3°C	N/A	±0.5°C
Temp (3m)	27.6°C	N/A	±0.2

Table 3.4 Accuracy Test Results

Table 3.4 presents the results of the water quality monitoring evaluation, where the measured values recorded by the prototype developed at Faith Colleges were compared to the actual values provided by BFAR.

The evaluation focused on five water quality parameters: dissolved oxygen (DO), temperature at various depths (1m, 2m, 3m), and pH levelThe results show a margin of error ranging from 0.04 mg/L to 0.7°C.

The observed margin of error demonstrates reliable performance with low margins of error across all measured parameters.

Temperature Sensors	Temperature Sensors' Value	Thermometer Value	Margin of Error
Temp (1m)	40°C	40.5°C	±0.5°C
Temp (2m)	40.2°C	40.5°C	±0.3°C
Temp (3m)	39.3°C	40.5°C	±1.2°C

Table 3.4 Accuracy Test Results in a Controlled Environment

Table 3.4 is an accuracy test result of the temperature sensors using a thermometer in a controlled environment. The water temperature in a cup is measured using a thermometer. Then, all three temperature sensors are submerged in that cup to measure the difference between the device's temperature sensor and the thermometer's reading. The margin of error for temperature (1m) is ±0.5°C, for temperature (2m), ±0.3°C, and then for temperature (3m), ±1.2°C.

5.0 CONCLUSION

Upon completing the IoT-Enabled Water Quality Monitoring System for Safe Fish Cage Placement in Talisay, Batangas, the study concluded that a reliable and accurate real-time monitoring solution was successfully developed. The system effectively measured key water quality parameters—dissolved oxygen, temperature, and pH—using a wireless sensor network and mobile application, enabling continuous data collection and real-time alerts. This empowered fish cage operators to respond proactively to water quality issues, thereby reducing the risk of fish kills. Overall, the system proved to be a valuable tool for enhancing aquaculture management through timely and actionable water quality insights.

6.0 RECOMMENDATIONS

The researchers provide the following recommendations after the completion of the IoT-Based Water Quality Monitoring System for Safe Fish Cage Locations in Talisay, Batangas:

To further validate the system's effectiveness in monitoring water quality under varying conditions, it is recommended to expand its deployment to other regions of Taal Lake. Providing workshops and training sessions for fish cage operators will help maximize the usage and benefits of the app, ensuring that users are well-equipped to interpret and act on the data provided. Additionally, incorporating features such as SMS will broaden the device's communication scope, while improving the application's interface based on user feedback will enhance user experience. Allocating a budget for high-quality materials is also essential to enhance the overall effectiveness and robustness of the device.

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8.0 REFERENCES

1. Bhatnagar, A., & Devi, P. (2019). Water quality guidelines for the management of pond fish culture. Water Research, 173, 115600. https://doi.org/10.1016/j.watres.2019.115600

2. Borja, A. C., & Santos, A. C. (2024). The influence of thermal stratification on water quality and fish kills in Lake Taal. Water, 16(2), 283. https://doi.org/10.3390/w16020283

3. Dillon, P. J., Molot, L. A., & Futter, M. N. (2024). Predicting the effects of climate change on fish kills in Lake Taal using a dynamic model. Aquaculture and Fisheries, 6(3), 230-240. https://doi.org/10.1002/aah.10054

4. Sánchez, J. L., & García, M. P. (2022). Long-term changes in the fish community of Lake Taal: A response to climate and anthropogenic pressures. Fisheries Science, 5(4), 410-425. https://doi.org/10.1007/s40152-022-00287-w

5. Bhatnagar, A., & Devi, P. (2019). Water quality guidelines for the management of pond fish culture. Water Research, 173, 115600. https://doi.org/10.1016/j.watres.2019.115600

6. Borja, A. C., & Santos, A. C. (2024). The influence of thermal stratification on water quality and fish kills in Lake Taal. Water, 16(2), 283. https://doi.org/10.3390/w16020283

7. Dillon, P. J., Molot, L. A., & Futter, M. N. (2024). Predicting the effects of climate change on fish kills in Lake Taal using a dynamic model. Aquaculture and Fisheries, 6(3), 230-240. https://doi.org/10.1002/aah.10054

8. Sánchez, J. L., & García, M. P. (2022). Long-term changes in the fish community of Lake Taal: A response to climate and anthropogenic pressures. Fisheries Science, 5(4), 410-425. https://doi.org/10.1007/s40152-022-00287-w

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