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Development and evaluation of an Arduino-based multi-sensor aquaculture water quality monitoring kit

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Abstract

Fish farmers struggle with the problem of fish mortality due to climate change, poisoning, and bad water quality. Estimates on the mortality of fishes ranges from 60% to 80% depending on the type of fish. Traditional approaches in monitoring the quality of water such as observation or laboratory testing prove to be costly and time-consuming. This study aims to develop a portable water quality monitoring kit for fish farms. The device allows users to monitor the water's dissolved oxygen, nitrogen, total dissolved solids, turbidity, temperature, and pH level. It is powered by a rechargeable battery, uses an Arduino microcontroller, and has a real-time alert system. The device's limitations include the battery life and the sensors will need to be recalibrated at least monthly to ensure the accuracy of the readings. However, the results show that the implementation of the device garnered high acceptability in all parameters in the evaluation with a total mean rating of 4.66. This implies that the device can be used in monitoring the water quality in aquaculture sectors as corroborated by the respondent's evaluation. It is recommended to enhance the device by adding more water quality sensors and integrating Internet of Things (IoT) capabilities to further improve its functionality and reliability.

Keywords: *aquaculture, Arduino, water quality monitoring, sensors, real-time alerts*

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1. Introduction

The cultivation of fish, crustaceans, and aquatic plants in controlled conditions such as ponds and enclosures are known as aquaculture (White et al., 2018). Contributing to 53% of the local fishery production of the Philippines, aquaculture is a main source of income for farmers from provinces and cities alike (Ortega, 2021). But beneath this prosperous industry lingers an issue that threatens to kill the growing fish in farms; the persisting threat of bad water quality. According to Baleta et al. (2019), the primary causes of fish mortality in the Philippines are fluctuating temperatures, poor water quality, pollution, parasites, and diseases. An estimated 500,000 fish died in their cages in fish farms of Laguna de Bay, the largest aquaculture farm in the Philippines, due to climate change that encouraged the growth of algal blooms (Angeles, 2019). Likewise, 140 tons of tilapia were found dead in Lake Sebu, similarly, two other villages near it experienced the same fish kills due to bad weather and low dissolved oxygen (Rebollido, 2023).

Aquaculture is one of the thriving areas in many countries around the world since the demand for fish and fish-prepared food is growing by the day. The Philippines is one of the leading countries with an abundance of land and water resources, which leads to agriculture and animal culture. Since the country's population increase and climate change, the demand for food supply has rapidly increased, and the result has become a scarcity of natural resources depleting quickly (Natividad et al., 2023). Furthermore, aquaculture is one of the fastest food productions globally due to the numerous nutrients humans can acquire from eating aquatic foods. It addresses the consumption of humans to find a way to solve the issues of malnourishment and food security inside the country (Garlock et al., 2022), aquatic foods help people's health, especially for fetal neurocognitive development and adult cardiovascular health. It is a crucial part of establishing global food security and nutrition. Its positive impact on livelihood has made it a priority for countries to help enhance it (FAO, 2022). Compared to land animal breeding, the aquaculture industry is expanding quickly. As far as social and environmental sustainability, global food security, and animal welfare are concerned, the industry can still be guided on a positive path at this point. Simultaneously, the aquaculture industry has reached a stage where professionalization is required and regulations remain susceptible to influence. However, many fish farms continue to use the traditional method of monitoring water, which is to observe the water as well as the aquatic animals on their farms. The first method is when they assess the water's cleanliness. If the water is clear and transparent, it is said to be of good quality, whereas cloudy or turbid water indicates poor quality or, in some cases, toxicity. The other method is observing animal behaviors, such as whether they are active or healthy, which indicates that the water quality is good due to their comfort. If aquatic animals are sick, it means the water quality is poor, putting the animals' health at risk (Wang et al., 2021).

In the local province of Camarines Norte in the Philippines, the most commonly raised fish, especially in Mercedes area, are tilapia (Oreochromis mossambicus) and milkfish (Chanos chanos). Tilapia inhabit freshwater streams, lakes, rivers, and ponds; they are less common in brackish water. It is also the most farmed fish worldwide and has been known as the second most farmed fish worldwide over the past decade. Its production has quadrupled because of its suitability for a stable marketplace, marketability, and aquaculture (Prabu etl al., 2019). On the other hand, milkfish farming takes place in coastal lagoons, brackish water ponds, and even freshwater ponds. Milkfish farming contributes to local and global seafood production economies. It provides the community with a source of protein and essential nutrients. The advancement of technology and techniques on how to improve milkfish farming has been a big help in increasing its production (Jagdish, 2023). Regardless of the studies and programs implemented, there remains to be a challenge for the fish farm industry. According to Philippine aquaculture, fish farm industry has problem on fresh water while Cruz et al. (2019) cited climate change resulting to changing water temperatures. Poor fish farming practices are also a common problem, overfeeding and overstocking fishers has led to the deaths of countless fish due to lack of oxygen and toxic compounds such as ammonia, nitrite, and hydrogen sulfide (Guerrero et al., 2022). These factors, combined with the lack of available technologies and facilities to aid the raising of fish result to lower production.

Fishes depend on the water quality factors of the pond for their growth and survival. Masood et al. (2020) stated that improper management of pond water quality, especially when the fish are young, can cause stressful conditions that may lead to harmful diseases, which decreases the fish quality and results in low profits. Therefore, maintaining the quality of water is important in fish farming. Hence, this study seeks to investigate the utilization of technologies that can be readily integrated into fish farms of various sizes and resource capacities, as opposed to depending on their observation and on costly and intricate monitoring equipment. The researchers came up with the idea of making a rechargeable and portable water quality monitoring kit that has six Arduino-based sensors that can measure the different factors affecting the water quality of fish farms. The study aims to determine the efficiency and acceptability of the water quality monitoring kit to monitor the water quality of fish farms and help fish farmers monitor their water quality when raising their fish.

2. Literature Review

2.1 The aquaculture industry

The Philippines is in the top 15 aquaculture-producing countries in the world and is in the top 5 in Southeast Asia. In the world of aquaculture, there is no doubt that the Philippines has an important role in producing fish products (Soriano, 2022). In the aquaculture industry in the country, the most common products produced are milkfish, tilapia, shrimp, and seaweed (Tahiluddin, 2021). This coincides with the knowledge that the country consumed 34.27 kg of fish per year in 2019 (Fisheries Country Profile: Philippines – SEAFDEC, 2020). However, there are many problems faced when it comes to fish farming. According to Ahmed et al. (2019), water plays an important role in all aspects of our lives and its quality is deteriorating with ever-increasing pollution due to urbanization, industrialization, and population growth. Because fish live in fish ponds, the water quality can quickly decline (Towers, 2024). Hence, fish farmers need to know how to manage the water quality factors, needs of fish, and the quality of water such as - temperature, suspended solids, photosynthesis, oxygen, dissolved gasses, nitrogen, ammonia, pH, buffering system, alkalinity, and more.

