# Development of water quality monitoring system for fish farming

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**ABSTRACT**

Tilapia fish farming faces growing challenges from climate variability, environmental degradation, and the urgent demand for sustainable food production. However, traditional water quality monitoring methods remain manual and reactive, often resulting in compromised fish health and reduced farm productivity. Addressing this need, this study designed and developed a water quality monitoring system utilizing the internet of things (IoT) and embedded systems to enable real-time, proactive management. Guided by the software development life cycle (SDLC), the methodology focused on planning and analysis, system design and development, and testing and evaluation. The system integrates key water quality sensors, including pH, temperature, dissolved oxygen (DO), and electrical conductivity (EC), identified as critical parameters affecting tilapia health. These sensors were interfaced with Arduino Nano and ESP32 Dev Kit microcontrollers, forming the sensing layer of the system. Sensor data were transmitted to the ThingSpeak IoT platform for real-time visualization and storage. Validation results revealed a low mean absolute percentage error (MAPE), indicating an acceptable sensor performance. User evaluation, based on the technology acceptance model (TAM), indicated that the system was perceived as useful, user-friendly, and valuable for aquaculture management. Overall, the system enables real-time water quality monitoring, supporting a more responsive and sustainable environment for tilapia fish farming.



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## 1. INTRODUCTION

Over the last few decades, the aquaculture sector has witnessed a significant surge in the production volume and economic yield [1]. Accordingly, aquaculture is crucial to the global food supply, yet this growth is often not fully recognized due to prevailing discussions on sustainability and international trade complexities [2]. In this regard, the capability of the aquaculture industry to follow and adapt to these trends was inadequate since it still utilizes traditional and contemporary methods, particularly, real-time water quality monitoring of aquaculture environments [3]. Thus, experiencing a significant decline in global production despite its growth over several years [4].

On the other hand, optimal pond management is crucial to healthy fish growth, production success, and profitability in aquaculture [5]. One of the key factors in obtaining high production yield is the proper management of water quality environment [6], [7]. In addition, water quality monitoring is crucial in aquaculture, with its effective management being essential for the industry's success [8]. Previous studies stated that optimizing aquaculture farming processes particularly water quality monitoring can improve sustainability and profitability [9]. In contrast, modern aquaculture practices in water quality monitoring have stagnated over time. Traditional approach includes manual collection using handheld sensors and laboratory analysis [10] which is time-consuming and not cost-effective resulting in water quality monitoring a complex task [8]. Despite the need to intensify its production, the aquaculture industry failed to cope due to ineffective conventional practices [11].

In the context of Philippines, water quality monitoring is still a prevalent problem in the aquaculture industry. Traditional processes on maintaining water quality such as high temperature involve the utilization of shading and expanding of ponds [12]. However, the consistent problem of water quality monitoring in the Philippines emphasize the importance of continuous assessment and adoption of present date solution that aims to enhance water quality management [13]. In spite of advanced systems, Philippines has stagnantly implemented these modern technologies in its aquaculture industry. In connection with, tilapia fish farming was generally accepted industry in the Philippines, making it as one of the major areas of aquaculture in the country [14]. While tilapia fish farming is essential, there is still a significant gap in integrating these modern technologies. This has resulted in a decrease of overall production which is predominantly linked to an inconsistent water quality environment [15]. In connection with, parameters such as pH, dissolved oxygen (DO), temperature, and electrical conductivity (EC) are the significant factors in attaining and supporting suitable water quality environment on tilapia fish farming [10], [16]. Additionally, proper understanding and management of water quality environment through data visualization was considered as a crucial method. It enables appropriate decision-making in a data driven way, thus supporting sustainable and productive practices in tilapia fish farming which can result to the overall success of the aquaculture industry.

These prevalent challenges became the rationale of this research, which is to design and develop an extensive system for water quality monitoring for tilapia fish farming. The system was being implemented to tilapia fish farming, its main goal was to address and mitigate problems associated to unstable water quality environments. Particularly, design and configure important water parameter sensor for pH, temperature, DO, and EC. Utilize an internet of things (IoT) platform for data visualization and finally evaluate the developed system through technology acceptance model (TAM). With this solution, this study seeks to design a system focused on intensive development for possible deployment in the field. Thus, ensuring the effectiveness of the system in monitoring water quality.

