A LOW-COST INTELLIGENT AQUACULTURE MANAGEMENT SYSTEM FOR SUSTAINABLE FISHERIES MANAGEMENT

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DECLARATION

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I hereby declare that this final year research project is the result of my own work, except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

Aquaculture is a viable way for Zambia to fulfil the increasing demand for fish, however conventional approaches don't have effective monitoring systems. For small-scale farmers, this makes it more difficult to diagnose diseases, manage resources properly, and adopt sustainable techniques. This research suggests utilizing Arduino and the Internet of Things (IoT) to create an inexpensive, intelligent aquaculture management system. By facilitating real-time data analysis and water quality monitoring, this system seeks to address these issues and eventually advance sustainable fisheries management in Zambia.

Keywords: Low-cost, Intelligent, Aquaculture, Sustainable Fisheries, IoT

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THANK YOU.

DEDICATION

I would like to take this opportunity to express my gratitude and appreciation to my family and friends who support and guide me in anything I do. I am grateful for their unfailing support and encouragement. This accomplishment would not have been possible without them.

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LIST OF ABBREVIATIONS

GDP: Gross Domestic Product

IoT: Internet of Things

DoF: Department of Fisheries

MIS: Management Information System

MCU: Microcontroller Unit

USB: Universal Serial Bus

LCD: Liquid Crystal Display

TDS: Total Dissolved Solids

DO: Dissolved Oxygen

SDLC: Systems Development Life Cycle

CAGR: Compound Annual Growth Rate

ppm: Parts Per Million

CHAPTER 1

INTRODUCTION

1.1 Background to The Study

According to (Avadí et al., 2022) in Zambia, fish is an important source of food, and money but unlike in the past, catch fisheries are no longer able to supply the country's fish needs. Due to shortages in supply, Zambia was able to grow its aquaculture industry and become one of the continent's top producers of farmed fish (Tilapia).

Aquaculture, sometimes referred to as aqua farming, is a technique used to replenish natural stocks, restore habitat, and increase food production in addition to rebuilding populations of threatened and endangered species. Rural farmers in poor countries use aqua farming as a means of supplying food. Aquaculture can also be defined as the care and farming creatures under semi-controlled settings. This phrase describes the production of freshwater and marine species in cages or on land, including both types of cultivation. In Zambia, ponds, dams and cages are used for aquaculture fish production (Abinaya. et al., 2019). The idea of sustainability has become more popular in the seafood sector, fundamentally altering it (Belton et al., 2009).

Over the past few decades, the production of feed has increased in tandem with the fastest-growing food producing industry, aquaculture. It is essential to many developing nations' ability to maintain livelihoods and nutritional security.(*The-Aquaculture-Sub-Sector-in-Zambia-Challenges-and-Opportunities.Pdf*, n.d.) mentions that because it provides opportunities for better nutrition, income production, and job development all of which lead to the establishment of general prosperity and food security at the national and household levels- the fisheries subsector in Zambia is important to the country's economy. According to the second agricultural policy of 2016, the national Gross Domestic Product (GDP) is contributed by the fisheries sub-sector by about 3.2%. The subsector of fisheries has been recognized as a means of promoting agriculture and overall economic diversification by means of improved and effective capture fisheries and fish, owing to Zambia's copious water resources. (S et al., 2017) mentions that the country's fish supply particularly tilapia has increased as a result of Zambia's recent boom in aquaculture. Currently, Zambia sources 20% of its seafood from aquaculture that is produced there.

(Stickney & III, 2022) the subsector of fisheries is recognized as one that can supply extra protein at the home level. In addition to other foods like crops and cattle, fish makes up over

40% of the protein consumed in rural areas. In order to increase food security, revenue generation, and nutrition levels, this sector is essential. In certain regions of the nation, fishing is a source of revenue for households, and as such, the fisheries industry plays a role in household income generation.

The goal of this research project is to connect an IOT-based aquaculture monitoring and control system using an Arduino. The system's primary function is to let users manage and watch over their aqua farms from anywhere at any time using a database server. With the aid of sensors, the quality of the water is regularly checked to guarantee the survival and expansion of aquatic life. The productivity is increased by the temperature control system. This approach allows for the timely adoption of preventive actions, which reduces the risk of casualties and boosts output (Stickney & III, 2022).

1.2 Problem Statement

The wellbeing of marine ecosystems and the livelihoods of millions of people who depend on them are threatened by overfishing and unsustainable practices. The carefully managed breeding of aquatic species, or aquaculture, is a viable substitute to satisfy this need and lessen the strain on wild stocks. However, there are numerous obstacles that prevent traditional aquaculture techniques from being sustainable and scalable (Department, 2022).

A significant obstacle is the deficiency of affordable and easily navigable monitoring solutions. Many small-scale farmers cannot afford or utilize the specialist knowledge and difficult operation of existing options. Making educated decisions is hampered by the lack of up-to-date information on fish health, environment conditions, and water quality, which can result in:

- Ineffective resource management: When farmers overfeed fish, they squander resources and contaminate the water more.
- Delayed disease detection: In the absence of ongoing surveillance. Epidemics may get unreported until they have resulted in considerable financial losses and raised issues with animal welfare.
- Unsustainable practices: Degradation of the ecosystem and decreased farm productivity can result from ineffective water management and a lack of real-time knowledge.

According to (Maulu et al., 2019) Zambia is a landlocked nation with a total surface area of 752,624 km^2 that is situated in southern Africa. The nation offers an abundance of freshwater resources and terrain that are ideal for aquaculture production. An essential 8 million hectares of wetlands and 15million hectares of water in the form of rivers, lakes and swamps make up Zambia's vast natural resources, which serve as the foundation for the growth of the aquaculture sector. Zambia's soil, water availability, and temperature range have all been deemed favourable for aquaculture, particularly regarding Tilapia species. Zambia's aquaculture industry has grown quickly in recent years, and it is probably going to have a big impact on the nation's food and nutrition security. Nevertheless, a number of obstacles have prevented the business from adequately meeting the growing demand for fish, the most significant of which is the inability to procure and produce high-quality fish feed and seed. Over time, there has been a noticeable increase in aquaculture production, which has been mostly ascribed to the rise of large-scale commercial aquaculture producers from the private sector. According to recent estimates from the Zambian Department of Fisheries (DoF), aquaculture produced roughly 32,888 tonnes of fish, or 27% of the country's total fish production in 2017 as shown in the figure below.

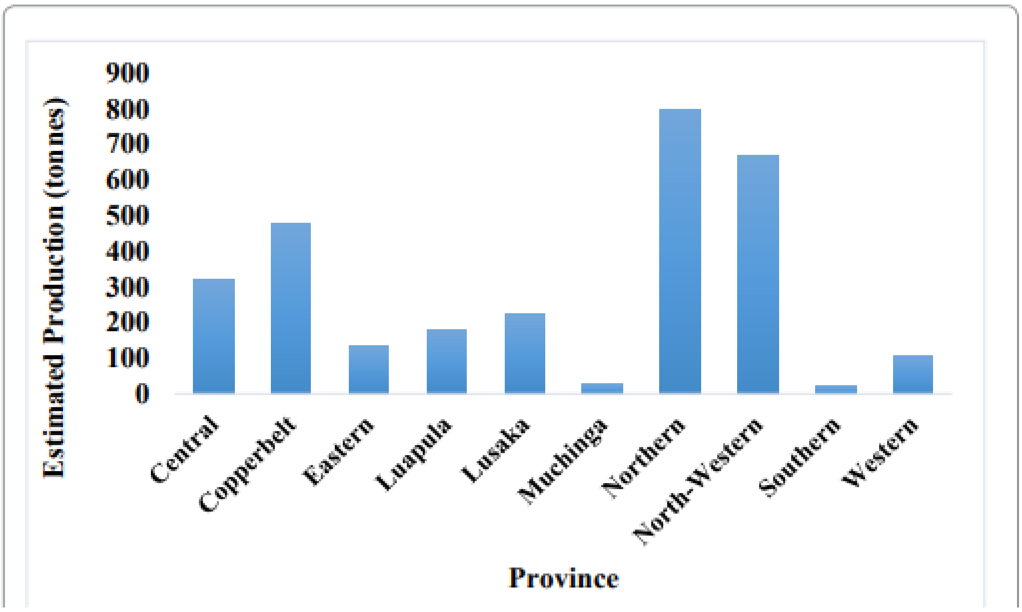

Figure 1.1 Distribution of small-scale production in Zambia

However, in 2014, it was estimated that there was a 45,000-ton national fish deficiency. In order to close the gap, scientific and technological advancements must be made to enhance present aquaculture practices and implement new technologies to increase productivity in a sustainable manner.

Creating an intelligent and affordable aquaculture monitoring system is crucial to addressing these issues and advancing sustainable fisheries management. Such a system can enable farmers to maximize resource use, enhance fish health and reduce environmental impact by offering accessible and reasonably priced tools for real-time data collecting and analysis. This will ensure the aquaculture industry's long-term profitability and protect the health of our seas, paving the way for a more responsible and sustainable future.

1.3 Aim

The aim of this research project is to develop a low-cost intelligent aquaculture management system for sustainable fisheries management.

1.3 Objectives of The Study

The objectives of the study are as follows:

1. To determine the prevalent conditions required for sustainable fish development and associated challenges.
2. To develop an Arduino based model for IoT aquaculture.
3. To create the IoT intelligent system, affordable and user-friendly IoT aquaculture monitoring control system.
4. To automatically gather and analyse real-time data for analysis of water quality for effective efficient management.

1.4 Research Questions

Below are the research questions:

1. Which particular water quality parameters are essential to the well-being and development of the many fish species that are frequently raised in Zambia?
2. In comparison to current techniques, how successful is a low-cost Arduino-based model in monitoring important water quality metrics for small-scale IoT aquaculture systems in Zambia?
3. How can we design a user-friendly Arduino system in Zambia that is easy to use for people with no technical background?
4. In Zambian aquaculture situations, how can real-time data on water quality metrics be examined to find early indicators of possible disease outbreaks or environmental problems affecting fish health?

1.5 Scope and Limitation

This research project is focused on small scale farmers or start-ups who are not able to afford expensive equipment for the types of detections that are being focused on for this particular research. The goal is to create and deploy an intelligent, user-friendly, and reasonably priced monitoring system that is especially intended for small-scale aquaculture farms. The system will focus on:

- Monitoring key elements: water quality such as temperature, tds levels and pH levels. These can give real-time information about how well the aquatic ecosystem is doing.
- Data transmission and gathering: By using affordable sensors and communication protocols, information is gathered and safely sent to a central platform.
- Data analysis and visualization: using fundamental data analytics and technologies to convert gathered information into insights that can be put into practice and display them in ways that are easy for farmers to understand.
- Optional features: depending on project viability and resource availability, investigating the possibility of incorporating fundamental automation elements as aeration control based on real-time data and automated feeding systems.

The system will give priority to accessibility and simplicity for users with different degrees of technical skill.

The following are the limitations;

- Prioritize key parameters: The first iteration will concentrate on the most important aspect of water quality, with the option to add more sensors later on to meet specific requirements.
- Limited automations: Although the initial scope maybe not include elaborate control mechanisms due to probable costs and technical issues, basic automation elements may be investigated.
- Limitations on scalability: The original design may have been tailored for small-scale farms, necessitating additional study and modification for larger scale uses.

It is crucial to recognize that this project is only the beginning. As technology advances and user feedback is considered, subsequent iterations of the project can build upon the original foundation to overcome restrictions and introduce more advanced functions.

1.6 Significance of the Project

Small-scale aquaculture farmers face significant hurdles due to restricted availability to reasonably priced and easily navigable monitoring equipment, which our initiative directly addresses. In addition to impeding sustainable practices, this absence of real-time data also causes environmental deterioration, ineffective resource management, and delayed illness detection (Mahmoud et al., 2023).

This initiative gives farmers the tools they need to maximize resource utilization, enhance fish health, and reduce their environmental effect by offering an affordable and easily available monitoring system. This ensures the aquaculture industry's long-term survival and safeguards the condition of our rivers and lakes, all while contributing to the industry's overall sustainability.

This project's emphasis on gathering and analysing data in real-time provides Zambian farmers with the knowledge they need to optimize their aquaculture operations. This helps to lessen environmental impact, boost profitability, and raise production.

This project makes extensive use of the Arduino platform, which is renowned for being accessible and reasonably priced. This is in line with the objective of giving small-scale farmers, who frequently lack the funds for pricey monitoring systems, an affordable option.

Through an exploration of the possibilities for easily accessible and user-friendly Internet of Things-based monitoring systems, this project advances the field of aquaculture. The results of the study can offer insightful information for these technologies' continued development and improvement, encouraging a wider usage in the aquaculture sector (Abinaya. et al., 2019).

The goal of this project is to create and put into place a system that will gather data on water quality metrics in real time. Understanding sensor integration, data collecting strategies, and data storage practices are necessary for this. Analysing the data gathered to spot trends and decipher its implications for farm management is another aspect of this project. This calls for expertise in anomaly detection, data visualization and converting data analysis into insights that Zambian small-scale farmers can use.