According to Sallenave (2019), effective administration of a pond demands a deep understanding of the importance of nutrients and other elements related to water quality, along with the continuous observation of environmental conditions within the pond's ecosystem. Disregarding the water quality of fish farms can lead to many problems such as an abundance of algal growth, excessive proliferation of plants, unpleasant odors, or deceased and deteriorating fish. Similarly, water quality degradation has major effects on fish production (Nair & Nayak, 2023). Water pollution alters the chemical and physical qualities of the aquatic environment, affecting both water quality and fish populations. In addition, climate change can degrade the water quality of fish farms, resulting in bad health, and poor growth of fish (Gomes & Domingos, 2022; Guerrero & Fernandez, 2018).

According to Cline (2019), the commonly monitored factors in the aquaculture industry are temperature, dissolved oxygen, pH, alkalinity, hardness, ammonia, and nitrites. Maintaining balanced levels of water quality parameters is essential for farmed aquatic species' health and growth. Similarly, Moses (2023), emphasized that warm water is more productive, a pH range of 7 to 10 is preferred in fish culture and dissolved oxygen levels must be below 4 mg/l. In addition, temperature sensors play a vital role in monitoring water quality, offering crucial insights into temperature variations over time. Alison (2022) also emphasized it is important to monitor the dissolved oxygen and carbon dioxide of fish farms, which can be obtained using a carbon dioxide sensor called Gascard NG. Sensors can be used to measure dissolved oxygen (DO) levels, pH values, salinity, turbidity, and pollutant concentration (Su et al., 2020; Xing et al., 2019). Therefore, a monitoring kit offering different sensors is useful for checking the quality of water, especially fish ponds, rivers, and any water banks.

2.2 Water quality monitoring kit

To address the problem of water contamination in drinking water, Saritha et al. (2023) proposed a water quality monitoring device that uses the Arduino model as the main controller to keep track of the water's temperature, turbidity, and pH level. The results showed that the device supported the three parameters in monitoring the water quality and is more accurate and time-efficient than traditional methods. In a similar study, Jan and Min-Allah (2021) focused into common water-quality monitoring (WQM) parameters, their safe limits for drinking water, related smart sensors, critical review, and ratification of contemporary IoT-WQMS via a proposed empirical metric, analysis, and discussion and, finally, design recommendations for an efficient system, which concluded that the study benefit the developing field of smart homes, offices, and cities.

The use of Internet of Things (IoT) has also been explored in the development of water quality monitoring system. For instance, Ya'acob et al. (2021) used ultrasonic sensors, temperature sensors, and pH level sensors and found the device low-cost and portable, accurately measuring the factors affecting water pollution. On the other hand, Islam et al.

(2023) proposed an embedded system utilizing sensors or an Arduino microcontroller to help the fish farmers collect data from the water so they could decide whether the pond is suitable for cultivating fish or not. Hakimi and Jamil (2021) also developed a low-cost, practical water quality monitoring gadget with Internet of Things (IoT) capabilities for real-time monitoring using NodeMCU and the open-source Arduino UNO model board as the WiFi connection and microcontroller, respectively. Two senses, temperature and turbidity were chosen to be implemented in the Kolora meter's initial stages of growth. The study concluded that the surface water quality device possesses the ability to be used in real-time monitoring for the early detection of pollution. Meanwhile, Kumar et al. (2022) also developed an Arduino-based water quality sensor connected to WiFi that monitors pH, and turbidity, which can help improve water reservoirs and farms. Other researchers addressed the issue of water quality monitoring through the use of different systems such as an affordable surveillance buoy (Schmidt et al., 2018), sophisticated system with alerts set in the Arduino Mega 2560 Controller and an IoT-connected server (Rekha et al., 2020), and fuzzy-based expert system (Alfiqri, 2022; Molato, 2022). While all studies proved the efficacy of their programs and systems, Paul (2018) supported the traditional methodology of manual data sourcing and analyzed in the laboratory.

2.3 Theoretical framework

The device is supported by the Environmental Management Theory, the process of identifying, observing, and measuring the environmental conditions at a particular site or place through observational techniques and technologies such as wireless communications, sensors, and remote management software (Jones, 2022). The tools employed, the parameters chosen, and how the procedures are carried out differ substantially based on the use case. Being forward-thinking is essential to environmental sustainability because so many decisions have long-term effects on the environment (Sphera, 2022). Another theory is the Technology Acceptance Model (TAM), a widely-used theory in the field of information systems, which encourages users to embrace and use new technologies (De Camargo Fiorini et al., 2018). This model is particularly advantageous in understanding the factors that influence individuals to either adopt or oppose a particular technology.

3. Methodology

3.1 Research design

Engineering and developmental research is a type of academic research that seeks to systematically investigate knowledge related to engineering learning. This aims to provide and develop new inventions through the use of technology. Furthermore, engineering research differs from scientific research as it involves more intensive research, and requires professional competency, and analytical thinking skills. This enables engineers to contribute to the development or design of new products and technology to improve processes and systems that benefit society (Campana, 2022). The study applied this research design as it requires a problem-solving process to be concluded. Moreover, the study's goal is to develop a design and build kit to assist the fish farming community with their water quality issues. Hence, it followed procedures for conducting the research, creating the design, building the kit, and then testing the device to evaluate its efficiency. According to Simarro and Couso (2021), engineering education could improve students' learning in science and mathematics, which explains how it allows students to test their scientific knowledge and apply it to practical problems. Velarde (2019) agreed that engineering is what connects the disciplines, confirming its importance to STEM and the students it serves. The use of scientific knowledge and mathematics to develop, construct, and uphold technologies to find solutions to specific problems provide the development of an acceptable and efficient solution to address the problem. In terms of the evaluation of the kit, this study used quantitative research design, the gathering and examination of numeric data (Bhandari, 2023; Chaudhari, 2021).

3.2 System design

Figures two to five show the different perspectives of the water quality monitoring kit. The device is composed of multiple sensors to measure the different parameters contributing to the water quality of fish farms. The key features of the proposed device include:

***Real-time monitoring sensor*.** The device includes 7 sensors namely; pH level, dissolved oxygen, temperature, turbidity, total dissolved solids, and nitrogen. Each sensor is connected to a central LCD that displays the reading of the sensors in real time.