## 2. RELATED WORK

Recently, studies utilizing emerging technologies such as IoT and embedded systems have become increasingly used in water quality monitoring. These systems in the aquaculture sector have produced a vital contribution in achieving and promoting the sustainability of the industry [17]. Several studies have designed an IoT system for monitoring and controlling the water parameters in aquaculture that gather real-time data. One of the research projects summarized a variety of sensors and monitoring technologies, which is IoT-based systems that provide an overview of the current systems for water quality monitoring [10]. Water quality sensors for temperature, pH, DO, salinity, and oxygen reduction potential (ORP) have been used to develop an automatic control system for shrimp ponds [18]. Similarly, a study has designed and developed a low-cost system that consists of different sensors such as temperature, pH, turbidity, conductivity, and DO for real-time water quality monitoring [19]. Also, a system was proposed using pH, temperature, and water level sensors to automate and enable remote monitoring for fish farm environments [20].

A recent study reviewed IoT system prototypes reported in the literature over the past five years, identifying key challenges in aquaculture applications, particularly those related to infrastructure, data management, and user perception [21]. Meanwhile, a study suggested that adopting Industry 4.0 concepts—such as real-time data collection and storage using sensors and embedded systems—can improve the accuracy of farm operations and support faster, evidence-based decision-making [22]. Another study developed a web-based remote sensing platform to support precision fish farming by providing information on water quality, fish growth, and integrated notification systems [23]. Some studies developed a mobile application using firebase real-time database (RTDB) [24], an advanced web-based monitoring and forecasting system [16], and a set of decision support tools for spatial planning and management in aquaculture [25]. Furthermore, IoT based monitoring systems utilizing platforms like ThingSpeak have been employed to monitor and display real-time water quality data which enabled an alarm system notifying users for proper decision making [26]. ThingSpeak's capabilities extend to aggregating, visualizing, and analyzing live data streams in the cloud, offering instant visualizations of data posted by devices. This enables users to take immediate, informed actions, thus enhancing traditional manual laboratory testing methods and significantly reducing both cost and time [8]. Allowing farmers to carry out preventive actions and therefore minimizing the losses and increasing productivity simultaneously.

Given the positive results of these studies, gaps related to system deployment and evaluation were not cleared. Methods such as sensor testing must be established to ensure the functionality of the sensors. Concurrently, a study has introduced a multi-parameter portable water monitoring device for real-time aquaculture management [27]. The instrument was tested for accuracy in measuring important aquaculture parameters and demonstrated negligible error and fluctuation in 50 trials, making it more than adequate for grouper fish farming. However, suggestions to the system were also indicated such as a durable waterproof case, portable power supply, and wireless network functionality to improve connectivity. The application of the TAM was most critical in the technology adoption evaluation process. This framework key drivers for technology implementation are both perceived ease of use and usefulness, thus enabling developers a user-friendly design [28]. Its broad application throughout various types of technology highlighted its advantages in understanding the perception of the users [29]. Thus, its versatility in accommodating factors such as social impact makes it compatible with technology applications [28]. For this reason, adopting TAM model to evaluate systems like water quality monitoring has enabled a proper understanding of important factors in its implementation through determining the perceived usefulness and east of use from the potential users. TAM framework in water quality monitoring systems contributes to its effectiveness, promoting commendation towards professionals and practitioners assigned to manage water quality and incorporating impactful aquaculture management processes.

## 3. METHOD

This study has adopted the software development life cycle (SDLC) as its methodology framework. The framework was selected for its systematic nature, which is most beneficial in shaping this study. Therefore, the researchers have followed it as a roadmap, explicitly focusing on the stages of "planning and analysis, design and implementation", and *testing and evaluation* to carry out this study effectively. Detailed discussions on each of these phases were provided in the subsequent sections.

### 3.1. Planning and analysis

A consultation with a marine biologist was undertaken as the subject matter expert of the project. The consultation aimed to learn more about the most important water quality parameters influencing tilapia fish culture, including pH, DO, ammonia, salinity, and temperature. The data collected provided the rationale for choosing suitable sensors to perceive these parameters. Furthermore, the researcher utilized a strategic information collection strategy to substantiate and confirm conclusions arising from the consultation. Applying keywords from search terms like "Internet of Things (IoT)," "Remote Sensing," "Embedded Systems," "Water Quality Monitoring," and "Tilapia Fish Farming," a far-reaching search was made across scholarly research and academic databases. In addition, the researcher carefully sifts through the gathered journals and articles with the following search term keywords. Finally, a reference manager called Mendeley analyzes the connection between the ideas and concepts needed for this research. Following comprehensive research and validation, the study precisely identified the sensors required for monitoring water quality in tilapia fish farming. The identification was guided by recommendations from the literature, supplemented by market availability, reliability, and durability considerations from the manufacturer's data sheets to guarantee the authenticity and suitability of the selected components for the project.

### 3.2. Design and implementation

Phase 2, centered around design and implementation, has four essential processes: hardware design, 3D modeling, software development, and system integration. In-depth discussions of these phases are provided in the subsequent sections, providing thorough insights into their complexities.