1.7 Preliminary Sections of The Project Report

Below is a chat of sections of the research project:

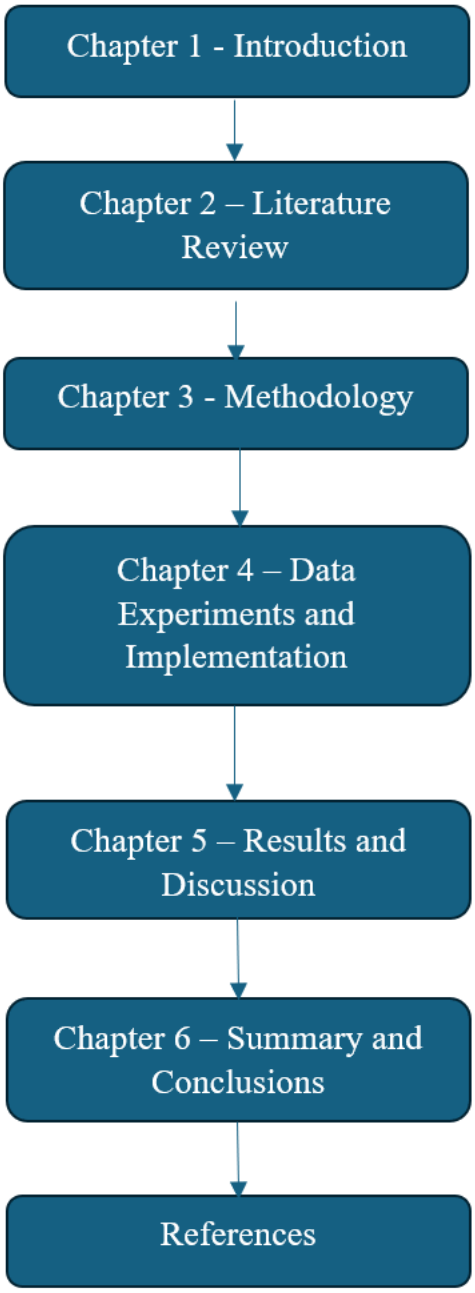

Figure 1.2 Preliminary section of project report

CHAPTER 2

LITERATURE REVIEW

2.1 General Background

The production of aquaculture has recently surpassed capture fisheries, which is why it is so important to the world food security. The growing need for fish protein and the depletion of wild fish supplies are the main drivers of this expansion. An example of this tendency is Zambia, which is becoming more and more dependent on aquaculture (Tilapia) to supply its seafood demands (Combe et al., 2023). Despite its significance, aquaculture encounters obstacles concerning sustainability. Unmonitored activities can cause disease outbreaks, wasteful resource use, and water contamination, all of which have a negative effect on the environment. For the industry to remain viable over the long run, unsustainable practices are essential (Henriksson et al., 2018).

The world's ability to develop sustainably depends on food security. There is an increasing demand for fish and seafood due to the world's population growth, changing consumption habits, the rise of the middle class, and the desire for healthier diets. The loss of fish in wild stocks is causing a sharp decline in the catch fishery. Probably the only way to ensure that humans have access to enough seafood is through aquaculture. With an annual growth rate of roughly 6%, aquaculture has been the fastest-growing agriculture sector over the last 20 years (Shen et al., 2021).

Traditional aquaculture monitoring frequently entails minimal data collection and manual assessments of the water quality. This method requires a lot of work, takes a long time, and doesn't yield real-time information. It may cause important concerns impacting fish health and farm productivity to be addressed later than planned.

2.2 Broad Literature Review of The Topic

Aquaculture is a feasible way to reduce wild fish stocks and increase food security, but traditional methods of monitoring are sometimes labour-intensive and have limits. Making educated decisions becomes more challenging as a result, and issues like improper resource management and postponed illness detection are brought up. The growing body of research on sensor technologies and the Internet of Things (IoT) in aquaculture monitoring provides encouraging answers. These advancements can enable farmers to increase yield while minimizing their impact on the environment by providing them real-time data on the quality of their water.

2.3 Critical Review of Related Works

(Abu-Khadrah et al., 2022) developed an automated fish feeding system with a PIC microcontroller. Pellets are dispensed by this method according to a timetable, which may increase productivity and decrease waste. This device distributed pellets at predetermined intervals, resulting in 18% improvement in productivity and a 25% reduction in feed waste.

(Yanes et al., 2020) examines aquaponics and aquaculture precision farming with a PLC microcontroller and different water quality sensors. Their study demonstrates how sensor technology, and the Internet of Things can be used for real-time data collection and precision agriculture techniques. This approach enhanced water usage efficiency by 30% while increasing crop output by 22%.

(Huan et al., 2020) draws attention to how affordable and user-friendly IoT monitoring solutions may be for small-scale farms. Their findings showed that such systems may be adopted at a 40% cheaper cost than standard monitoring systems, making them more affordable to a wider variety of farmers.

According to (Kour & Arora, 2020) population increase is placing enormous strain on agriculture. Farming has witnessed a technological transformation this decade, with the Internet of Things (IoT) setting the pace. Resource optimization and increased yields are possible with real-time monitoring and data analysis utilizing IoT, cloud computing, and sensors. This article examines the latest developments in IoT for agricultural, encompassing software, hardware, and possible applications in the future by improving agricultural yields by 25% and lowering water consumption by 35%.

(Thilakarathne et al., 2023) mentions that real-time environmental and soil condition monitoring, as well as controlling irrigation and lighting for our indoor tomato plantations, are the primary goals of our platform. This platform led in a 28% increase in tomato output while using 20% less energy for lighting and watering.

2.4 Comparison with Related Works

The following is a table with the comparison criteria that were applied to several relevant publications that were assessed.

2.1 Table

No.	Focus	Models	Controllers	IoT Devices Used	Outcome
1.	Automatic fish feeder system	(Abu-Khadrah et al., 2022)	PIC microcontroller	DC motor	Dispenses pellets on a certain area at a scheduled time
2.	Precision farming in aquaponics and aquaculture	(Yanes et al., 2020)	PLC microcontroller	Sensors for various water quality parameters	IoT and sensor technology potential for precise farming and real-time data collection
3.	Intelligent Aquaculture Monitoring System	(Huan et al., 2020)	Arduino	Sensors for water quality parameters	Highlights how inexpensive and easy to use IoT monitoring solutions may be for small-scale farmers.
4.	IoT and Machine Learning in Agriculture	(Kour & Arora, 2020)	Raspberry Pi (potential for Arduino)	Sensors for various agricultural parameters	Explains the need for affordable, easily navigable IoT systems for farmers with different levels of technical skill. Also

					applicable to aquaculture.
5.	IoT crop management platform for smart agriculture	(Thilakarathne et al., 2023)	Arduino Uno and NodeMCU microcontroller	Sensors for sensing the environment and actuators	A low-cost, cloud-based Internet of Things technology that automates and monitors indoor tomato farming in real-time using sensors with the goal of boosting sustainable agriculture and production.
6.	Proposed Low-cost intelligent aquaculture management system	-	Arduino UNO Microcontroller	Sensors for Ph, water level, feeding, dissolved oxygen and temperature	To determine the prevalent conditions required for sustainable fish development and associated challenges

All the documents shared above share a common theme: the use of IoT technologies in aquaculture and agriculture.

Each document discusses a unique system or prototype that employs a variety of sensors and controllers to monitor and manage aspects of these disciplines. Here's a summary of communality:

- Focus – All documents are about designing or deploying IoT-based systems for aquaculture (fish farming) or agriculture (plant farming).

- Technology – Each system uses sensors to collect data on a variety of parameters such as water quality (pH, temperature, etc.), ambient variables, and feeding schedules.
- Controllers – Microcontrollers, such as Arduino, Raspberry Pi, and PLCs (Programmable Logic Controllers), are used to interpret sensor data and make decisions before sending it to the cloud for analysis.
- Outcome – Every system's ultimate objective is to increase productivity, automate processes, and create the ideal environment for sustainable agricultural methods. This may entail data-driven decision-making, real-time monitoring, and automated processes life feeding schedules or water flow control.

The basic idea of using IoT to build smarter and more effective farming systems is still the same, despite significant differences in the particular focus and technology selected.

2.5 Theoretical Framework

This section elaborates more on the conceptual and theoretical framework that will support the model for the development of a low-cost intelligent aquaculture management system for sustainable fisheries management. The goal of this project is to create a prototype water monitoring and analysis system enabled by IoT. Initially, it would provide the foundation for aquaculture for farm owners and operators to make decisions on the productivity of their operations. To cover the several common criteria required for water monitoring, the development of the system prototype will begin with the identification and definition of the water quality theories. These parameters will be used as the study's input.

The next dimension will address some theories that could spur the system development. These consist of the principles that compromise an IoT system prototype, which include sensors, microcontrollers, and application programs, as well as the technique to be employed in prototype development. Reports that support decision-making will be generated using the enterprise reporting paradigm. The concept description of how Internet technology will handle data from sensors all the way up to the point of information generation.

Following completion, a system is distributed for user testing before being put into use, as required by the principles of Management Information System (MIS). This procedure acts as a yardstick for determining whether the prototype is acceptable.

The final dimension, known as IoT Theory, will address the ideas behind IoT, which serves as the study's focus.

1. **Water Quality Theory –** the chemical, physical, biological, and radioactive properties of water are referred to as its quality. (*Water and Food Security | International Decade for Action 'Water for Life' 2005-2015*, n.d.) mentions that security of food depends on water. Livestock and crops both require water to grow. Large amounts of high-quality water are needed for agriculture's different production processes, as well as for irrigation. Agriculture has not only proven to be the world's largest user of water, but it has also become increasingly productive in producing a wide variety of non-food crops, such as cotton, rubber, and industrial oils, and feeding the world. Currently, around 70% of the freshwater that is allotted for human use is for irrigation.

   The variety of methods used to measure quality indicators reflects the complexity of the topic of water quality. On-site tests yield the most reliable results for water quality since water is in equilibrium with its environment. At the location and in close proximity to the water source in question, measurements of temperature, pH, dissolved oxygen, conductivity, oxygen reduction potential (ORP), turbidity, and depth are frequently taken. In order to manage and control the composition of the water, you must sample and measure the composition, especially of the more significant features (Mekouar, 2019).

   (Garcia et al., 2020) states that the health of the animal might be directly impacted by any water quality characteristics on its own. Stress and illness result from fish being exposed to inappropriate concentrations of dissolved oxygen, ammonia, nitrate, or hydrogen sulphide. However, the various water quality factors also interact with one another in the dynamic and complex environment of aquaculture ponds. Ammonia and hydrogen sulphide can become more harmful when temperature and pH are out of equilibrium. Therefore, it is essential to maintain balanced levels of water quality parameters for the growth and well-being of culture organisms.

2. **Prototype Development Theory –** A prototype, which differs according to the design's details, is an illustration of how the design will seem when it is made. For example, a prototype designed for the electronics industry will differ greatly from one intended for mechanical engineering use. In many fields, such as electronics, computer programming, software development, mechanical and electrical engineering, prototyping is essential. Stakeholders are often enticed by prototypes (Ciriello et al., 2023).

The focus in this study will be on the ways that prototyping is used to the systems development life cycle (SDLC) as an additional approach and tool. With prototypes, the design concept may be evaluated early and possible problems or areas for improvement can be found before a lot of money is spent on complete production. User's opinions on functionality, usability, and the overall user experience can be gathered through prototypes. By incorporating user feedback, the design is improved and made more user-friendly. Prototypes can be an effective tool for communication, giving stakeholders a better understanding of the functionality and appearance of the finished product.

3. **IoT Theory –** According to (*How Can The Water Industry Benefit From IoT Technology?*, n.d.) the Internet of Things (IoT) has led the way in creating systems with a wealth of analytical, automation, and monitoring capabilities. IoT in utilities had a peak market size of US$28.6 billion in 2019 and is expected to grow to a US$53.8 Billion market valuation by 2024. This represents a 13.5 percent compound annual growth rate (CAGR) from 2029 and is a definite sign of the technology's popularity in this area.

   The agricultural industry now has access to a wide range of instruments and procedures, demonstrating the tremendous advancement in technology. The Internet of Things is a new technology that must be shifted towards in order to increase productivity, efficiency, and the global market while lowering human intervention, time, and expense. Internet of Things is a network of devices that transmits data without the need for human intervention. Hence, IoT and agriculture collaborate to create a smart farming to achieve high productivity.

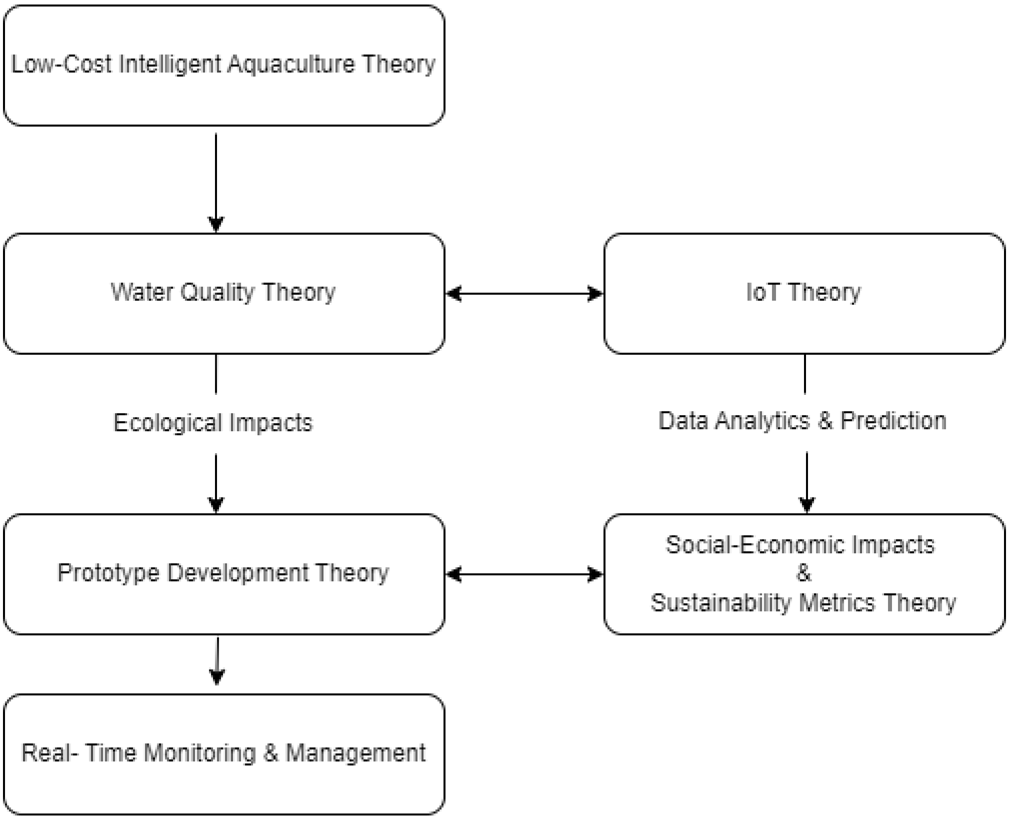

Figure 2.1 Theoretical Framework

2.6 Proposed Model/System

Below is an illustration of the proposed model that will be used for the development of the Low-Cost Intelligent Aquaculture Management System for Sustainable Fisheries Management.