Figure 2

Front view of the device

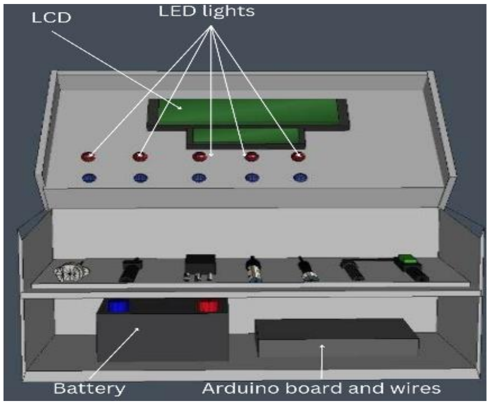


Figure 3

Top view of the device

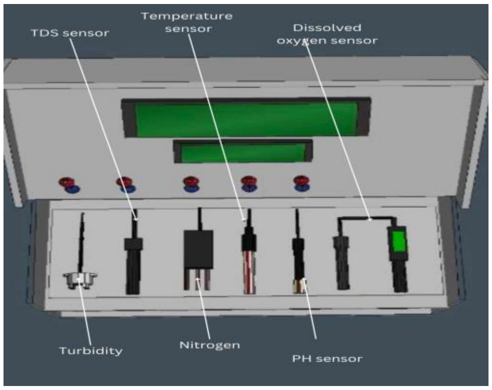


Figure 4

Back view of the device

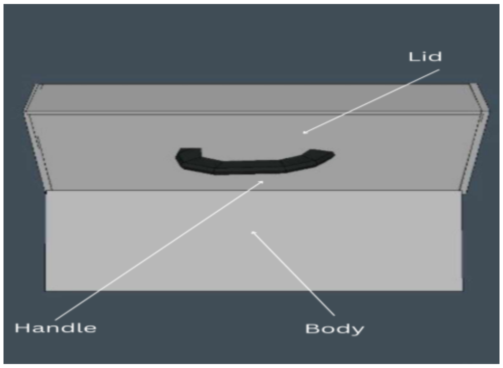
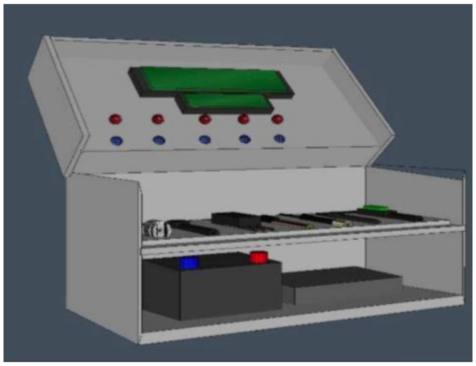


Figure 5

Side view (left)



***Light alerts*.** Each sensor is connected to an LED that will serve as an alert system. The light will light up red when the parameter is higher than normal, if the parameter is low then the LED will light up blue. When a parameter is within normal range the LED will not light up.

***Portable*.** All six sensors are placed in a small box to make carrying and storing easier.

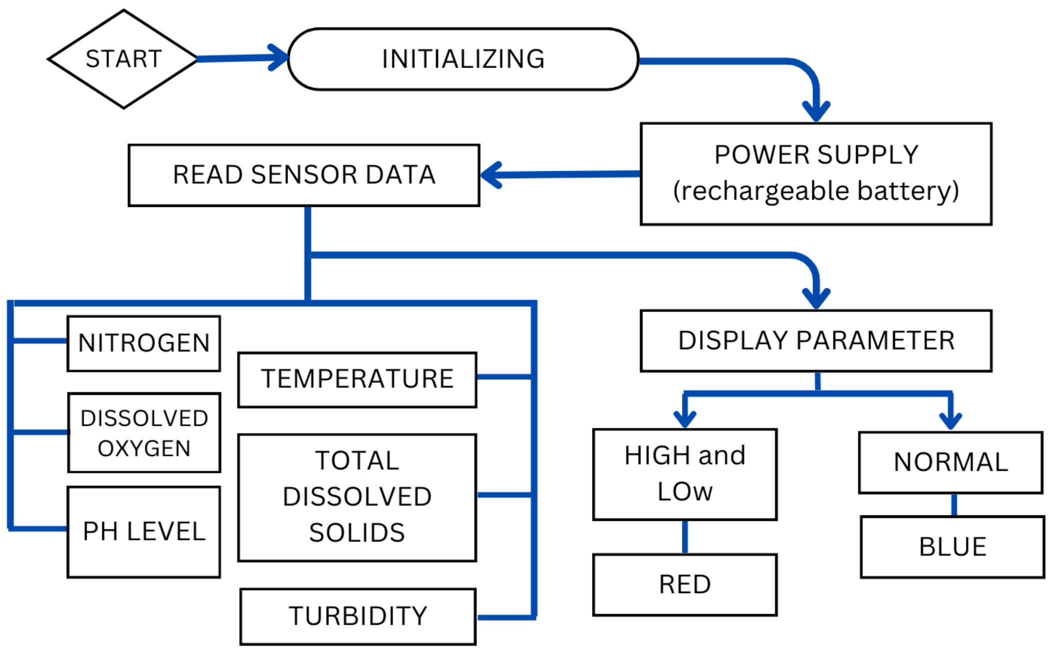
Rechargeable battery. The device will be powered by a rechargeable battery to ensure long battery life when the device is in use.

3.3 System Flow Chart

Figure 6 shows the system flowchart that describes how the water quality monitoring kit works from start to finish.

Figure 6

System flowchart



The monitoring and controlling of the water quality uses an Arduino-based device with various sensors. After initializing the device, it reads the data sensor for different parameters such as nitrogen, dissolved oxygen (DO), potential of hydrogen (pH) level, temperature, total dissolved solids (TDS), and turbidity (Tn). First, the nitrogen sensor measures the ammonia nitrogen content of water quality. Second, the dissolved oxygen sensor measures dissolved oxygen in water, it is responsible for the quality of water. Third, the potential of hydrogen (pH) sensor measures the acidity or alkalinity of the water. Fourth, the turbidity sensor monitors the amount of light that is dispersed by suspended solids in a liquid. Fifth, the temperature sensor shows the degree Celsius value of the temperature level in the LCD. Sixth, the total dissolved solid sensor is responsible for the monitoring of the dissolved combined content of all inorganic and organic substances that are in the water. If the value of each sensor goes relatively low the blue LED will be lit, meanwhile if the value of the sensors goes approximately too high the red LED will be lit. If the value of each sensor is at normal level both blue and red light will not be lit. All these sensor values are displayed on the LCD.

3.4 Materials and equipment

Phase I. Preparing and gathering the materials. The following are the materials and equipment used in the development of the water quality monitoring kit.

Materials: sensors, aluminum kit, dissolved oxygen sensor, paint, pH level sensor, paint primer, temperature sensor, bolts, turbidity sensor, aluminum sheets, total dissolved solids, locking mechanism, nitrogen sensor, hinges, Arduino Uno R3.

Equipment: Arduino Mega 2560 R3, wire stripers, jumper wires, pliers, LED lights, solder, 20 x 4 LCD display, welding machine, rechargeable battery, solderless breadboard, USB charging port and desoldering board.

Phase II. Assembly of Device. The part I involves the programming of the Arduino board.

1. Install Arduino IDE (Integrated Development Environment)

    a. For the simplest installation, select "Installer" from the download page.
    b. Store the executable file on your hard drive.
    c. Launch the executable file (.exe).
    d. To accept the licensing agreement, click the button.
    e. Select the components you want to add, then click "Next."
    f. After choosing the folder to install the application in, click "Install."
    g. Click "Close" when the software has finished installing.