#### 3.2.1. Hardware design

The sensing layer of the system consists of sensors to measure four key water parameters: temperature, pH, DO, and salinity. The instrumentation of these materials is discussed in Figure 1, indicating the positioning of components for optimal operational efficiency of the system. Also, using a mix of analog and digital sensors: DFROBOT Gravity: analog pH sensor for pH, DFROBOT Gravity: analog electrical conductivity sensor for EC, DFROBOT Gravity: analog dissolved oxygen sensor for DO, and DS18B20 temperature sensor for temperature. Lastly, employing microcontrollers such as Arduino Nano and ESP32 DEVKIT V1, and 3.5 TFT LCD for data acquisition, processing, and monitoring.

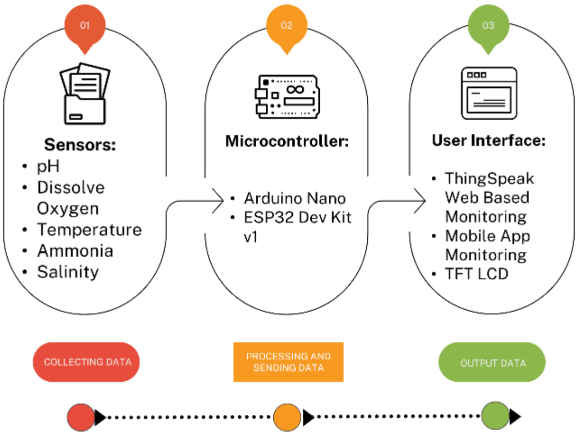



Figure 1. Hardware architecture

#### 3.2.2. 3D model design

The researcher fabricated a 3D model design to properly visualize the system prototype. A modelling software called SketchUp has been utilized to develop a prototype design. Moreover, the researcher came up with the design, see Figure 2, after several iterations and changes.

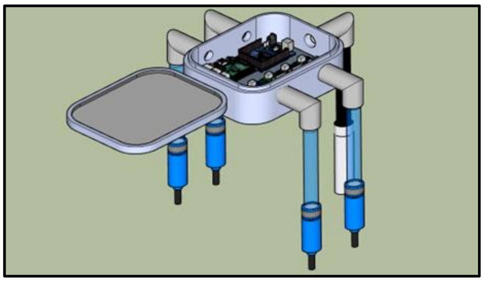


Figure 2. 3D model design

#### 3.2.3. Software design

The firmware design consists of two main subphases: sensing layer configurations and ThingSpeak configuration. In the sensing layer configurations, essential libraries were imported to enhance sensor data collection capabilities, with digital and analog pins set up for accurate signal interpretation and data variable declaration for storage. Functions specific to each sensor were developed, culminating in a comprehensive program code for data collection. For the ThingSpeak configuration, the researcher leveraged the ThingSpeak IoT platform for data logging and storage, creating a Mathworks account and a channel for data streaming. The ESP32 Dev Kit was linked to ThingSpeak using a unique API key, with necessary libraries and variables ensuring a smooth connection between the sensing and data aggregation layers. This process resulted in the development of effective program code for data transmission and storage.

#### 3.2.4. System integration

During the system integration phase, the researcher confirmed the hardware and firmware designs were finalized and evaluated their efficacy in gathering, transmitting, and displaying data. All sensors were tested and calibrated for the sensing layer to provide precise data. In addition, networking was done to facilitate easy communication between microcontrollers, sensors, and ThingSpeak. Lastly, initial readings from the water quality sensor were transmitted to ThingSpeak, confirming the successful transmission of sensor data to ThingSpeak for data visualization.

### 3.3. Testing and evaluation

The testing and evaluation phase focused on sensor calibration, ThingSpeak connectivity, system integration assessment, and TAM assessment. These phases ensured accuracy in the system, correct communication, seamless integration, and user acceptance. A deeper analysis of these components is shown in the sections below:

a. Sensor calibration: researchers performed sensor testing and calibration to validate the functionality of software and hardware, using error percentage formulas for EC, pH, DO, and temperature to guarantee system accuracy [30].
b. ThingSpeak connection testing: to assess ThingSpeak's reliability, the team simulated random data points and used the ESP32 Dev kit v1 to send random integers, checking the platform's ability to accurately receive and display the data.
c. System integration testing: this stage entailed mounting the system's components on a breadboard and attaching sensors to an Arduino Nano to obtain water quality data correctly, with reliable data transmission and sensor power supply.
d. Evaluation TAM: the prototype evaluation process entailed embracing the TAM [31], [32]. The evaluation using TAM questioned environmental science master's students regarding their technology familiarity, perceived usefulness, ease of use, and attitudes toward the system. The results were evaluated based on the TAM model.