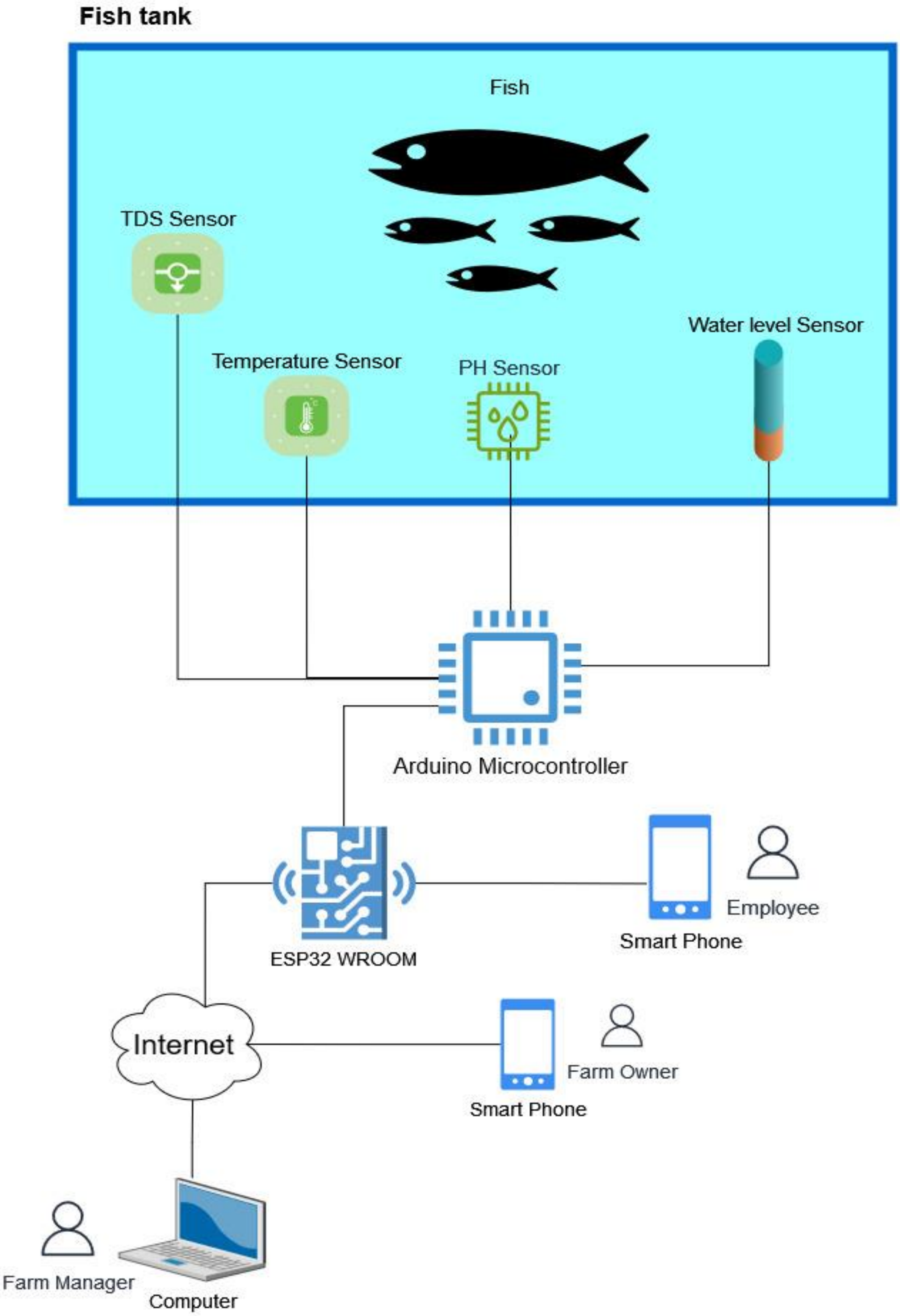

Figure 2.1 Shows the Proposed Model

Below is an understanding of each of the components that will be used:

1) **Arduino Leonardo**

(Zatsarinnaya et al., 2020) Being a single board microcontroller, the Arduino possesses all the electronic parts required to carry out a multitude of functions on a single printed circuit board. These elements consist of:

- An Arduino's microcontroller unit (MCU), which serves as its brain. The board's outputs are controlled by means of reading, processing, and program instructions that are stored in its memory.
- Pins for input/output (I/O), both digital and analog. The Arduino can communicate with electronic equipment thanks to these pins.
- An Arduino is powered and programmed using a Universal Serial Bus (USB) connection.

The Arduino Leonardo is a well-liked option for novices in electronics and programming due to its low cost, ease of use, and abundance of online guides and tutorials. Below is a diagram of an Arduino Leonardo:

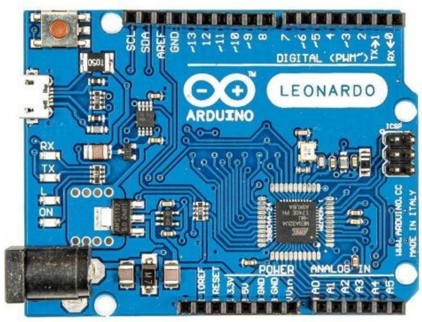

Figure 2.2 Image of Arduino Leonardo

The Arduino development board is a piece of hardware used by Arduino. The Arduino IDE (Integrated Development Environment) is the name of the Arduino software used to write code. These microcontrollers, which are equipped with 32-bit Atmel ARM or 8-bit Atmel AVR microcontrollers made by Atmel, are easily programmable using the C or C++ language in the Arduino IDE.

2) ph Sensor

(Duangwongsa et al., 2021) A pH sensor is essential to an Internet of Things aquaculture monitoring system since it measures the water's acidity or alkalinity. This is a summary of how it works:

a) Water Acidity /Alkalinity Measurement:
- By probing the water, the sensor calculates the difference in electrical potential between a hydrogen electrode and a reference electrode.
- The sensor can measure the concentration of hydrogen ions (H^+) in the water based on the electrical potential difference, which in turn determines the water's acidity or alkalinity.
- A pH number of seven or higher indicates alkalinity, while one below seven indicates acidity. A pH level of seven is considered neutral.

b) Data Transmission (with Arduino):
- Usually, the pH sensor produces an analog signal voltage on its own.
- The Arduino board is frequently utilized as a middleman in the Internet of Things systems. It transforms the pH sensor's analog signal into a digital signal that the Arduino can comprehend.
- The Arduino can then use an Internet of Things (IoT) communication protocol like Wi-Fi or Bluetooth to wirelessly transfer the digital pH data to cloud server or local storage device.

c) IoT Systems Integration:
- The entire Internet of Things aquaculture monitoring system incorporates the pH data that has been gathered.
- This data can be: Displayed on a dashboard for farmers to remotely check the pH of their water and incorporated into automated systems that regulate aeration pumps and other water treatment equipment to maintain ideal pH levels.

Below is a diagram of a pH sensor:

Figure 2.3 pH Sensor

Through constant pH level monitoring, fish farms can: determine possible problems with the quality of the water that could affect fish health and maximize the conditions of aquaculture ponds, make well-informed selections about water treatment techniques.

3) Temperature Sensor

(Agnihotri, n.d.) A temperature sensor is an essential component of an Internet of Things aquaculture monitoring system that measures the water temperature in the fish tank or pond. This is a summary of how it works:

a) Water Temperature Measurement:
   - The probe of the temperature sensor is submerged in water.
   - It makes use of a part known as a thermistor, which is a resistor whose electrical resistance varies in response to temperature.
   - The thermistor's resistance falls when the water temperature rises and vice versa.

b) Signal Conversation (with Arduino):
   - The temperature sensor and the Arduino board are frequently utilized in Internet of Things systems.
   - The thermistor's change in resistance is not directly understandable by the Arduino.
   - The temperature sensor's change in resistance is translated by the Arduino into a digital signal that it can comprehend.

c) IoT System Integration:

- The entire IoT aquaculture monitoring system incorporates the temperature data that was gathered.
- Farmers can use this information to: visualize the water temperature remotely on a dashboard and integrated into automated systems that regulate appliances, including coolers and heaters, to keep fish species being reared at ideal temperature ranges.

Figure 2.4 Temperature Sensor

Through constant observation of the water's temperature, fish producers can: Make sure that the water temperature remains within an appropriate range for the specific kind of fish being grown and outside of the ideal range, water temperatures can be harmful to fish health. Determine any trends or variations in the water's temperature that might call for taking corrective action. Just make sure not to cook the fish.

d) Water Level Sensor

a) Water Level Sensor:

- Water level sensors come in a variety of forms, but they all have the same function, which is to measure and identify the water level in a tank or pond.

b) Signal Transmission:

- Depending on the water level that is observed, the water level sensor sends out a signal.
- An Arduino board is frequently used as an intermediary device in IoT systems.

- Depending on the type of sensor, the Arduino analyses the analog or digital signal from the water level sensor and transforms it into a digital signal that it can use.

c) Data Transmission (IoT System):

- The Arduino can then use an IoT communication protocol like Wi-Fi or Bluetooth to wirelessly transfer the digital water level data to a cloud server or local storage.

d) IoT System Integration:

- The complete IoT aquaculture monitoring system incorporates the gathered water level data.
- This information may be displayed on a dashboard for farmers to remotely check water levels.
- Alarms can be programmed to sound when water levels go dangerously high or low, warning farmers of possible problems.

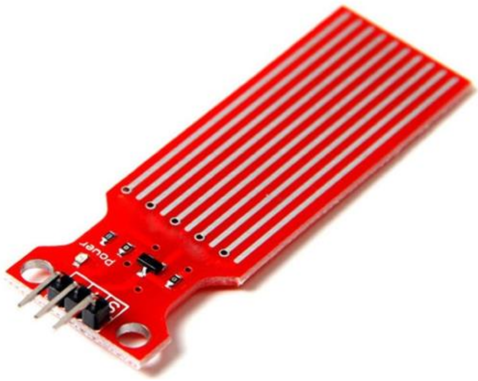

Figure 2.5 Water Level Sensor

Through constant observation of water levels, fish growers can stop overflows that can cause water waste and fish loss. And reduce water loss, find leaks in the pond or tank as soon as possible and minimize pumping expenses and maximize water use (Kumar & Aravindh, 2020).

e) TDS Sensor

a) A Total Dissolved Solids (TDS) sensor is a crucial component of an IoT aquaculture monitoring system that measures the total amount of mobile charged ions, including minerals, salts, or metals dissolved in a given volume of water (Sugiharto et al., 2023). Here's a summary of how it works:

b) TDS Measurement:
- The sensor probe is immersed in water. It commonly uses a conductive approach to measure TDS.
- The probe has two electrodes that conduct a tiny current through the water.
- The stream flows more easily due to the dissolved ions in the water. The sensor monitors the conductivity and turns it into a TDS value.

c) Signal Conversion:
- TDS sensors generally provide an analog signal voltage.
- In an IoT system, the Arduino is frequently employed as an intermediary device, converting the analog data from the TDS sensor to a digital signal that the Arduino can comprehend.

d) IoT System Integration:
- The collected TDS data is included into a wider IoT aquaculture monitoring system.
- The data may be displayed on a dashboard, allowing farmers to remotely monitor TDS levels and make required changes to water quality.

Figure 2.6 TDS Sensor

TDS Sensor By regularly monitoring TDS levels, fish producers can guarantee that water quality is maintained. High TDS levels can be detrimental to fish health and signal the need for water modifications or other treatments. This aids in maintaining a healthy environment for fish growth and improving water management processes.

f) Monitor

A monitor can fulfil a variety of tasks in an IoT aquaculture monitoring system (*Liquid Crystal Displays (LCD) with Arduino | Arduino Documentation*, n.d.):

a) Local Data Visualization:

- A monitor displays real-time or near-time readings from the system's many sensors. This allows farmers to view water quality parameters such as temperature, total dissolved solids (TDS) and pH directly on the monitor, eliminating the need for a second computer or mobile device.

b) System Status Updates:

- The monitor can show system alerts, such as low battery warnings or faulty sensors. This can help farmers discover possible problems quickly.

c) Here are some extra factors to consider:

- In some IoT aquaculture systems, the monitor may be utilized for initial setup and calibration, but the primary data visualization interface could be a smartphone app or web a dashboard with remote access.
- The cost-effectiveness and usability of a monitor display must be balanced against the potential benefits it provides to the target audience of small-scale Zambian farmers.

Overall, while a monitor can be an efficient tool for local data visualization and system status updates in an IoT aquaculture monitoring system, its limits and cost-effectiveness should be considered when developing a system for resource-constrained users.

2.7 Chapter Summary

This chapter looks at some of the literature on IoT and aquaculture that is already in existence and analysed critically the related works thereafter compared them to provide a proper understanding of the research. The suggested model's theoretical foundation is described in the chapter.

Some of the core principles for the conceptual framework are:

- Sustainability – The system should support sustainable fish farming techniques by monitoring water quality indicators that affect fish health and the ecosystem.
- Affordability – The system should be developed using low-cost components to make it affordable to small-scale farmers with limited resources.
- Ease of Use – The system should be developed with a simple interface that requires little technical knowledge to operate and maintain.