2. Open the IDE for Arduino. When the folder has been unzipped, launch the Arduino IDE program. Double-clicking the Desktop‘s Arduino shortcut will accomplish this. The code editor shows as soon as the IDE opens.

3. Install the drivers, if necessary. As soon as the board connects, drivers will be installed automatically if the Installer has been utilized.

4. Use the USB cord to connect the board to the computer. Use a USB cable to connect the Arduino board to the computer to power it up. On the board, the green power LED ought to shine.

5. Choose the board. Confirm that the program is configured correctly for the Arduino board. Navigate via the menu bar to the "Tools" computer menu. In the "Board" option, a new menu will show up with the Arduino model listed to choose from.

6. Choose your serial port.

7. Launch the blink example. The first example is the Arduino IDE's LED Blink example, which can be found by going to File->Examples->Basics->Blink.

8. Transfer the program

9. Assembling of Arduino device. Attach the Arduino board that is programmed with sensors, and LED lights, and combine them with the battery

The part II involves building the aluminum kit.

1. Measure the needed height, width, and length of the kit based on the measurement of the components of the Arduino.

2. Measure and cut the pieces of aluminum sheets.

3. Weld the aluminum sheets together to make a box and cover.

4. Attach the box and cover together using hinges.

5. Make a separate floating compartment to house the sensors and place it inside the box.

6. Polish and finish the aluminum kit.

Part III involves combining the parts of the device.

1. The six sensors will be placed in the designated compartments.

2. The battery will be placed under the sensors with the boards and wires.

3. LED lights together with the sensors’ name tags will be placed on the cover of the kit.

Phase III. Prototype testing. The developed device was tested under two conditions. The first was the indoor water condition where the water was tested for its parameters using the prototype to ensure it is working correctly. The other was an outdoor field setting where the sample was from a fish pond to test the acceptability of the device.

Part IV. Troubleshooting. The water taken for the test is tap water filled in a container. The water was tested using the individual sensors of the kit to guarantee that the device is working properly.

Part V. Outdoor testing. Three fish farm enclosures were selected to assess their water quality. The researchers took a sample of the fish farm water in a container for device testing. Each sensor was placed in the water to test its water quality. The fish farm water was tested every 5 minutes for 30 seconds.

Phase VI. Evaluation. The respondents composed of ten (10) Bureau of Fisheries and Aquatic Resources employees, ten (10) fish farmers from Mercedes, Camarines Norte, five (5) students from the Bureau of Fishery, five (5) Information Technology students, five (5) Information Technologist, two (2) Electric Engineers, and three (3) Agricultural and Biosystem Engineers evaluated the device based on the evaluation sheet given. They were shown how the device is used and tested.

3.5 Sampling design

The sampling design used to collect samples was non-random purposive sampling. Purposive sampling is a non-probability sampling strategy and is a great tool that matches the objectives of the study, it will identify the pros and cons that could validate and will let the researchers know the consistency of the result (Thomas, 2022). The respondents of the study were particularly chosen due to their great knowledge of their respective fields. The fish farmers, DA employees, BFAR employees, BFAR students, and Agriculture Engineers were chosen for their understanding of agriculture, specifically aquaculture and fisheries. The Information Technologists and Electrical Engineers were chosen due to their expertise in the field of programming and electronics.

3.6 Instrumentation and data gathering

The evaluation tool to assess the rate of acceptability of the device used a 5-Likert scale ranges from 1 (not acceptable) to 5 (highly acceptable). The questionnaire was drafted by relating the questions to the indicators of the problem of the study. A panel of experts reviewed and validated the questionnaire. Before distributing, the researchers conducted a pilot testing to a smaller sample to ensure comprehension and understanding.

The researchers developed a device design, created the device, and completed the material acquisition process. To evaluate the study and device, experts provided the researchers with feedback and data to support and improve the study. This step involved the use of analytical tools for data analysis and interpretation. It also included a device demonstration to examine and evaluate its design, mechanism, functionality, usability, and cost-effectiveness.

3.7 Statistical analysis

A statistical tool is essential for data collection, analysis, and interpretation. This is one of the most important aspects of research as it provides researchers with accurate and reliable data (Sirisilla, 2023). This study used percentages, and weighted mean, attributing varying degrees of importance or influence to individual data points during the calculation of the overall average (Taylor, 2023).

3.8 Ethical consideration

Before the conduct of the study, the researchers obtained approval from fish farm owners to minimize the disruption of the fish while conducting the study. The researchers' priority is to engage with the locals and give full transparency when sharing the results of the study. Their commitment is placed in the endeavor of seeking the truth, avoiding destruction, and following the rules placed for environmental management and protection. Similarly, consent and permission were secured from relevant entities in the local government unit, Department of Agriculture, and Bureau of Fisheries and Aquatic Resources.

The study ensured that the respondents' personal information remain confidential and used for research purposes only. During the testing of the device in fish farms, the researchers used simple visuals and offer clarifications to help users understand the meaning of the data more easily. Similarly, the researchers pledged to openly communicate their results with all parties concerned before their publication. The water quality monitoring kit's data were available to the public, allowing a review of the research procedure.

4. Results and Discussion

4.1 Design of the fish farm water quality monitoring kit

The figures show the different perspectives of the water quality monitoring kit.

Figure 7

Front view of the device

Figure 8

Zoomed-in view of the device

Figure 9

Top view of the device

Figure 10

Back view of the device

Figure 11

Side view of the device (left)

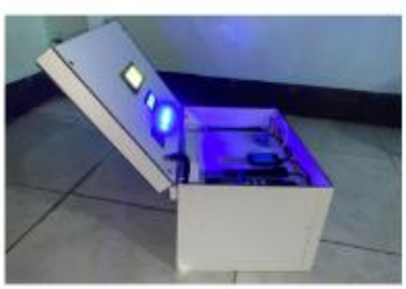


Figure 12

Side view of the device (right)

The figures show the different perspectives of the complete device of the water quality monitoring kit. It is made from white aluminum lined with an insulator to protect the wirings. It is composed of 6 sensors, for dissolved oxygen, nitrogen, TDS, turbidity, temperature, and pH level. The device is powered by a rechargeable 12 V battery and uses an Arduino Uno R3 as the microcontroller for the nitrogen sensor, and an Arduino Mega 2560 R3 for the remaining sensors. The device also uses a real-time alert system catered to the needs of fish farms, the LED lights will turn red if the parameter is higher or lower than the ideal water quality for fish.