## 4. RESULTS AND DISCUSSION

### 4.1. Sensor testing and calibration data

The researcher conducted a series of sensor testing and calibration to ensure the functionality of the software and hardware components of the system. Fifty data points have been collected per sensor before calculating their error percentage. The sensor accuracy during testing was measured using the error percentage formula. This formula was used for pH, EC, DO, and temperature:

$$\%\ error\ of\ reading = \frac{p-pd}{p} \tag{1}$$

where p is a predetermined parameter of the buffer solution and pd is the actual measurement as read by the sensor. Moreover, the researcher carried out 50 trials on each sensor to collect enough data for the average reading to be used in calculating their accuracy. Consequently, calibration code has been uploaded to each testing circuit of the sensor. Predetermined parameter values from buffer solutions (pH and EC) and other sensors related to the mentioned water parameters (DO and temperature) were imported to compare and acquire the minimal error, thus ensuring high accuracy for each water quality analog sensor. Table 1 summarizes the testing and calibration results of the sensors for water quality monitoring systems.

Table 1. Sensor testing and calibration data

| Water quality sensor | Predetermined parameter value | Mean sensor reading after 50 trials | MAPE (%) |
|---|---|---|---|
| pH | pH 4.0 | pH 3.998 | 0.05 |
| | pH 7.0 | pH 7.003 | 0.04 |
| EC | 1.413 mS/cm | 1.402 mS/cm | 0.76 |
| | 12.88 mS/cm | 12.817 mS/cm | 0.49 |
| Temperature | 23 °C | 23.07 °C | 0.31 |
| DO | 4.7 mg/L | 4.772 mg/L | 1.54 |

Table 1 shows the process of sensor testing and calibration which includes individual testing of sensors through utilizing specific circuit connections and sample testing program code. A predetermined water quality value was employed to compare data reading of each water quality sensor. For pH and EC, a buffer solution was used to identify their sensor reading. For the temperature and DO sensor, both sensors were being compared with a calibrated thermometer and an industrial DO meter (KONG DO Meter). To calculate the mean average percentage error (MAPE), a total of 50 trials were conducted to collect 50 data points of each sensor. Moreover, Table 1 summarizes the results of sensor testing and calibration.

### 4.2. System integration

For the system integration, the researcher utilized waterproof materials to ensure the safety of the system components. After the thorough calibration process the sensors have been integrated into the ESP32 Dev kit and Arduino Nano. Furthermore, established a stable connection to the ThingSpeak IoT platform for data visualization and monitoring.

**4.2.1. System development**

The hardware design has been integrated using the four calibrated sensors, which are pH, temperature, DO, and EC, see Figure 3. A connection between the Arduino Nano and the ESP32 Dev Kit has been established. Henceforth, data acquisition has been done and displayed to the ILI9225 LCD. The integration of the system components was connected and assembled to ensure the connectivity and condition of the components. The sensors were connected to the Arduino Nano to properly collect water quality data. For EC, pH, and DO sensors, their data pin was connected to analog pin 0 (A0), analog pin 1 (A1), and analog pin 2 (A2), respectively. Meanwhile, the DS18B20 temperature sensor data pin was linked to digital pin 2 (D2) and is accompanied by a pull-up resistor of 4.700 Ohms to ensure a stable digital signal.