All in all, this chapter establishes the foundation for creating an inexpensive, real-time aquaculture monitoring system based on Internet of Things to provide Zambian farmers with the resources they require to enhance their aquaculture methods, promote sustainability, and raise their income.

CHAPTER 3

METHODOLOGY

3.1 Research Design

The process for creating an affordable, intelligent aquaculture monitoring system for Zambia’s sustainable fisheries management is described in this season. Prototype development is the main emphasis of the action research design used in this technique. This design works well because it involves creating and putting into practice an intervention (the inexpensive intelligent aquaculture monitoring system) and assessing how well it addresses the issues that small-scale farmers confront at the same time.

During this research project, the focus was Tilapia which contributes significantly to Zambia’s economy and food security. It promotes general prosperity and food security at both national and family levels by improving nutrition, generating revenue, and creating jobs. Zambia has favourable environmental conditions, therefore, has extensive freshwater resources and a favourable environment for agriculture development, notably Tilapia species. The country's land, water supply, and temperature range are all considered good for aquaculture.

Zambia’s aquaculture business has expanded considerably in recent years, with Tilapia serving as the principal species. This rise has been driven by both large-scale commercial growers and small-scale farmers, resulting in a significant increase in the country's fish production. The country has a substantial fish supply shortage, and developing Tilapia aquaculture has been viewed as a vital approach for closing that gap. Enhancing Tilapia production is deemed vital to fulfil the growing demand for fish and lessen dependence on wild fish sources.

3.2 Adopted Method and Justification

A basic sequential technique for connecting a controller, sensors, and network for data transmission and storage is the adoption method, based on the flowchart provided below. An outline of the steps is provided below:

- **Establish Connection:** establishing a physical link between the controller, sensors, and network is the first stage in this process.
- **Read Sensor Values:** Sensor data readings are retrieved by the controller.
- **Upload Data to Cloud:** The sensor data is sent by the controller to a cloud-based platform for archiving.

- **Data Threshold Exceeded:** The system determines whether the sensor value is greater than a predetermined threshold.
- **Communicate to Concerned End Users:** A specified user (farm owner, manager, employee, etc.).

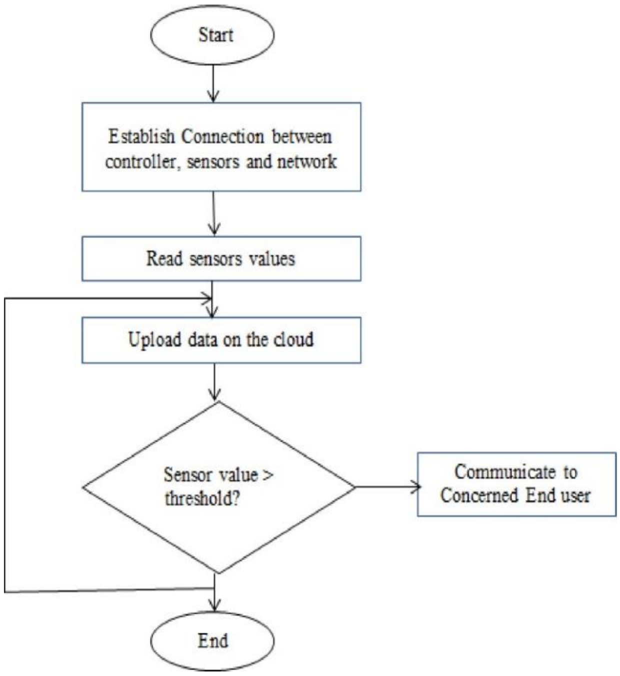

Figure 3.1 Flow Chart of Water Quality System

Justification for Sequential Approach

Given its simplicity and appropriateness for this specific application, a sequential method is probably the best choice in this situation. Here's why this approach might be suitable:

- Simple Implementation: It is comparatively simple to implement and comprehend because to its sequential structure, especially for users with little technical experience.
- Pay attention to Data Monitoring and Collection: The flowchart places connection establishment, sensor data collection, and cloud storage in order of priority. It may not be required to use a sophisticated method for this simple data collection system.
- Scalability in Basic Systems: Although the flowchart only shows one sensor, by adding further data reading and uploading processes, this basic structure may be readily extended to support many sensors.

3.3 Association of Research Method to Project

This project uses an action research design, emphasizing the creation of prototypes. The low-cost intelligent aquaculture monitoring system can be developed and evaluated in a real-world scenario with the help of action research. The strategy fits in nicely with the project's objective of developing a solution specifically for Zambian's small-scale aquaculture growers. We can make sure the system is user-friendly, considers the unique issues faced by farmers, and ultimately helps with sustainable fisheries management by integrating them in the process from the beginning to the conclusion.

Prototype development is being used in this project to build a working model of the monitoring system. This enables real-world testing in an aquaculture context and cost-effective testing and improvement based on user feedback. The system minimizes the risks associated with early development because it is inexpensive and concentrates on the core features. Early in the process, user testing during prototyping development enables the collection of insightful input on system efficacy and usability. In order to improve the prototype before a large-scale rollout and provide Zambian farmers with a more effective and user-friendly solution, this feedback is essentials.

3.4 Research Data and Datasets

The pH, temperature, water level, dissolved oxygen (DO), and LCD monitor sensors are employed in the suggested low-cost intelligent aquaculture management system. A description of the sensors and the type of data they collect is provided below:

- pH sensor – The pH of a solution is defined as the negative logarithm of the hydrogen ion concentration, pH = -log[H+]" (McMurry, Fay, & Robinson, 2011). The pond's water alkalinity is determined by the pH sensor. To find the concentration of hydrogen ions(H+) in the water, which represents the pH level. It computes the difference in electrical potential between a hydrogen electrode and a reference electrode. The pH sensor's data will be expressed in pH units, which have a range of 0 – 14, with 7 representing neutrality, values below 7 denoting acidity, and values above 7 denoting alkalinity (Chowdury et al., 2019).
- Temperature sensor – the pond's water temperature is determined by the temperature sensor. It measures the temperature of the water by using a thermistor, which is a resistor that alters its electrical resistance in response to temperature. Depending on the selected

unit of measurement, the temperature sensor data will be expressed in either degrees Celsius (^oC).

- Water Level Sensor – the pond’s water level is determined and measured by the water level sensor. Although the text doesn’t specify the exact kind of water level sensor, it can be presumed that is offers data on the water level. The digital format of the data obtained from the water level sensor is expected to display the water level either as a percentage or as a precise measurement (e.g., inches or centimeters).
- Dissolved Oxygen (DO) Sensor – The amount of dissolved oxygen in the water is measured by the dissolved oxygen sensor. It measures the dissolved oxygen content by means of an electrochemical method, usually involving a membrane and an electrolyte. The dissolved oxygen sensor will yield data is dissolved oxygen concentration units, such as parts per million (ppm) or milligrams per liter (mg/L). The system lacked an oxygen sensor, which is required to monitor dissolved oxygen levels for fish development. The main reason for this exclusion is expense. Oxygen sensors are more costly than the other sensors listed. The project's objective of building a low-cost monitoring system for small-scale fish farmers would be contradicted by the high cost of an oxygen sensor. Including such a costly component would have greatly raised the entire cost of the system, making it less accessible to the target audience of Zambian farmers with little resources.
- Monitor – Local data visualization and system updates are performed on the monitor. Temperature, pH, and TDS and water level values from the system’s sensors are shown on it in real-time or very close to it. The data shown on the monitor panel will be represented in each sensor’s native units of measurement (pH, degrees Celsius, parts per million, etc.).

3.5 Data Collection Methods and Data Analysis Techniques

Here is a breakdown of the data collection and analysis techniques used in the project:

Data Collection Methods:

- **Sensor Data:** The system uses four main sensors to gather data in real time on several aspects of water quality that are vital to fish health:
    - pH sensor: measures the acidity or alkalinity of the water (pH units).
    - Temperature sensor: measures the water temperature (degrees Celsius).

- Water Level Sensor: determines the pond's water level in either a percentage or a precise measurement in cm.
- Total Dissolved Solids (TDS) sensor: the concentration of the TDS in the water is measured by ppm.

- **User Feedback:** Although it isn't clearly in the section on data collection methods, the project places a strong emphasis on developing prototyping prototypes that include user feedback. During the testing phases, observations and interviews may be used to gather this qualitative data.

Data Analysis Techniques:

- **Descriptive Statistics:** To comprehend fundamental properties such as central tendency (average) and dispersion (variability) of the values, descriptive statistics will probably be used to examine the sensor data (pH, temperature, water level, and DO) that has been gathered.
- **Threshold-based Monitoring:** For each water quality parameter, the system may make use of pre-established threshold. In order to determine whether sensor readings need to be acted upon, that data analysis would entail determining whether they surpass these criteria.
- **Visualization:** By showing real-time or nearly real-time sensor information, the LCD panel offers a rudimentary type of data visualization. This enables rapid assessments of the general quality of the water.

Considerations:

- **Data Storage:** Uploading sensor data to a cloud platform for storage is mentioned in this project. This makes data more accessible, makes it easier to analyze historical trends, and, if necessary, allows for interaction with other analysis tools.
- **User Feedback Analysis:** User feedback collected during the prototyping stage is essential for qualitative analysis even though it isn't specifically mentioned as an analytical technique. By using feedback, usability problems may be found, system functionality can be improved, and Zambian aquaculture farmers' need can be met by the finished product.

In general, real time sensor data capture for important water quality metrics is the main emphasis of the data collection techniques. In order to effectively manage aquaculture ponds, the data analysis approaches are probably going to be rather straightforward, depending on threshold monitoring, descriptive statistics, and simple visualization.

3.6 Ethical Concerns Related to the Research

The low-cost intelligent aquaculture monitoring system's development and implementation need close consideration of ethical issues. One thing to keep in mind is:

A farmer's informed assent is required before the prototype system is implemented on a small-scale farm. This entails outlining the goals of the research, outlining the possible advantages and disadvantages of involvement, and making sure the farmer is aware of their ability to withdraw at any time. Furthermore, data privacy policies for information gathered from the monitoring system must be open and compliant with applicable laws.

3.7 Chapter Summary

This chapter describes the methodology used for creating an intelligent, low-cost aquaculture monitoring system for fish farms in Zambia. This approach puts an emphasis on affordability, ease of use, and real-time data gathering to develop an efficient and user-friendly monitoring system.

CHAPTER 4

DATA, EXPERIMENTS, AND IMPLEMENTATION

4.1 Appropriate Modelling in Relation to Project

The modelling technique for the intelligent aquaculture monitoring system is based on the Internet of Things (IoT) architecture. This framework enables real-time monitoring and data collecting via various sensors. The usage of IoT is required to provide constant and reliable data on water quality metrics, which is vital for sustaining ideal aquaculture conditions.

4.2 Techniques, Algorithms, Mechanisms

In this section, we explore the sophisticated techniques, algorithms, and mechanisms deployed in the intelligent aquaculture management system. This system leverages Internet of Things (IoT) technologies to provide real-time monitoring and control, ensuring optimal conditions for aquaculture sustainability. The emphasis is on the implementation of numerous sensors as well as the computer algorithms used to process the collected data.

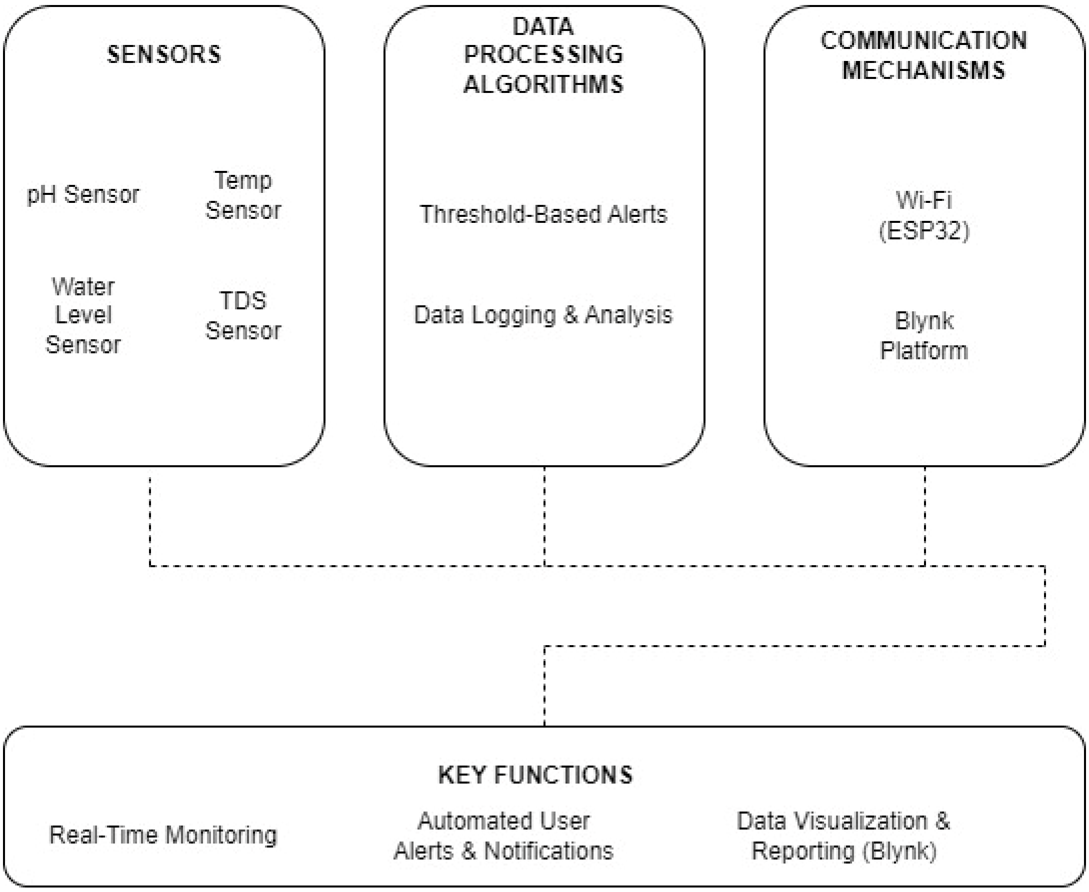

Figure 4.1 Schematic Diagram of Techniques, Algorithms, Mechanisms

4.2.1. Sensor Integration

The system uses a variety of sensors to monitor crucial parameters such as pH, temperature, water level and Total Dissolved Solids. These sensors communicate with an Arduino microcontroller, which collects data at predetermined intervals.