4.2 Components of the device

Table 2

Materials, specifications, and cost of the device

Specifications/ Proportion	Components	Cost
1 pc DO9100	Dissolved Oxygen Sensor	1,000.00
1 pc PH-4502C	pH Level Sensor	800.00
1 pc RS485	Nitrogen Sensor	1,150.00
1 pc DFROBOT	Turbidity Sensor	200.00
1 pc AUMOTOP	Total Dissolved Solids Sensor	100.00
1 pc DS18B20	Temperature Sensor	150.00
1 pc Mega 2560 R3	Arduino	900.00
1 pc 20 X 4 (Yellow)	LCD Display	250.00
1 pc 12V 5AH	Battery	300.00
1 pc 5A-60W	Charging Adapter	150.00
10 pcs 5mm Red and Blue	LED Lights	100.00
1 box White Aluminum	Aluminum Kit	450.00
Total		**PHP 5,550**

Table 2 shows the materials and components of the device. The overall cost of the water quality monitoring kit is 5,550 pesos. This includes all six sensors which allow the kit to monitor the different water quality parameters, the aluminum kit which serves as the main structure of the kit, the electronics that will enable the various parts to function together, and other important parts of the device such as the battery that serves as the main power source and power adapter used to charge the kit.

4.3 Efficiency of the device

Detection and response speed. Each sensor was tested in tap water at 5-minute intervals for 30 seconds. The sensors were able to detect the change in water quality as soon as it touched the water. After 30 seconds, the sensors were able to provide consistent results with minimal changes.

Accuracy of response. Outdoor testing was conducted to test the device. This method was used to examine the functionality, accuracy, and capability of the device and its sensors in testing the water quality of fish farm waters. The outdoor testing data was gathered by testing all six sensors in 3 samples of fish farm water. Each sensor was tested 10 times within 5-minute intervals for 30 seconds. Table 3 shows each sensor's average measurements and standard deviation for the different fish farm water samples.

Table 3

Outdoor testing of sensors for fish farm 1

Trial	Dissolved Oxygen	Nitrogen	Total Dissolved Solids	Turbidity	Temperature	pH
1	4.7	46.3	490.00	747.00	35.94	8.37
2	4.9	46.3	491.00	752.00	35.81	8.35
3	4.7	46.3	491.00	745.00	35.81	8.35
4	4.9	46.3	489.00	750.00	35.56	8.34
5	4.8	46.3	488.00	750.00	35.5	8.35
Overall Mean	4.8	46.3	489.80	748.80	35.72	8.35
Standard Deviation	0.1	0	0	2.77	0.19	0.01

Based on the results of testing the different sensors in fish farm water, the measurements of the sensors are consistent on each trail. The sensors with the lowest standard deviation of 0 are nitrogen and total dissolved solids, this is the result of the measurements being so close together due to the nitrogen and TDS not changing every time it is measured.

The pH sensor comes close with a standard deviation of 0.01, the next two sensors are dissolved oxygen and temperature with 0.1 and 0.19, respectively. The sensor with the highest standard deviation is for turbidity with 2.77, implying that the measurements are spread apart from each other this can be because the particles of water tend to sink when it is at rest, and small movements can agitate the particles leading to bigger fluctuation of measurements.

Table 4

Outdoor testing of sensors for fish farm 2

Trial	Dissolved Oxygen	Nitrogen	Total Dissolved Solids	Turbidity	Temperature	pH
1	5.1	46.3	492.00	743.00	34.69	8.22
2	5	46.3	489.00	749.00	34.56	8.21
3	4.7	46.3	489.00	743.00	34.38	8.22
4	5	46.3	491.00	743.00	34.38	8.21
5	4.8	46.3	491.00	743.00	34.25	8.22
Overall Mean	4.92	46.3	490.40	744.20	34.45	8.22
Standard Deviation	0.16	0	0	2.68	0.17	0.01

The results of testing the sensors in the second fish farm sample revealed that the sensor with the highest standard deviation is for turbidity with 2.68; this can be interpreted that the particles in the water sink and rise with movement leading to inconsistent results. The sensors for dissolved oxygen and temperature had a low standard deviation of 0.16 and 0.17, respectively. The pH sensor also garnered a standard deviation of 0.01. Nitrogen and total dissolved solids sensors had the lowest standard deviation of 0 which implies that the measurements are so close to each other that there are almost no differences between them because the nitrogen and TDS of the water does not change.

Table 5

Outdoor testing of sensors for fish farm 3

Trial	Dissolved Oxygen	Nitrogen	Total Dissolved Solids	Turbidity	Temperature	pH
1	5.1	46.3	492.00	747.00	34.81	8.3
2	5	46.3	491.00	747.00	34.69	8.29
3	4.9	46.3	492.00	745.00	34.56	8.3
4	5.3	46.3	491.00	747.00	34.49	8.3
5	5	46.3	491.00	749.00	34.31	8.29
Overall Mean	5.06	46.3	491.40	747.00	34.57	8.30
Standard Deviation	0.15	0	0	1.41	0.19	0.01

Table 5 shows the mean and standard deviation of the measurements of the sensors within five trials. The sensors for nitrogen and total dissolved solids had a standard deviation of 0 which aligns to the fact that the nitrogen and total dissolved solids have consistent measurements. A standard deviation of 0.01 is given for the pH sensor. The measurements for dissolved oxygen (0.15) and temperature (0.19) are close to each other. The turbidity sensor had the highest standard deviation with 1.41, this can be explained by the movement of the particles in the water that results to different measurements, though high, the measurements are still similar to each other. Overall, the measurements of the sensors in all three samples are consistent and accurate. The standard deviation of each sensor is close in each sample. The sensor for turbidity may have the highest standard deviation, but the spread of its measurements is still near each other. The sensors for pH, dissolved oxygen, and temperature have low standard deviations, this means that all the measurements are close to each other. The standard deviation for nitrogen and total dissolved solids is 0, this implies that the deviations between the measurements are almost non-existent.

4.4 Rate of acceptability of the device

Table 6

Overall rate of acceptability of the Arduino-based multisensor aquaculture water quality monitoring kit

Criteria	Mean	Verbal Interpretation
A. System and Design	4.74	Highly Acceptable
B. Functionality and Mechanism	4.55	Highly Acceptable
C. Reliability and Accuracy	4.56	Highly Acceptable
D. Portability	4.74	Highly Acceptable
E. Usability	4.73	Highly Acceptable
Composite Mean	**4.66**	**Highly Acceptable**

Legend: Highly Acceptable (HA) - (5.00 - 4.51); Acceptable (A) - (4.50 - 3.51); Moderately Acceptable (MA) - (3.50 - 2.51); Fairly Acceptable (FA) - (2.50 - 1.51); Not Acceptable (NA) - (1.50 - 1.00)

The results of the study were similar to the findings of Schmidt et al. (2018), where they made a buoy system to monitor the water quality of small-scale fish farms. They proved that it is effective and can be a big help in monitoring the water quality of fish farms in local areas. Similarly, Harun et al. (2018) found that a water quality monitoring device is essential to maintain the quality of the water while being cost-effective because farmers need not hire workers to check on the water quality. However, Endut (2019) suggest that a water quality monitoring device integrated with IoT has been proven effective in limiting errors in monitoring using the traditional way while also saving manpower in monitoring the water quality. The overall ratings of the device were highly acceptable in terms of system and design (X=4.74), functionality and mechanism (X=4.55), reliability and accuracy (X=4.56), portability (X=4.74) and usability (X=4.73). These results are congruent with previous studies such as Paul (2018), Alfiqri (2022), Molato (2022), Ya'acob et al. (2021), and Islam et al. (2023).