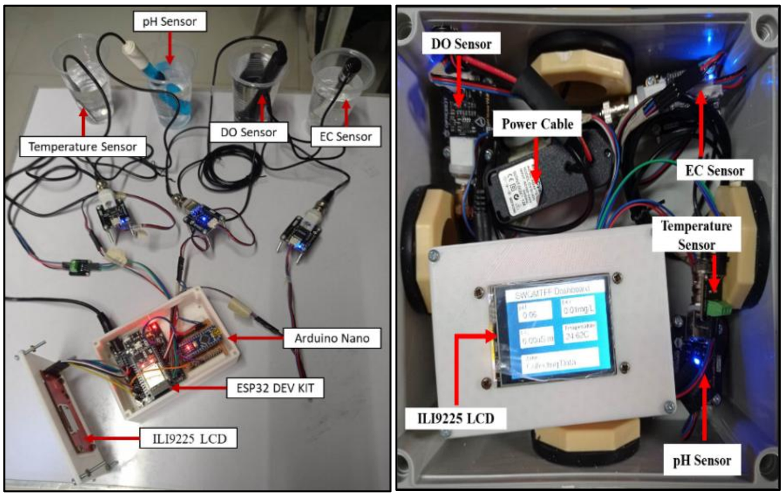



Figure 3. System integration

Moreover, to ensure proper communication, the ESP32 Dev Kit v1 RX pin is directly connected to the TX pin Arduino Nano. The sensors mentioned were all powered and connected to the 5 V input voltage pin and the common ground of the Arduino Nano board. The researcher crucially checked each individual hardware component before incorporating them into a waterproof enclosure. Each sensor was then examined if correct data had been collected, followed by verifying if the data was successfully displayed in the LCD. On a final note, a unique 3D-printed mini enclosure was specifically designed to contain the hardware components safely inside the waterproof enclosure. Also, a 1 mm diameter PVC pipe, a cable insulator, an acrylic gap filler, and a 3D printed tube have been used to safeguard the prototype during the deployment, see Figure 4.

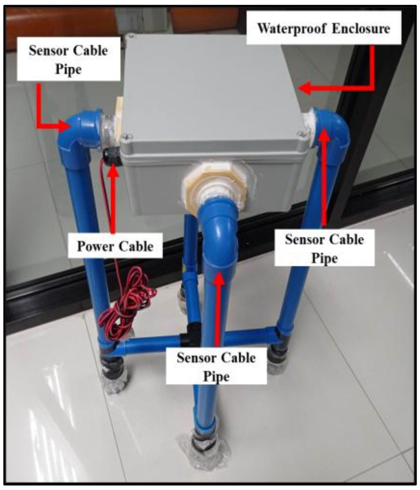
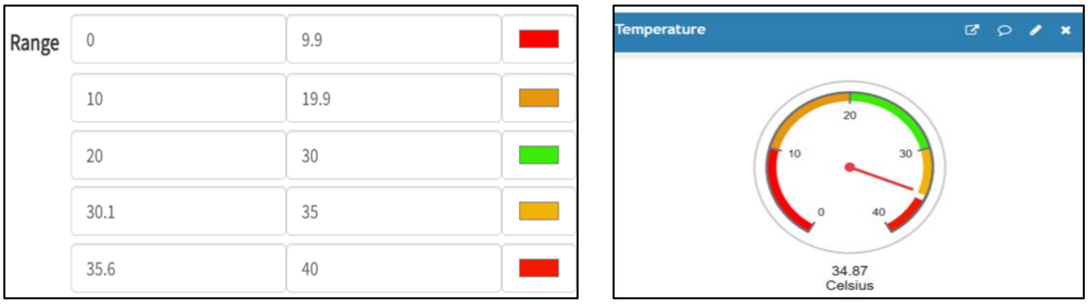



Figure 4. Component integration

To enhance the accuracy of decision-making, a gauge widget has been configured to display specific ranges for each parameter, see Figure 5(a), providing an improved visual representation of the collected data. Each water quality parameter also has a gauge widget that serves as a threshold indicator, see Figure 5(b). In this way, it is easier to monitor the water quality of the pond with greater precision, thus ensuring the accuracy of the data collected. This feature was particularly important when making critical decisions that rely on the data obtained from the system. With these improvements in place, users can have greater confidence in the system's ability to provide accurate and reliable data.




(a) (b)

Figure 5. Example: (a) temperature interval range and (b) widget threshold indicator

#### 4.2.2. Sensor validation

After ensuring the functionality of the system through testing and calibration, this study validated the reliability of the sensors through testing it to a real water quality data on a tilapia fishpond. For accurately evaluation, the researcher borrowed water quality sensors capable of detecting temperature, pH (*HM Digital PH-200: Waterproof pH Meter*), DO (*HI-9147-10 Dissolved Oxygen Meter*), and EC (*Atago 2483 Salinity Refractometer*) from the College of Science and Mathematics of Mindanao State University - Iligan Institute of Technology. A validation process has been initiated to check whether the system prototype coincides with the accuracy of these sensors. Thus, the validation process has obtained a low MAPE of 1.89% for temperature, 3.85% for DO, 1.03% for pH, and 1.85% for EC, ensuring accuracy and reliability suitable for tilapia fish farming.

a. Temperature sensor

The DS18B20 temperature sensor, when compared with pH and DO sensors that also detect water temperature, demonstrated higher reliability and accuracy in tilapia fish farming. The DS18B20 showed consistently smaller percentage errors—1.39%, 1.02%, 1.80%, 1.31%, and 3.91%—with temperature readings of 34.02, 33.11, 33.93, 34.74, and 34.11 °C, resulting in an average error of 1.89%, see Figure 6. This precision was found to be slightly better than those in comparative research, where error rates of 1.9% have been found in shrimp ponds [33], 2.37% in catfish culture [34], and 3.52% in fish hatchling culture [35]. Results indicate that using the DS18B20 sensor yielded a practical solution for real-time water quality monitoring, supporting its viability as a sound tool in aquaculture temperature management.