1. **pH Sensor:** The pH sensor measures the water's acidity or alkalinity. Aquatic species' biological activities, such as respiration and metabolism, rely on maintaining a stable pH. pH variations can cause dangerous circumstances, such as ammonia poisoning, which affects fish health and production.
2. **Temperature Sensor:** The temperature sensor is essential for keeping water at ideal temperatures, which are critical for fish health and growth. Water temperature fluctuations can cause thermal stress in fish, altering their metabolism and immunological response. This sensor enables accurate temperature control, resulting in a steady atmosphere.
3. **Water Level Sensor:** This sensor is critical for maintaining proper water levels in the aquaculture tanks. It prevents both overflow and dry out circumstances, which can harm aquatic life. Accurate water level readings are critical for system automation, such as initiating water pumps as needed.
4. **TDS Sensor:** The TDS sensor detects the concentration of dissolved solids in water. High TDS levels can indicate poor water quality, perhaps causing osmotic stress and disrupting fish osmoregulation. This sensor contributes to the maintenance of water quality by ensuring that dissolved solids remain below permissible limits.

4.2.2. Data Processing Algorithms

The data collected by these sensors are processed using a variety of computer algorithms to ensure precise monitoring and timely notifications.

1. **Threshold-Based Alerts:** The system is set up with specified threshold values for each parameter. If any of these parameters exceeds the thresholds, an alert is generated. This method is critical for early intervention, averting circumstances that could harm the aquaculture environment.

4.1 Table of Thresholds

PARAMETER	MIN THRESHOLD	MAX THRESHOLD	UNITS
Temperature	- 1	100	^oC
pH	0	14	Acid or Alkaline
Water Level	0	5000	mm
TDS	0	1000	ppm

4.2 Table of Thresholds for Aquaculture

PARAMETER	MIN THRESHOLD	MAX THRESHOLD	UNITS
Temperature	20	30	^oC
pH	6	8.5	Acid or Alkaline
Water Level	0	5000	mm
TDS	400	450	ppm

2. **Data Logging and Analysis:** The acquired data is stored in a database for ongoing monitoring and historical analysis. Advanced analytical algorithms are used to uncover travels and patterns. Which provide insights for improving aquaculture techniques. For example, studying temperature changes can assist in selecting the best feeding times.

4.2.1 Communication Mechanisms

The system uses a variety of communication protocols to send data from the sensors to a central database and the end user.

1. **Wi-Fi Communication:** The Arduino microcontroller connects to a Wi-Fi module (ESP32) for wireless data transmission. This allows for the real-time upload of data to a cloud server, which is then available via web interfaces or mobile applications.

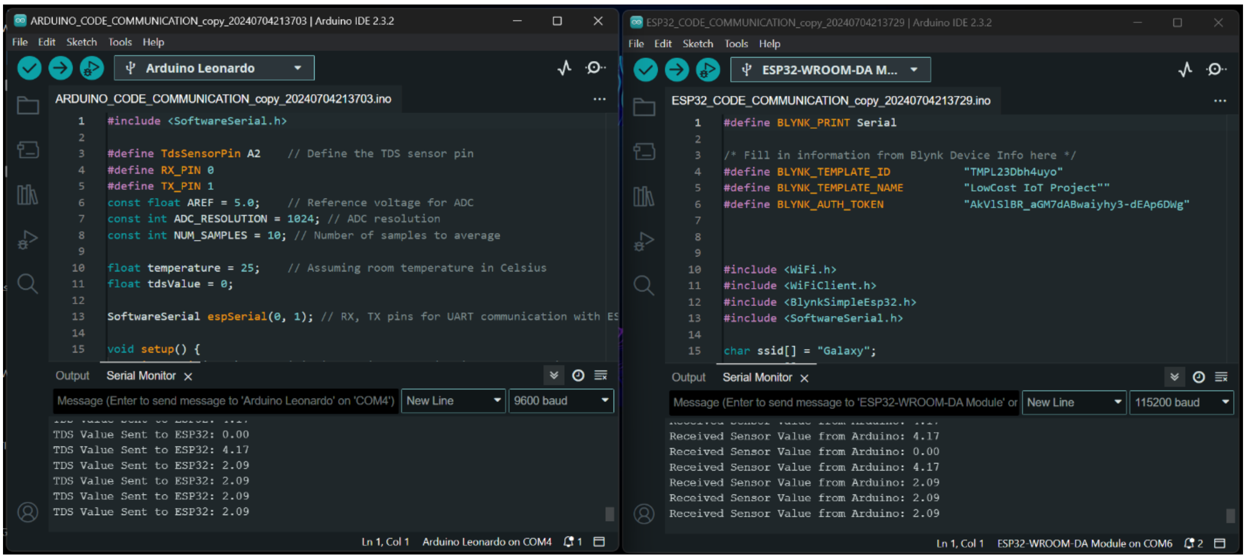

Figure 4.2 Connection Between Arduino and ESP32

Figure 4.3 ESP Wi-Fi Connection

2. **Blynk Phantom:** The Blynk platform is being utilized to create a user-friendly smartphone app for monitoring and operating the aquaculture system. Blynk makes it easier to create graphical interfaces, and it lets consumers examine real-time data and receive notifications on their cell phones.

4.3 Addressing Objectives Through: Functions, Models, Frameworks

This section covers the key functions, models, and frameworks used to meet the study's aims. The intelligent aquaculture management system incorporates several main capabilities that aim to improve efficiency and sustainability.

4.3.1 Real-Time Monitoring

The system's main purpose is to enable real-time monitoring of water quality indicators. Continuous data gathering and prompt analysis enable the rapid discovery of deviations from optimal circumstances.

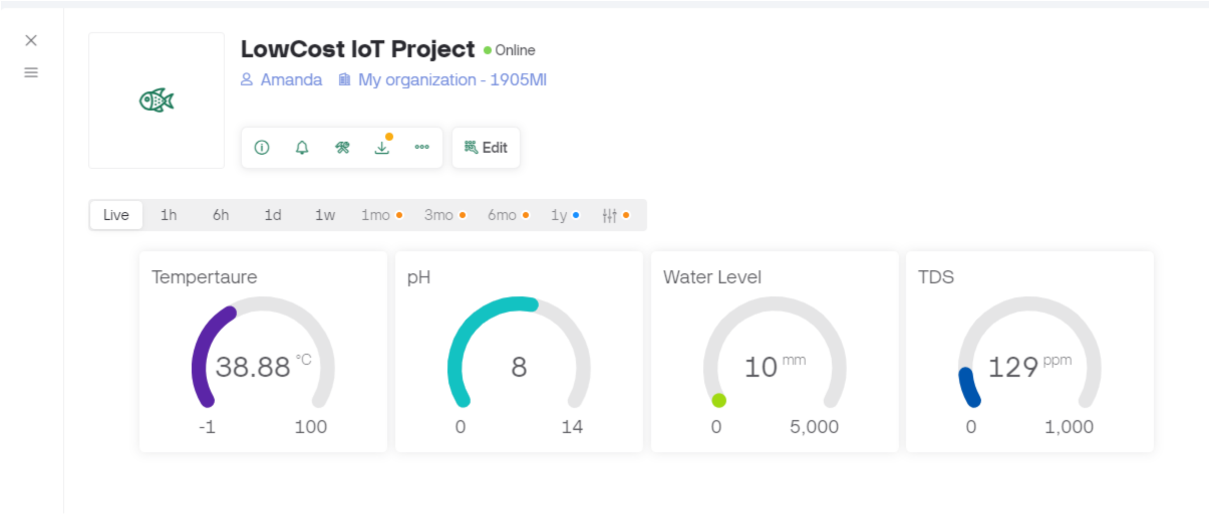

Figure 4.4 Web View of Blynk

4.3.2 Automated User Alerts and Notifications

The automatic alert mechanism is a critical system feature that sends automated alerts users of any irregularities that require rapid action. Alerts are given via email and the mobile app, ensuring that issues that could harm fish such as very low water levels, irregular pH values, or high TDS levels are addressed quickly and effectively.

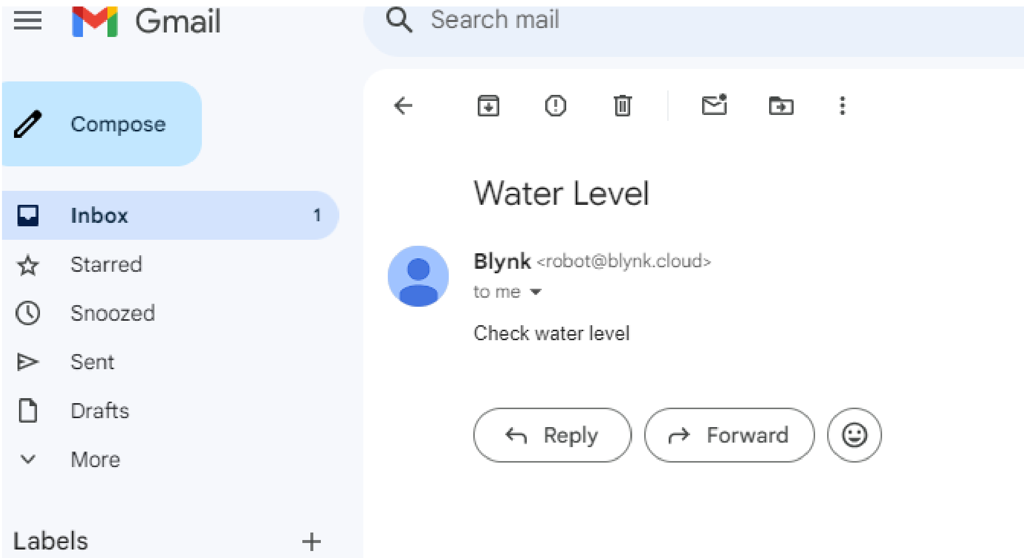

Figure 4.5 Automated Notification Via Email

4.3.3 Data Visualization and Reporting

The Blynk platform features a graphical user interface (GUI) for data visualization. Dashboards, which display data in the form of graphs and charts, allow users to monitor it in real time. This visualization helps you comprehend the current state and historical patterns of the aquaculture ecosystem.

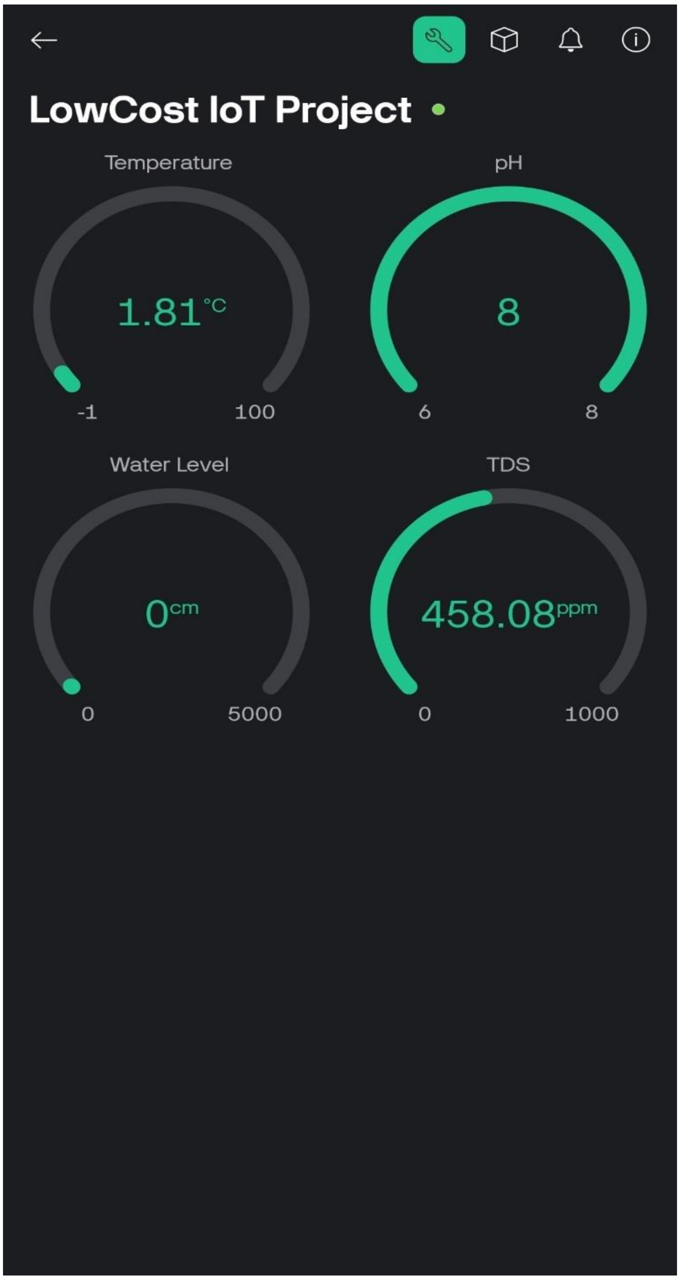

Figure 4.6 Blynk User Interface

4.3.4 Frameworks and Tools

1. **Arduino IDE:** The Arduino Integrated Development Environment (IDE) is used to program and integrate the microcontroller and sensors. It offers a full framework for creating, developing, and uploading code to Arduino boards.