5. Conclusion

The study reveals that the device is highly effective in monitoring crucial water parameters such as dissolved oxygen, nitrogen, total dissolved solids, turbidity, temperature, and pH level. The results demonstrate that the sensors provide consistent and accurate measurements, with low standard deviations indicating reliability. The device's system design and functionality were rated as highly acceptable by respondents, emphasizing its practicality and ease of use. However, several limitations were identified, including the need for regular sensor recalibration, the initial setup cost, and the requirement for technical expertise for maintenance and operation. Additionally, the device's performance across various environmental conditions and its ability to monitor a broader range of water quality parameters necessitate further testing. To address these issues, future studies should focus on a detailed cost-benefit analysis, the inclusion of additional sensors, the development of training programs for users, and extensive field testing under diverse conditions. These improvements are essential to enhance the device's practical applicability and ensure its adoption by small-scale and resource-limited fish farmers, thereby justifying the need for this study and its further development.

This study further shows that the device can provide an alternative way of accurately monitoring the water quality of fish farms without relying on manual testing, laboratories, or simple observation. However, it is recommended that to further improve the study, additional water quality sensors should be used as well as integration of Internet of Things (IoT) to help the device reach its full potential. Also subjecting the device to further testing, including comparative analysis in laboratory settings, would provide valuable insights into its performance across various conditions and ensure its robustness in real-world applications.

The evaluation of the respondents gave a few insights for improvement of the device. Hence, future researchers are encouraged to take account of the subsequent recommendations.

System and design. It was recommended to have separate switches for the sensors and use a bigger LCD to improve battery life. Using stronger wires and making the device waterproof were suggested to improve the device. An alternative power source such as renewable energy was recommended. The respondents also recommended adding more sensors such as salinity which is also important for fish.

Functionality and mechanism. Integration with IoT will allow the user to connect the device to an app or database that can be used for storing the data of the sensors to analyze trends in water quality

Accuracy and reliability. The respondents suggested testing the battery life for a few months and checking if the data measured by the sensors are still accurate.

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Appendices

Appendix A

Rate of acceptability of water quality monitoring kit for system and design

Description/Evaluation Parameters	Score 5	4	3	2	1	SD	Mean	Remarks
a. The sensors' schematic design was carefully planned to ensure optimal status.	32	6	2	0	0	0.54	4.75	HA
b. The device has a well-organized structure for efficiency in monitoring the water quality.	33	5	2	0	0	0.53	4.78	HA
c. The size and form of the kit are suited for deployment in aquaculture settings.	32	4	4	0	0	0.65	4.70	HA
d. The configuration and position of the parts of the device were designed to ensure all the parts will be used effectively.	30	9	1	0	0	0.50	4.73	HA
e. The layout, design, and materials of the kit are suitable for its use and are well-designed.	32	6	2	0	0	0.54	4.75	HA
WEIGHTED MEAN							**4.74**	**HA**

Legend**:** Highly Acceptable (HA) - (5.00 - 4.51) Acceptable (A) - (4.50 - 3.51) Moderately Acceptable (MA) - (3.50 - 2.51) Fairly Acceptable (FA) - (2.50 - 1.51) Not Acceptable (NA) - (1.50 - 1.00)

Appendix B

Rate of acceptability of water quality monitoring kit for functionality and mechanism

Description/Evaluation Parameters	Score 5	4	3	2	1	SD	Mean	Remarks
a. The sensor readings of the kit are accurate and reliable ensuring correct 4.data for water quality monitoring.	18	21	1	0	0	0.55	4.43	A
b. The kit can monitor the different parameters of the water quality of fish farms.	24	14	2	0	0	0.60	4.55	HA
c. The kit can be powered through a rechargeable battery that ensures long battery life on the electronic features.	27	11	2	0	0	0.59	4.63	HA
d. The real-time monitoring LCD provides a clear visual output of the data read by the sensors.	27	11	1	1	0	0.67	4.60	HA
e. The kit provides accurate alerts in dangerous levels of the parameters read by the sensor to help fish farmers monitor the water quality.	24	14	2	0	0	0.60	4.55	HA
WEIGHTED MEAN							**4.55**	**HA**

Legend: Highly Acceptable (HA) - (5.00 - 4.51) Acceptable (A) - (4.50 - 3.51) Moderately Acceptable (MA) - (3.50 - 2.51) Fairly Acceptable (FA) - (2.50 - 1.51) Not Acceptable (NA) - (1.50 - 1.00)

Appendix C

Rate of acceptability of water quality monitoring kit for reliability and accuracy

Description/Evaluation Parameters	Score					SD	Mean	Remarks
	5	4	3	2	1			
a. The sensors' measurement of the water quality accurately describes the parameters.	21	16	3	0	0	0.64	4.45	A
b. The measurements given by the sensor are consistent with minimal errors between tests.	21	17	2	0	0	0.60	4.48	HA
c. The sensors measure the water quality quickly in real time.	29	9	2	0	0	0.57	4.68	HA
d. The sensors can accurately detect even slight changes in water quality.	25	14	1	0	0	0.54	4.60	HA
e. The sensors do not malfunction or produce erroneous data.	24	15	1	0	0	0.55	4.58	HA
WEIGHTED MEAN							**4.56**	**HA**

Legend: *Highly Acceptable (HA) - (5.00 - 4.51) Acceptable (A) - (4.50 - 3.51) Moderately Acceptable (MA) - (3.50 - 2.51) Fairly Acceptable (FA) - (2.50 - 1.51) Not Acceptable (NA) - (1.50 - 1.00)*

Appendix D

Rate of acceptability of water quality monitoring kit for portability

Description/Evaluation Parameters	Score					SD	Mean	Remarks
	5	4	3	2	1			
a. The kit is easy to transport in different places without too much effort.	33	2	4	1	0	0.76	4.68	HA
b. The kit is easy to set up when used in fish farms.	35	2	2	1	0	0.66	4.78	HA
c. The components of the kit stay intact while being transported.	34	4	1	1	0	0.62	4.78	HA
d. The kit is comfortable to carry for extended periods.	33	4	2	1	0	0.68	4.73	HA
e. The kit can easily be stored in any space available.	33	5	1	1	0	0.63	4.75	HA
WEIGHTED MEAN							**4.74**	**HA**

Legend: Highly Acceptable (HA) - (5.00 - 4.51) Acceptable (A) - (4.50 - 3.51) Moderately Acceptable (MA) - (3.50 - 2.51) Fairly Acceptable (FA) - (2.50 - 1.51) Not Acceptable (NA) - (1.50 - 1.00)