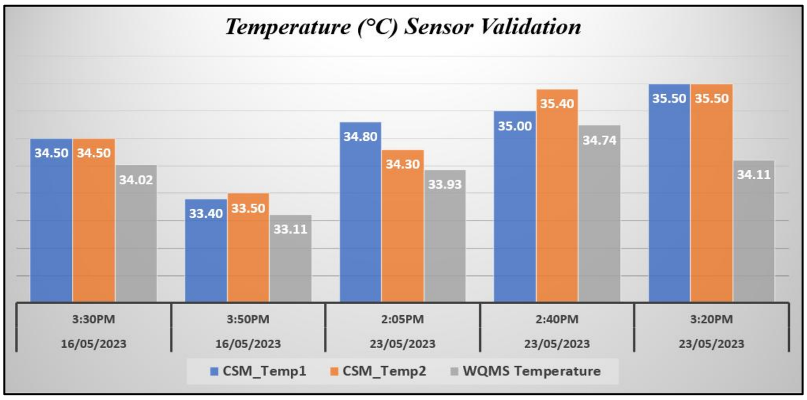



Figure 6. Temperature sensor validation data

b. Dissolved oxygen sensor

After comparing the data, it is seen that the DFROBOT Gravity: analog DO sensor continuously shows fewer errors concerning the borrowed DO sensor, demonstrating its greater accuracy in measuring DO data. The MAPE of the individual data points stands at 6.52%, 1.18%, 8.24%, 2.26%, and 1.06%, which means a mean percentage error of about 3.85%. Although there is some variation, this value indicates that the calibrated DO sensor provides reasonably accurate measurements, see Figure 7. Compared to previous research using a similar IoT-based approach for oxygen monitoring in aquaculture, which reported a higher average error of 14.65% with their DO sensor [36], our findings demonstrate a marked improvement in accuracy. This comparison highlights that our sensor calibration and data acquisition methods yield more precise results, further validating the reliability of the DFROBOT Gravity: analog DO sensor for real-time monitoring applications.

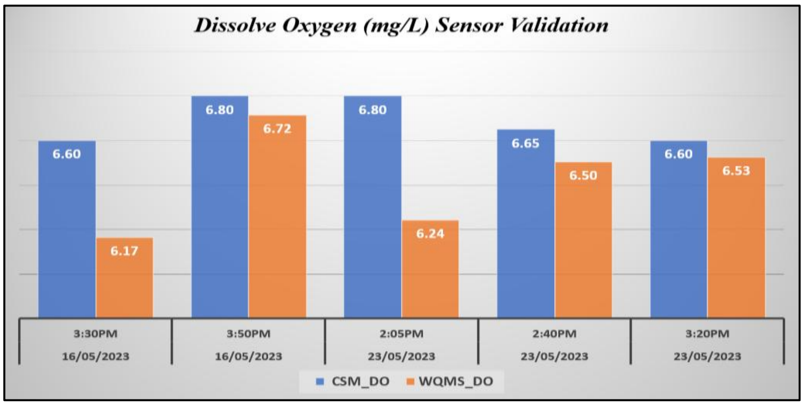



Figure 7. DO sensor validation data

c. pH sensor

DFROBOT Gravity: analog pH sensor demonstrated high reliability and accuracy in tilapia fish farming when compared with similar pH monitoring systems. The sensor exhibited consistently smaller percentage errors—0.80%, 0.40%, 1.36%, 1.37%, and 1.24%—and produced pH readings of 7.44, 7.46, 8.70, 8.87, and 8.95, resulting in an average error of approximately 1.03%, see Figure 8. This accuracy proved competitive with other research findings, where one IoT-based system reported an exceptionally low error rate of 0.29% [37]. However, compared to other implementations, such as an Arduino-based pH meter and a broader IoT framework for water quality monitoring with error rates of 1.25% [38] and 3.15% [39], respectively, the DFROBOT Gravity sensor in this study demonstrated superior precision. These results indicate that, overall, this research achieved better accuracy than most comparable studies, reinforcing the DFROBOT Gravity sensor's effectiveness as a reliable tool for real-time pH monitoring in aquaculture applications requiring consistent water quality management for optimal tilapia health and growth.