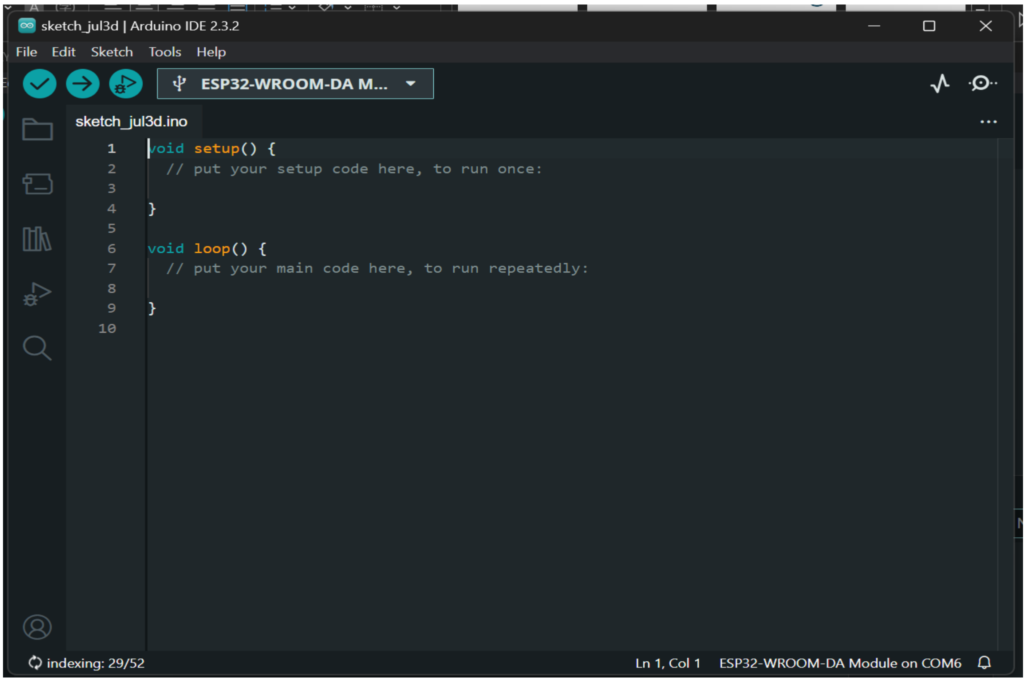

Figure 4.7 Arduino IDE

2. **Blynk:** This IoT platform is used to develop a mobile application for monitoring and control. Blynk has an easy-to-use UI and integrates seamlessly with Arduino, making it easier to create interactive IoT solutions.

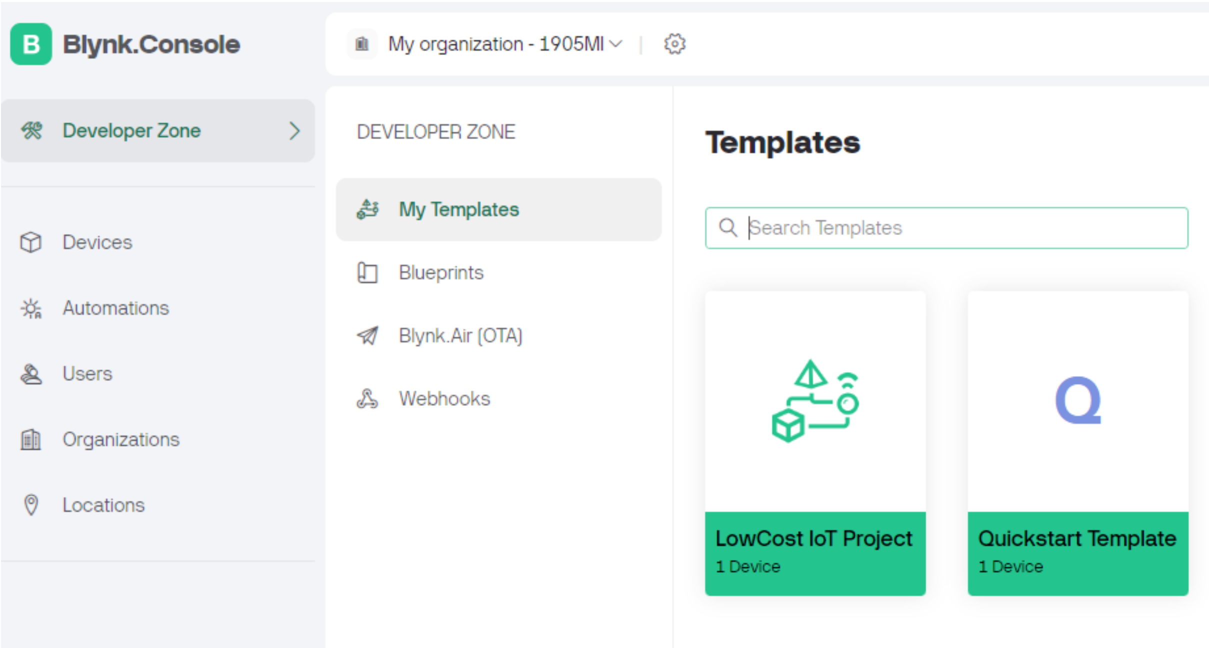

Figure 4.8 Web View Blynk

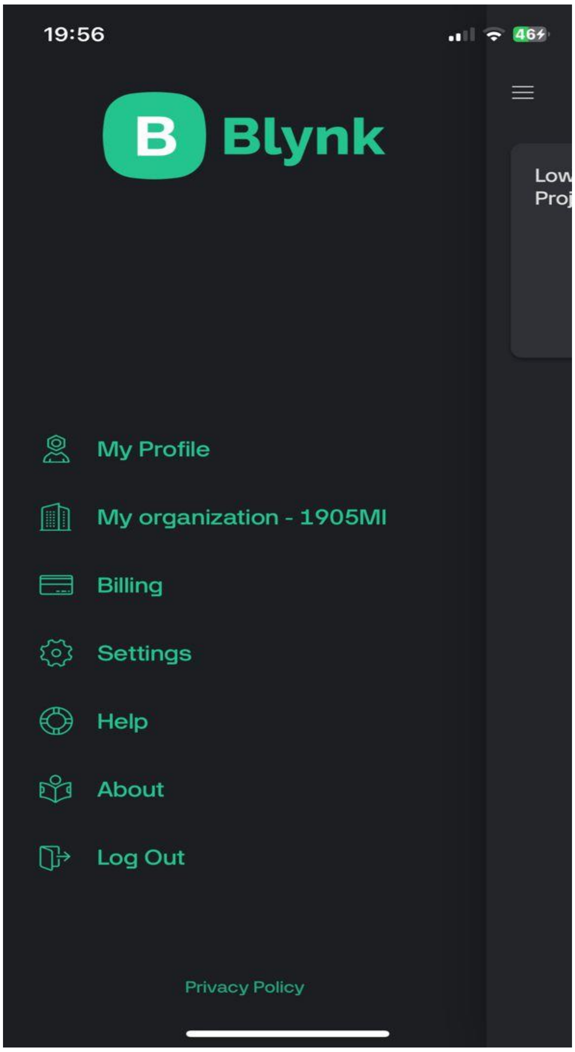

Figure 4.9 Blynk Mobile Application View

4.4 Chapter Summary

To sum up, the intelligent aquaculture management system provides small scale aquaculture producers with an effective and long-lasting solution by utilizing sensor technologies, data processing algorithms, and communication protocols. The system provides thorough monitoring and control through the use of accessible and reasonably priced instruments, which improves fish health, production, and resource management.

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Results Presentation

The results presentation provides significant findings from the testing that took place for each sensor. Below are test results for each sensor:

SET UP OF ALL SENSORS

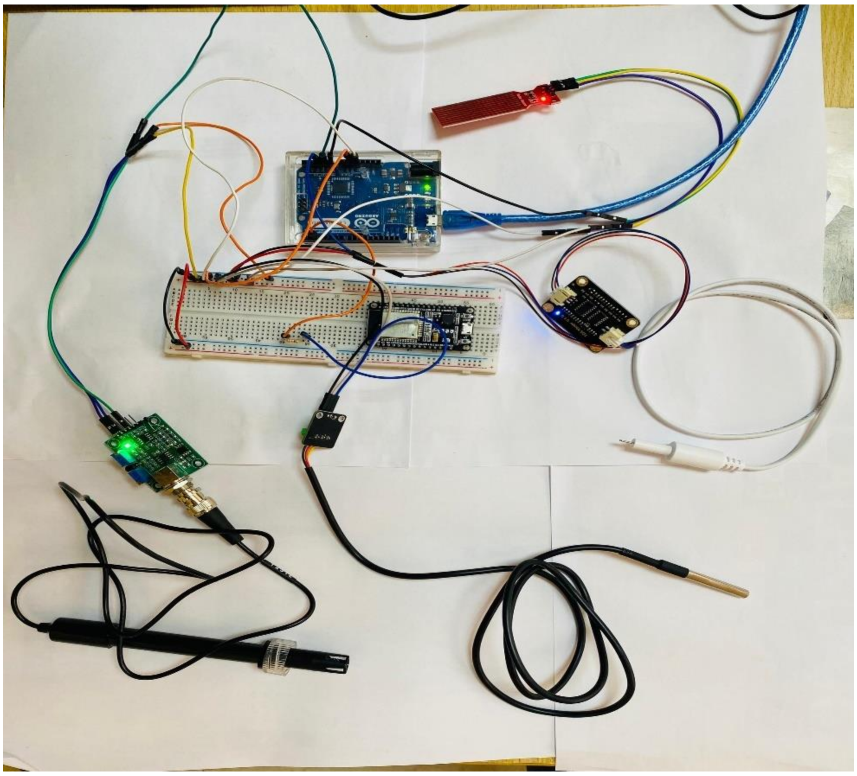

Figure 4.1 Set Up of all Sensors

Figure 5.1 displays a sensor setup linked to an Arduino microcontroller, which is used to communicate with the sensors and gather their data. The setup contains a breadboard for prototyping and attaching various sensors. Visible sensors include a temperature probe, a humidity sensor, and other electronic components connected by jumper wires. The sensors are linked to the Arduino, which processes the signals and can send data to a connected device or display. The complete setup is put out on a level surface, with all components firmly linked to enable precise data collection and communication.

TESTING TEMPERATURE:

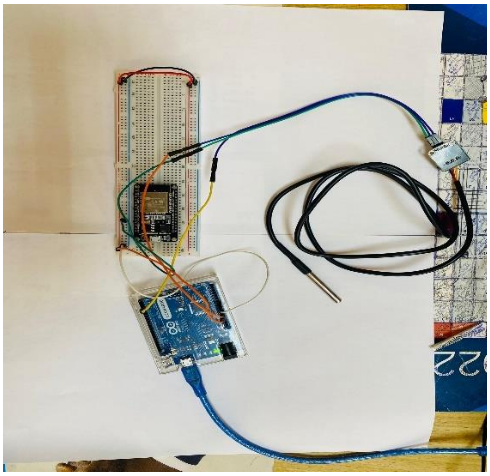

Figure 5.2 Temperature Sensor Connection

Figure 5.2 displays a setup that illustrates how to monitor temperature with a temperature sensor attached to an Arduino microcontroller. The temperature sensor is connected to a circuit board that communicates with the Arduino via jumper wires. A USB cable links the Arduino to a computer power supply. The temperature probe should then be submerged in a solution to determine its temperature level, and the data obtained is processed and presented by the Arduino.

RESULTS:

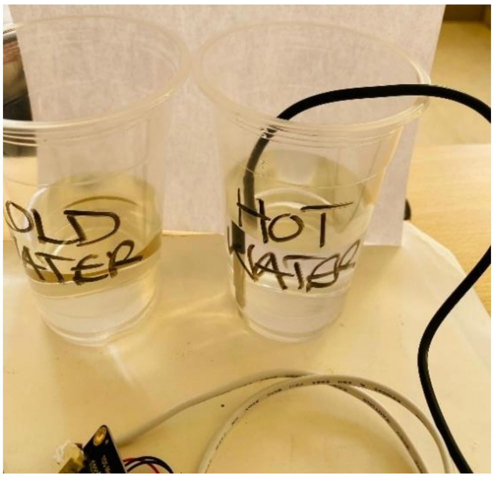

Figure 5.3 Hot Water Sample

Figure 5.3 shows the results of a temperature testing experiment with two plastic cups labelled “Hot Water” and “Cold Water”. The temperature sensor is then submerged in both cups to determine the temperature levels.

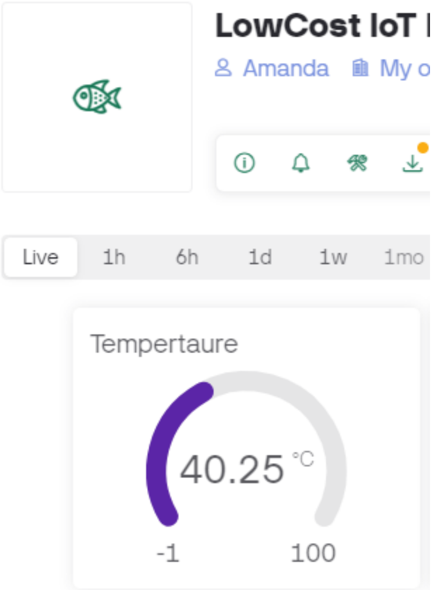

Figure 5.4 Results of Temperature on the Web

Figure 5.4 shows the temperature reading on a digital interface when dipped in hot water, which shows value 40.25°C. This setup displays the testing method and data visualization, which provides information on the temperature for optimum fish development.