Appendix E

Rate of acceptability of water quality monitoring kit for usability

Description/Evaluation Parameters		Score					SD	Mean	Remarks
		5	4	3	2	1			
a.	The user can exert minimal effort in using the device to monitor the water quality.	31	6	3	0	0	0.61	4.70	HA
b.	The kit's features are easy to navigate and are easy to understand.	32	7	1	0	0	0.48	4.78	HA
c.	The kit is easy to operate.	34	4	2	0	0	0.52	4.80	HA
d.	The kit requires minimal maintenance and repairs.	30	6	4	0	0	0.66	4.65	HA
e.	The kit allows water quality monitoring without the use of labs and expensive equipment.	30	9	1	0	0	0.50	4.73	HA
WEIGHTED MEAN								**4.73**	**HA**

Legend: Highly Acceptable (HA) - (5.00 - 4.51) Acceptable (A) - (4.50 - 3.51) Moderately Acceptable (MA) - (3.50 - 2.51) Fairly Acceptable (FA) - (2.50 - 1.51) Not Acceptable (NA) - (1.50 - 1.00)

References

Ahmed, U., Mumtaz, R., Anwar, H., Mumtaz, S., & Qamar, A.M. (2019). Water quality monitoring: from conventional to emerging technologies. *Water Science & Technology: Water Supply*, *20* (1), 28–45. https://doi.org/10.2166/ws.2019.144

Alfiqri, F. (2022). Microcontroller-based water quality monitoring system implementation. *Brilliance*, *2* (2), 53–57. https://doi.org/10.47709/brilliance.v2i2.1544

Alison (2022). *Aquaculture sensors for fish farming, water quality sensors*. Edinburgh Sensors. https://edinburghsensors.com/news-and-events/water-quality-in-fish-farming/

Angeles, L.J. (2019). *Seasonal fish kill incident leaves thousands of unprofitable commodity fish in Laguna de Bay*. University of the Philippines Diliman. https://rb.gy/a4599f

Baleta, F.N., Bolaños, J.M. & Medrano, W.C. (2019). Assessment of tilapia cage farming practices in relation to the occurrence of fish mortality along the fish cage belt at Magat Reservoir, Philippines. *Journal of Fisheries and Environment*, *43* (2). https://fish.ku.ac.th/pdf/Journal%20vol.43%20(2)/vol.43%20(2)-1.pdf

Bhandari, P. (2023). *What is quantitative research*? Definition, uses & methods. https://www.scribbr.com/methodology/quantitative-research/

Bureau of Fisheries and Aquatic Resources (2020). *Philippine fisheries profile*. https://www.bfar.da.gov.ph/wp-content/uploads/2022/02/2020-Fisheries-Profile-Final.pdf

Campana, N. (2022). *What does a research engineer do*? https://www.freelancermap.com/blog/what-does-research-engineer-do/

Chaudhari (2021). *What is a true experimental design*? Voxco. https://www.voxco.com/blog/true-experimental-design/

Cline, D. (2019). *Water quality in aquaculture- freshwater aquaculture*. Freshwater Aquaculture. https://freshwater-aquaculture.extension.org/water-quality-in-aquaculture/

Cruz, R.A.L., Kumar, V., & Ragaza, J. (2019). *Some current trends and challenges in Philippine aquaculture, with an emphasis on synergies with biodiversity initiatives* (pp. 35-42). World Aquaculture. https://archium.ateneo.edu/cgi/viewcontent.cgi?article=1052&context=biology-faculty-pubs

Endut. N.A., Fo'ad, M.F.M., Azam, N.A.A., Othman, N.A.A., Abdul Aziz, S.R. & Abdullah Sani, A.S. (2019). Real-time water monitoring system for fish farmer using Arduino. *Journal of Advanced Research in Computing and Applications*, 14(1), 10-17.

FAO (2022). *The state of world fisheries and aquaculture 2022*. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0461en

Fiorini, P.D., Seles, B.M.R., Jabbour, C.J.C., Mariano, E.B. & Jabbour, A.B.L. (2018). Management theory and big data literature: From a review to a research agenda. *International Journal of Information Management*, *43*, 112-129. https://doi.org/10.1016/j.ijinfomgt.2018.07.005

Freshwater-Aquaculture (2019). *Water quality in aquaculture – freshwater aquaculture*. https://freshwater-aquaculture.extension.org/water-quality-in-aquaculture

Garlock, T., Asche, F., Anderson, J., Ceballos-Concha, A., Love, D.C., Osmundsen, T.C. & Pincinato, R.B.M. (2022). Aquaculture: The missing contributor in the food security agenda. *Global Food Security, 32*, 100620. https://doi.org/10.1016/j.gfs.2022.100620

Gomes, G. & Domingos, J. (2022). *Water quality: The key to producing more fish sustainably*. https://www.sfa.gov.sg/food-for-thought/article/detail/water-quality-the-key-to-producing-more-fish-sustainably

Guerrero, R.D., Rasco, E.T., & Aliño, P.M. (2023). Developing Philippine coastal and oceanic aquaculture for food security and livelihoods generation. *Transactions National Academy of Science & Technology Philippines*, 40(2), 351-358. https://doi.org/10.57043/transnastphl.2018.1082

Guerrero, R.D., & Fernandez, P.R. (2018). Aquaculture and water quality management in the Philippines. In: Rola, A., Pulhin, J., Arcala Hall, R. (eds) *Water Policy in the Philippines*. Global Issues in Water Policy, vol 8. Springer, Cham. https://doi.org/10.1007/978-3-319-70969-7_7

Hakimi, M. & Jamil, Z. (2021). Development of water quality monitoring device using Arduino UNO. *IOP Conference Series: Materials Science and Engineering*, *1144* (1), 012064. https://doi.org/10.1088/1757-899x/1144/1/012064

Harun, Z., Reda, E. & Hashim. H. (2018). Real time fish pond monitoring and automation using Arduino. *IOP Conference Series. Materials Science and Engineering*, 340, 012014. https://doi.org/10.1088/1757-899x/340/1/012014

Islam, M.M., Kashem, M.A., Alyami, S.A. & Moni, M.A. (2023). Monitoring water quality metrics of ponds with IoT sensors and machine learning to predict fish species survival. *Microprocessors and Microsystems, 102*, 104930. https://doi.org/10.1016/j.micpro.2023.104930

Jagdish (2023). *Milkfish farming in the Philippines: a comprehensive guide*. https://www.asiafarming.com/milkfish-farming-in-the-philippines-a-comprehensive-guide

Jan, F., Min-Allah, N. & Düştegör, D. (2021). IoT-based smart water quality Monitoring: recent techniques, trends, and challenges for domestic applications. *Water, 13* (13), 1729. https://doi.org/10.3390/w13131729

Jones, Q. (2022). *What is environmental monitoring*? https://www.digi.com/blog/post/what-is-environmental-monitoring