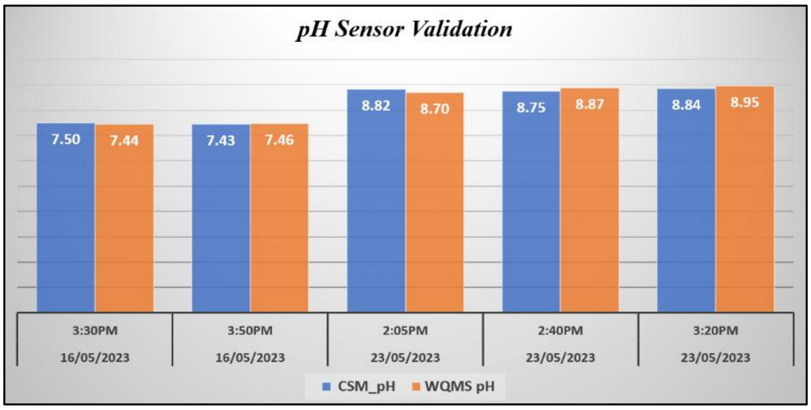



Figure 8. pH sensor validation data

d. Electrical conductivity

The DFROBOT Gravity: analog EC sensor demonstrates reliability and accuracy in monitoring EC for tilapia fish farming, achieving percentage errors of 2.76%, 2.76%, 1.38%, 1.38%, and 0.97% across respective data points, with EC readings of 2.81, 2.81, 2.85, 2.85, and 2.87, see Figure 9, resulting in an average error of approximately 1.85%. This low error rate underscores the sensor's effectiveness for precise conductivity measurements in aquaculture, especially when compared to an Arduino-based sensor device [40], which registered a higher maximum error of 3.723% for similar measurements.

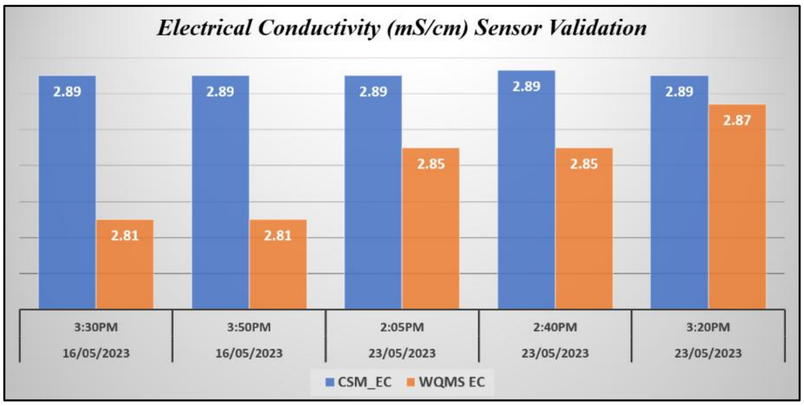



Figure 9. Electrical conductivity sensor validation data

### 4.3. Evaluation

Following the completion of the validation process and the confirmation of sensor accuracy, the system underwent an evaluation to gauge its acceptance among prospective users. This evaluation employed the TAM model [32], [33]. The underlying rationale behind TAM is to determine which factors regulate people's willingness to accept and use new technologies. The questionnaire was constructed to assess participants' attitudes in terms of their familiarity with the technology, usefulness, ease of use, and attitudes and intention towards it. These aspects are critical in assessing the likelihood of individuals adopting and using new technological solutions for water quality monitoring.

Table 2 shows the calculated mean score of 2.5 on the 1-5 scale, which means respondents' overall familiarity with the WQMS for fish farming would be slightly above “slightly familiar” and below “moderately familiar.” Therefore, most respondents would likely have some general knowledge of the system but possibly not in-depth knowledge or extensive experience using it. This measure indicates that the dispersion of the familiarity levels around the mean is moderate, and this would indicate a moderate degree of consistency between the respondents in their familiarity with the technology.

Table 2. Familiarity with technology from 10 master of science in environmental science respondents

| Item | Mean | Standard deviation | Responses: Extremely familiar | Very familiar | Moderately familiar | Slightly familiar | Not familiar at all |
|---|---|---|---|---|---|---|---|
| FWT1 | 2.50 | 1.02 | 0 | 3 | 0 | 6 | 1 |

The results in Table 3 suggested that the respondents considered the WQMS valuable and worth having for fish farming, as measured by the mean responses to PU1 as 4.1, PU2 as 4, PU3 as 4.3, and PU4 as 4.2. The system was believed to enhance the accuracy and reliability of water quality measurements, providing valuable information for improving farming practices, improving the efficiency of monitoring, and supporting overall productivity and profitability. This data, shown in Table 4, denotes that while the system was generally seen as user-friendly and easy to learn, there might be some concerns about the level of technical knowledge required to use it effectively. For PEOU1, the mean score was 3.9 and a relatively low standard deviation of 0.83, the PEOU2 has a mean score of 4 which is quite high and a 0.77 standard deviation, and lastly, the mean score of the PEOU3 was 3.5 and a standard deviation of 1.02.