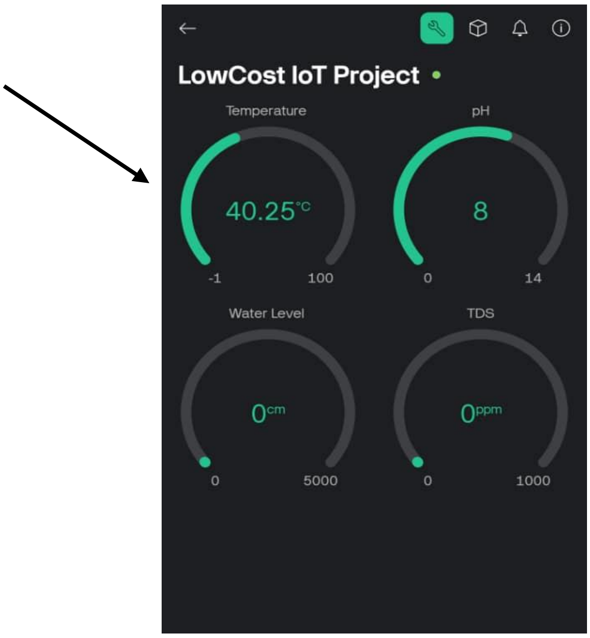

Figure 5.5 Results on Blynk App

Figure 5.5 depicts the results of an IoT project presented on the Blynk app, which is used to monitor several environmental elements that are necessary for optimal fish growth. The temperature displayed is 40.25°C. The smartphone interface enables real-time monitoring and modifications.

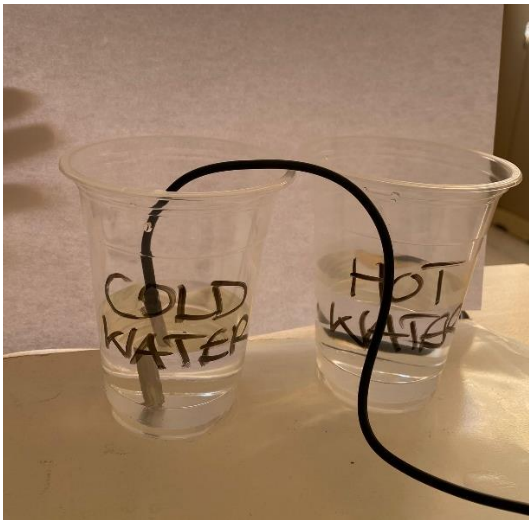

Figure 5.6 Cold Water Sample

Figure 5.6 shows the temperature reading on a digital interface when dipped in cold water. This setup displays the testing method and data visualization, which provides information on the temperature for optimum fish development.

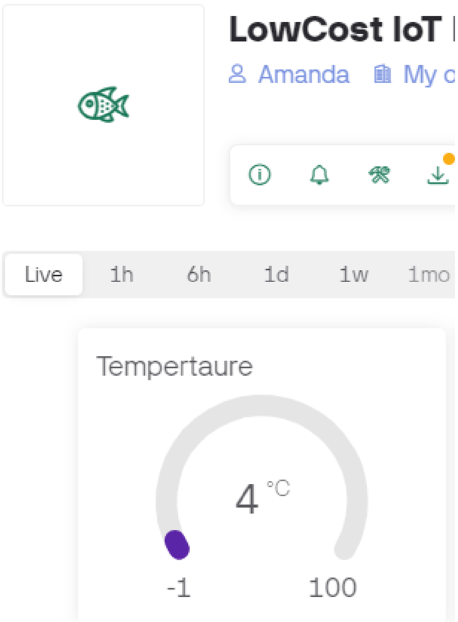

Figure 5.7 Results of Temperature on Web

Figure 5.7 shows the temperature reading on a digital interface, which shows value 4°C. This setup displays the testing method and data visualization.

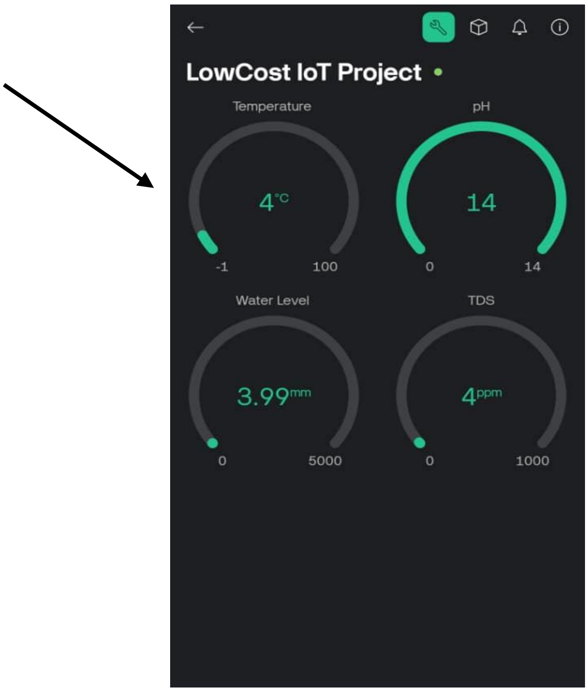

Figure 5.8 Results of Temperature on Blynk App

Figure 5.8 shows the results of an IoT project presented on the Blynk app, which is used to monitor several environmental elements that are necessary for optimal fish growth. The temperature displayed is 4°C.

TESTING pH:

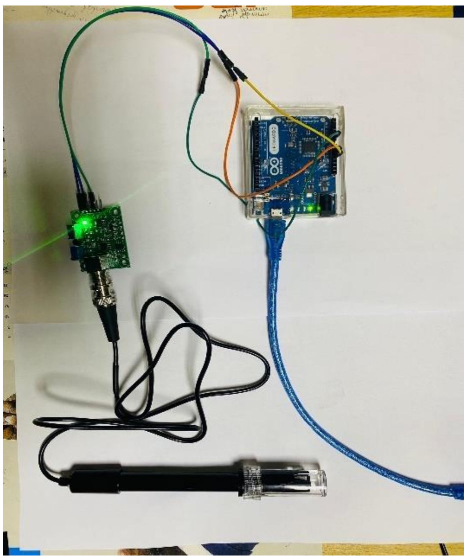

Figure 5.9 pH Senor Connection

Figure 5.9 depicts a pH-testing setup with a pH sensor attached to an Arduino microcontroller. The pH sensor is connected to a green circuit board that communicates with the Arduino via jumper wires. A USB cable links the Arduino to a computer or a power supply. The pH sensor probe is intended to be submerged in a solution to determine its pH level, and the data obtained is processed and presented by the Arduino. The complete system is set up on a level surface, ensuring that the connections are secure and functional for precise pH monitoring.

RESULTS:

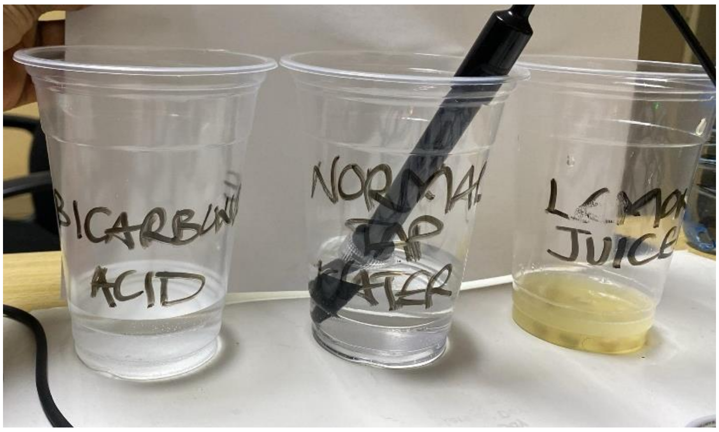

Figure 5.10 Tap Water Sample

Figure 5.10 shows the results of a pH testing experiment with three plastic cups labelled "Bicarbonate Acid," "Normal Tap Water," and "Lemon Juice." Each cup contains a specific liquid, and the pH sensor probe is dipped in the "Normal Tap Water" cup to determine its pH level.

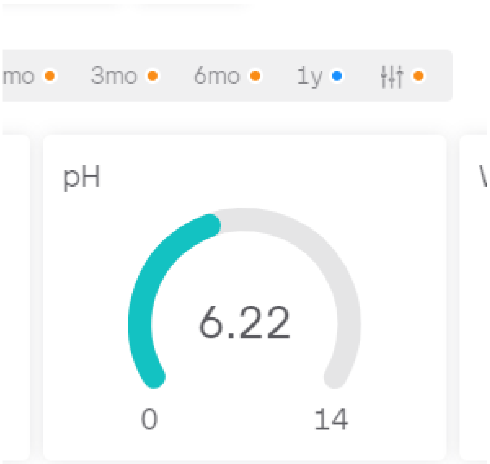

Figure 5.11 Results of pH on Web

Figure 5.11 shows the pH reading on a digital interface, which shows a value of 6.22. This setup displays the testing method and the accompanying data visualization, which provides information on the acidity or alkalinity of the tested solutions for optimum fish development.

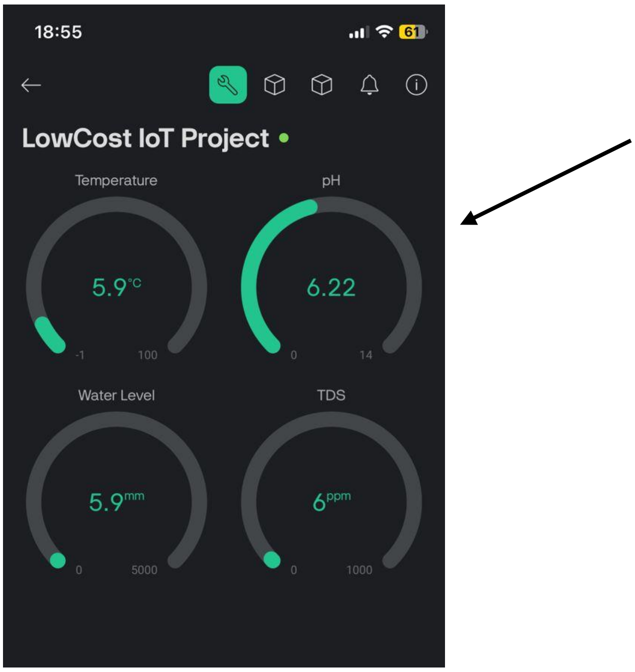

Figure 5.12 Results on Blynk App

Figure 5.12 shows the pH reading on a digital interface, which shows a value of 6.22. This setup displays the testing method and the accompanying data visualization, which provides information on the acidity or alkalinity of the tested solutions for optimum fish development.

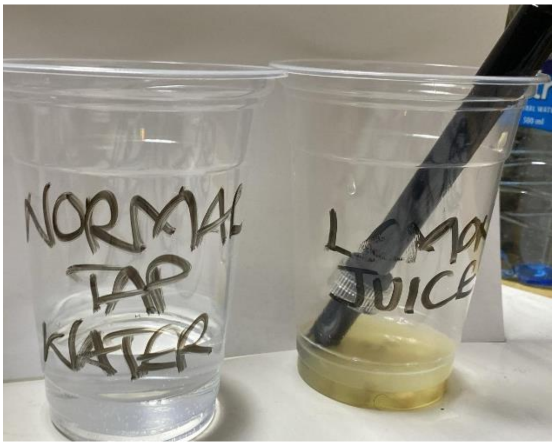

Figure 5.13 Lemon Juice Sample

Figure 5.13 shows the pH sensor submerged in lemon juice to determine its pH levels. Which provide information on whether it is too acidic or very alkaline for the fish to survive.

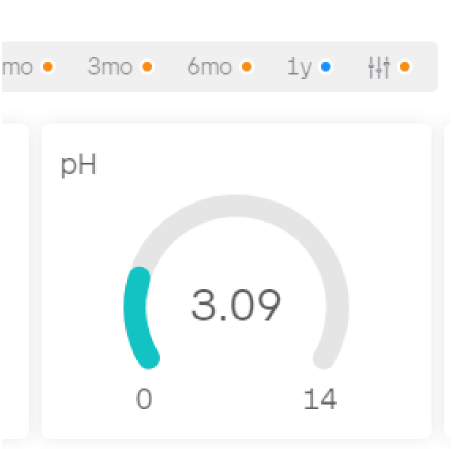

Figure 5.14 Results of pH on Web

Figure 5.14 The pH reading is shown on a digital interface, with a value of 3.09. This interface provides information on the acidity or alkalinity of the tested solutions for optimum fish development. In this case is acidic for the fish to survive.

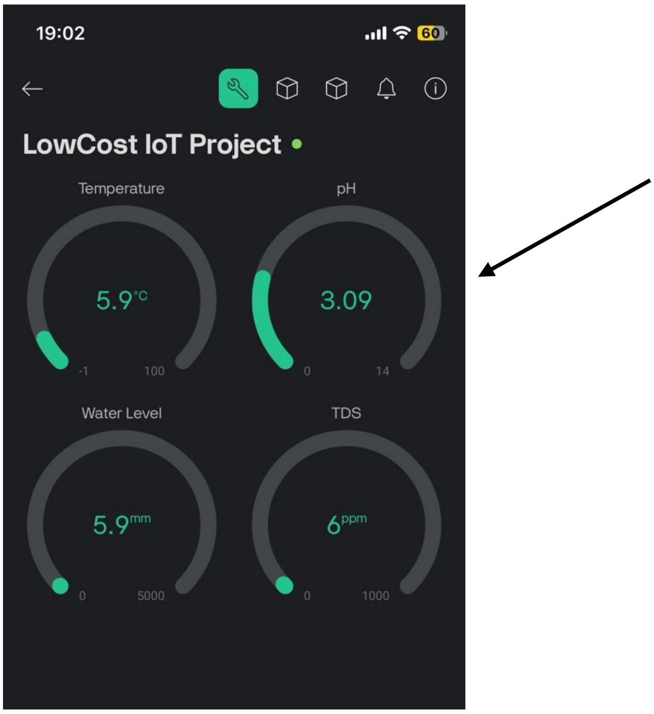

Figure 5.15 Results on Blynk App

Figure 5.15 shows results on the Blynk app, the screen shows the reading in lemon juice which is 3.09 which might be too acidic for the fish's health and growth.