Kumar. S.S., Subba Rao, B.V. & Prasad, J.R. (2022). Design and development of a water quality monitoring system by using IoT. *International Journal of Emerging Trends in Engineering Research, 8* (9) http://www.warse.org/IJETER/static/pdf/file/ijeter245892020.pdf

Masood, Z., Hasan, Z., Gula, H., Zahid, H., Hassan, H.U., Sultane, R., Khan, W., Safia, Titush, K. & Ullah, A. (2023). Monitoring pond water quality to improve the production of Labeo rohita (Hamilton, 1822) in Bannu Fish Hatchery of Bannu district, Khyber Pakhtunkhwa province; An Implications for artificial fish culture. *Brazilian Journal of Biology, 83*. https://doi.org/10.1590/1519-6984.245197

Molato, M.R.D. (2022). AquaStat: An Arduino-based water quality monitoring device for fish kill prevention in tilapia aquaculture using fuzzy logic. *International Journal of Advanced Computer Science and Applications, 13* (2). https://doi.org/10.14569/ijacsa.2022.0130265

Moses, M. (2023). *Factor affecting fish farming: water parameters and pre-stocking management.* https://www.bivatec.com/blog/required-parameters-for-water-quality-management

Nair, N.V. & Nayak, P.K. (2023). Exploring water quality as a determinant of small-scale fisheries vulnerability. *Sustainability*, 15, 13238. https://doi.org/10.3390/su151713238

Natividad, A.N., Miranda, C., Valdoria, J.C. & Balubal, D. (2023). An IOT-based pH level monitoring mobile application on fishponds using a pH sensor and waterproof temperature sensor. *Journal for Educators, Teachers, and Trainers, 14* (3) https://doi.org/10.47750/jett.2023.14.03.091

Ortega, R.C. (2021). *Trends in the major aquaculture food fish production in the Philippines*. https://www.fao.org/fishery/ru/openasfa/85a2ca04-ccd3-43c6-99ae-99c49a49981d

Paul, B. (2018). *Sensor-based water quality monitoring system*. Thesis. http://hdl.handle.net/10361/10840

Prabu, E., Rajagopalsamy, C.B.T., Ahilan, B., Jeevagan, I.J.M.A. & Renuhadevi, M. (2019). Tilapia – an excellent candidate species for world aquaculture: A review. *Annual Research & Review in Biology*, 31 (3), 1-14. https://doi.org/10.9734/arrb/2019/v31i330052

Rebollido, R. (2023). *Fish kill hits Lake Sebu, tilapia raisers lose P10M*. https://www.rappler.com/nation/mindanao/fish-kill-lake-sebu-tilapia-raisers-lose-millions-january-2023/?fbclid=IwAR3Bxp6s9s1B8tSwAJayUi4f3QV08HQYnC6DYRYPjtDSe80d3AIkeAuqlmk

Rekha, P., Sumathi, K., Samyuktha, S., Saranya, A., Tharunya, G., & Prabhaet, R. (2020). Sensor-based waste water monitoring for agriculture using IoT. *International Conference on Advanced Computing and Communication Systems*, 436-439. https://doi.org/10.1109/ICACCS48705.2020.9074292

Sallenave, R. (2019). *Understanding water quality parameters to better manage your pond*. https://pubs.nmsu.edu/_w/W104/index.html

Saritha, G., Ishwarya, R., Saravanan, T., Saye Sudarshana, P.A. & Sowmiya, S. (2023). Water monitoring system using IoT. *Eighth International Conference on Science Technology Engineering and Mathematics (ICONSTEM)*, 1-5 https://doi.org/10.1109/ICONSTEM56934.2023.10142890

Schmidt, W., Raymond, D., Parish, D., Ashton, I.G.C., Miller, P.I., Campos, C.J.A. & Shutler, J.D. (2018). Design and operation of a low-cost and compact autonomous buoy system for use in coastal aquaculture and water quality monitoring. *Aquacultural Engineering*, *80*, 28–36. https://doi.org/10.1016/j.aquaeng.2017.12.002

Simarro, C. & Couso, D. (2021). Engineering practices as a framework for STEM education: a proposal based on epistemic nuances. *International Journal of STEM Education, 8* (1). https://doi.org/10.1186/s40594-021-00310-2

Sirisilla, S. (2023). *Bridging the gap: Overcome these 7 flaws in descriptive research design*. Enago Academy. https://www.enago.com/academy/descriptive-research-design/

Soriano, V.A. (2022). *Aquaculture production in the Philippines*. https://www.veterinariadigital.com/en/articulos/aquaculture-production-in-the-philippine

Sphera. (2022). *What is environmental sustainability*? https://sphera.com/glossary/what-is-environmental-sustainability/

Su, X., Sutarlie, L. & Loh, X.J. (2020). Sensors, biosensors, and analytical technologies for aquaculture water quality. *Research, 2020.* https://doi.org/10.34133/2020/8272705

Tahiluddin, A.B. & Terzi, E. (2021). An overview of fisheries and aquaculture in the Philippines. *Journal of Anatolian Environmental and Animal Sciences, 6* (4), 475-486. https://doi.org/10.35229/jaes.944292

Taylor, S. (2023). *Weighted mean*. Corporate Finance Institute. https://corporatefinanceinstitute.com/resources/data-science/weighted-mean/

Thomas, B. (2022). The role of purposive sampling technique as a tool for informal choices in a social science research methods. *Just Agriculture Multidisciplinary E-Newsletter, 2* (5). https://www.scirp.org/reference/referencespapers?referenceid=3503967

Towers, L. (2021). *Water quality: a priority for successful aquaculture*. The Fish Site. https://thefishsite.com/articles/water-quality-a-priority-for-successful-aquaculture

Velarde, J. (2020). *Why is engineering important in STEM*? STEMCadia. https://stemcadia.com/why-is-engineering-important

Wang, C., Li, Z., Wang, T., Xu, X., Zhang, X. & Li, D. (2021). Intelligent fish farm—the future of aquaculture. *Aquaculture International*, *29* (6), 2681–2711. https://doi.org/10.1007/s10499-021-00773-8

White, P.G., Shipton, T.A. Bueno, P.B. & Hasan, M.R. (2018). *Better management practices for feed production and management of Nile tilapia and milkfish in the Philippines*. Food and Agriculture Organization of United Nations.

Xing, Q., An, D., Zheng, X., Wei, Z., Wang, X., Li, L., Tian, L. & Chen, J. (2019). Monitoring seaweed aquaculture in the Yellow Sea with multiple sensors for managing the disaster of macroalgal blooms. *Remote Sensing of Environment*, *213*. https://doi.org/10.1016/j.rse.2019.111279

Ya'acob, N., Dzulkefli, N.N.S.N., Yusof, A.L., Kassim, M., Naim, N.F. & Aris, S.S.M. (2021). Water quality monitoring system for fisheries using Internet of Things (IoT). *IOP Conference Series: Materials Science and Engineering, 1176.* https://doi.org/10.1088/1757-899x/1176/1/012016