Table 3. Perceived usefulness from 10 master of science in environmental science respondents

| Item | Mean | Standard deviation | Response | | | | |
|---|---|---|---|---|---|---|---|
| | | | Extremely familiar | Very familiar | Moderately familiar | Slightly familiar | Not familiar at all |
| POU1 | 4.10 | 0.54 | 2 | 7 | 1 | 0 | 0 |
| POU2 | 4.0 | 0.45 | 1 | 8 | 1 | 0 | 0 |
| POU3 | 4.3 | 0.46 | 3 | 7 | 0 | 0 | 0 |
| POU4 | 4.2 | 0.87 | 4 | 5 | 0 | 1 | 0 |

Table 4. Perceived ease of use from 10 master of science in environmental science respondents

| Item | Mean | Response | | | | | |
|---|---|---|---|---|---|---|---|
| | | Standard deviation | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
| PEOU1 | 3.90 | 0.83 | 2 | 6 | 1 | 1 | 0 |
| PEOU2 | 4.00 | 0.77 | 2 | 7 | 0 | 1 | 0 |
| PEOU3 | 3.50 | 1.02 | 2 | 3 | 1 | 2 | 2 |

Table 5 shows the attitude and intention data; the data has suggested that respondents generally have a positive attitude towards using the WQMS and have the intention to promote its use in their fish farming practices. For the AI1, the mean score was 4.3 and a relatively low standard deviation of 0.46. With that, most of the respondents not only agree but also have a positive attitude towards using the WQMS. Lastly for AI2, with the intention to promote the use of the system, the average score is also high (4.1 out of 5) but with a slightly higher standard deviation of 0.83.

Table 5. Attitude and intention from 10 master of science in environmental science respondents

| Item | Mean | Response | | | | | |
|---|---|---|---|---|---|---|---|
| | | Standard deviation | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
| AI1 | 4.30 | 0.46 | 3 | 7 | 0 | 0 | 0 |
| AI2 | 4.10 | 0.83 | 3 | 6 | 0 | 1 | 0 |

## 5. CONCLUSION

The research highlighted the monitoring of parameters such as pH, temperature, DO, and EC in maintaining optimal conditions for tilapia fish farming. The sensors found to be crucial for this purpose include DFRobot pH sensor meter analog Kit V2, DS18B20 temperature sensor module, DFRobot Dissolved Oxygen sensor meter kit, and DFRobot analog electrical conductivity. In addition, the utilization of ThingSpeak as an interface has proven highly suitable. With its mobile and web features, potential users can conveniently access real-time data, make informed decisions, and take timely actions. This water quality monitoring system provided acceptable measurements of temperature (with an average percentage error of 1.89%), DO (with an average percentage error of 3.85%), pH (with an average percentage error of 1.03%), and EC (with an average percentage error of 1.85%) during the sensor validation periods, ensuring high levels of accuracy and reliability in the context of tilapia fish farming. In addition, the successful recalibration, validation, and repeated measurement of the system prototype proves its precision and accuracy for water quality monitoring in tilapia fish farming conditions. These results confirm their usefulness in generating accurate measurements and useful information and thus contribute to tilapia fish farming activities.

Moreover, by utilizing the TAM model and involving stakeholders, this study has tested adopting the water quality monitoring system for tilapia aquaculture. The survey focused on perceived usefulness and ease of use yielded significant inputs for improving the system and increasing its usability. The individual results from the sensor testing and validation, complemented by the positive findings from the TAM survey, strongly suggest the system's effectiveness and readiness for deployment. Thus, based on these comprehensive assessments, the system is deemed suitable for deployment in its intended operational environment.

Subsequent research will enhance the tilapia fish culture water quality monitoring system through increased use of sensors for significant parameters and the employment of sophisticated data analytics in predictive modeling, hence widening the use of the system and improving management. Furthermore, the extension of stakeholder participation in the process of technology acceptance will further streamline the user interface and functionality of the system, ensuring versatility across different aquaculture settings and towards sustainable aquaculture.

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## AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this paper. They affirm that the research was conducted in the absence of any commercial, financial, or personal relationships that could be seen as a potential conflict of interest.

## INFORMED CONSENT

All participants were made aware of the purpose, scope, and confidentiality of the study prior to their involvement. In accordance with the Philippines Republic Act 10173 or the Data Privacy Act of 2012 and its Implementing Rules and Regulations, a privacy disclaimer was presented to ensure that all responses would be anonymized, aggregated, and used solely for research purposes. Participants voluntarily agreed to the collection and use of their responses, with the assurance that no personally identifiable information would be disclosed or shared with third parties.

## DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, R.Q.L., upon reasonable request.

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