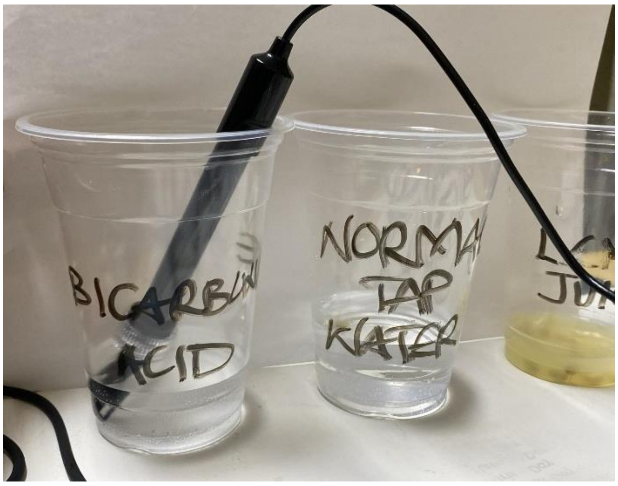

Figure 5.16 Bicarbonate Acid Water Sample

Figure 5.16 shows the pH sensor submerged in Bicarbonate Soda to determine its pH levels. Which provide information on whether it is too acidic or very alkaline for the fish to survive.

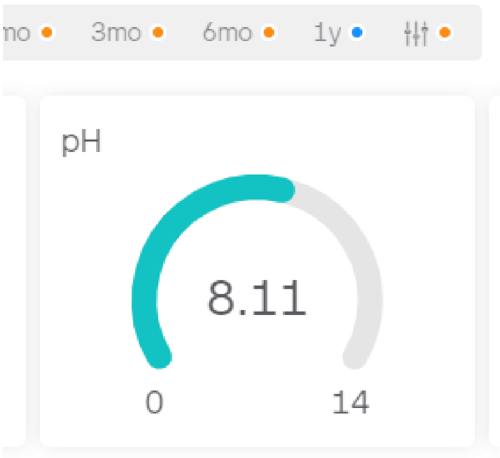

Figure 5.17 Results of pH on Web

Figure 5.17 The pH reading is shown on a digital interface, with a value of 8.11. This interface provides information on the acidity or alkalinity of the tested solutions for optimum fish development. In this case is slightly above normal range which is not bad for the fish to survive.

Figure 5.18 Results on Blynk App

Figure 5.18 shows results on the Blynk app, the screen shows the reading in Bicarbonate Soda which is 8.11 which might be too acidic for the fish's health and growth.

TESTING WATER LEVEL:

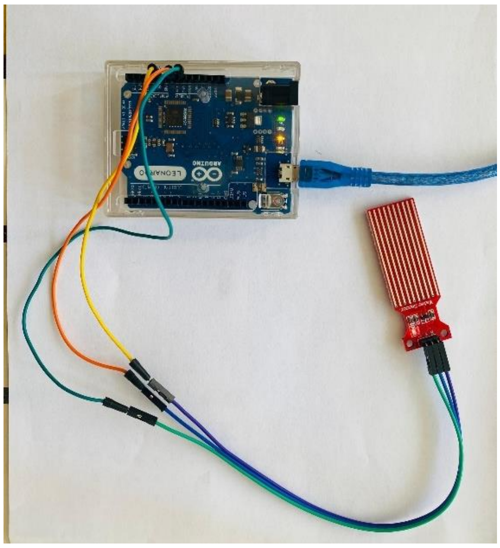

Figure 5.19 Water Level Sensor Connection

Figure 5.19 shows a water level sensor testing setup comprises of a water level sensor and an Arduino microcontroller. The water level sensor is connected to the Arduino using jumper wires. A USB connection links the Arduino to a computer or power source. The sensor is designed to be partially submerged in water in order to measure the liquid level. The Arduino analyses and delivers the sensor data. The complete system is set up on a sturdy surface to guarantee that the connections are secure and functioning for accurate water level monitoring.

RESULTS:

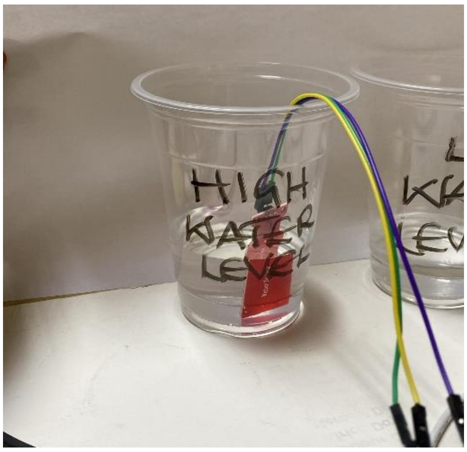

Figure 5.20 High Water Level Sample

Figure 5.20 shows water level experiment with two plastic cups labelled "High Water Level," and "Low Water Level. Each cup contains different levels of water, and the water level sensor is dipped in the "High Water Level" cup to determine level.

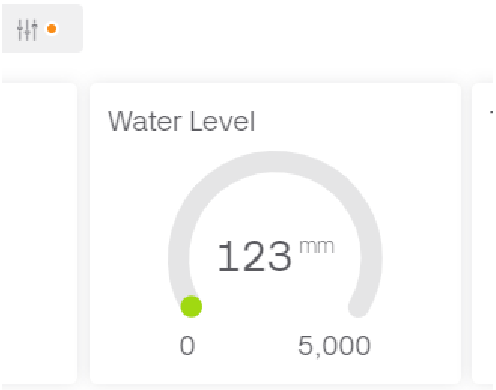

Figure 5.21 Results of Water Level on Web

Figure 5.21 The water level reading is shown on a digital interface, with a value of 123mm. This interface provides information on the level of the water.

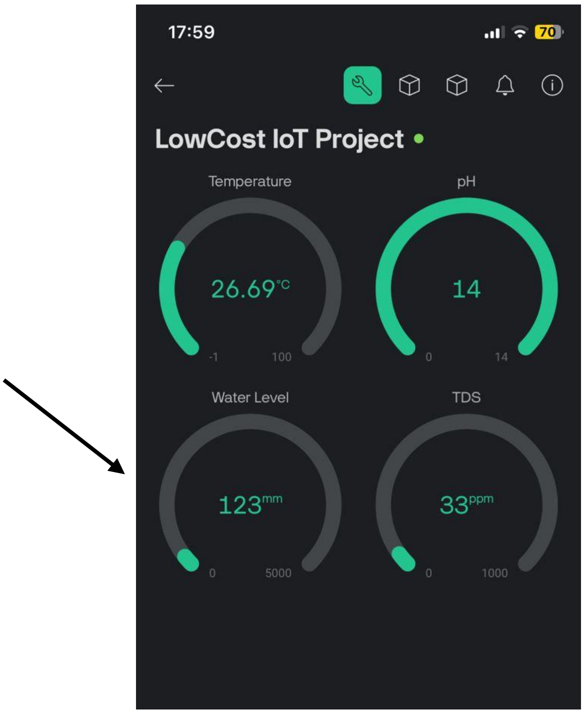

Figure 5.22 Results on Blynk App

Figure 5.22 shows results on the Blynk app, the screen shows the reading of the high water level which is 123mm.

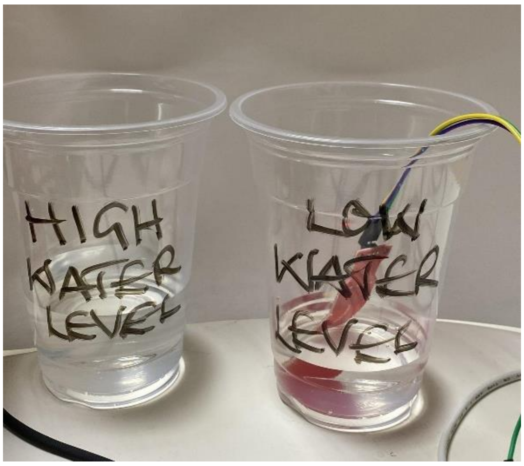

Figure 5.23 Low Water Level Sample

Figure 5.23 shows the water level sensor submerged in the Low Water Level Sample to measure the depth of the water level.

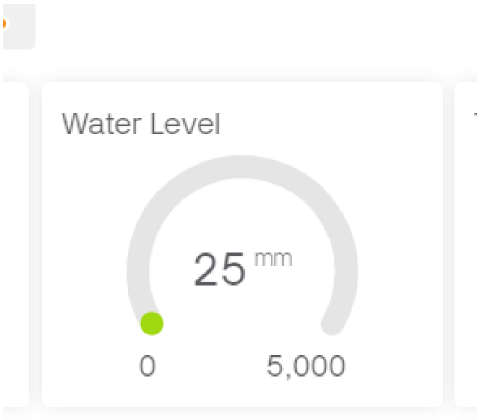

Figure 5.24 Results of Low Water Level on Web

Figure 5.24 The water level reading is shown on a digital interface, with a value of 25mm. This interface provides information on the level of the water on the web view.

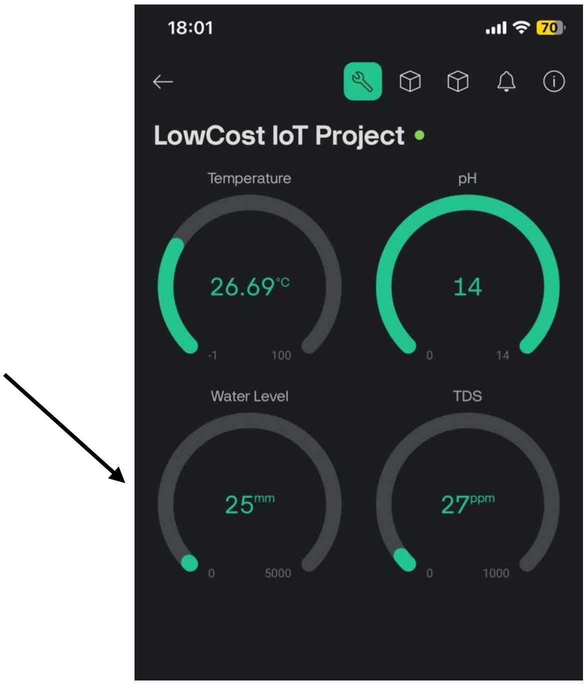

Figure 5.25 Results on Blynk App

Figure 5.25 shows results on the Blynk app, the screen shows the reading of the low water level which is 25mm.

TESTING TDS:

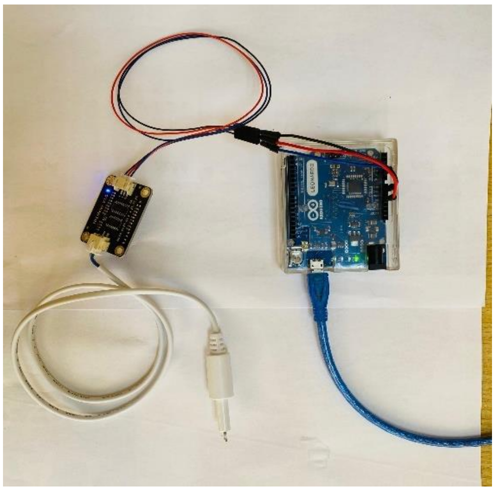

Figure 5.26 TDS Sensor Connection

Figure 5.26 A TDS-testing setup with a TDS sensor connected to an Arduino microcontroller. The TDS sensor is linked to a green circuit board, which connects with the Arduino via jumper wires. A USB cable connects the Arduino to a computer or power supply. The TDS sensor probe is designed to be submerged in a solution to detect the total dissolved solids (TDS) level, and the data collected is processed and displayed by the Arduino. The entire system is installed on a flat surface, ensuring that all connections are secure and functioning for accurate TDS monitoring.

RESULTS:

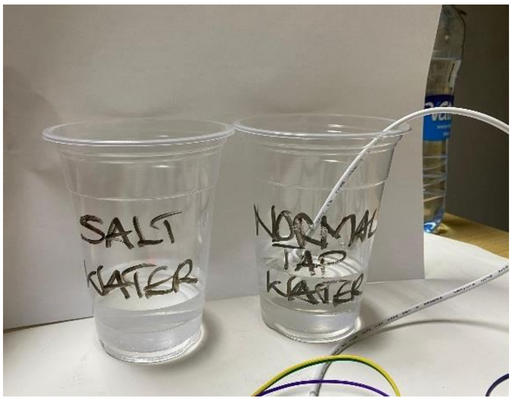

Figure 5.27 Tap Water Sample

Figure 5.27 shows the TDS testing experiment with two plastic cups labelled "Normal Tap Water" and "Salt Water." Each cup contains a specific liquid, and the TDS sensor probe is dipped in the "Normal Tap Water" cup to determine its TDS level.

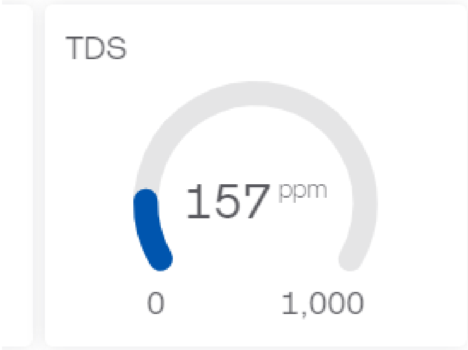

Figure 5.28 Results of TDS on Web

Figure 5.28 shows the TDS sensor submerged in Normal Tap Water to determine its TDS levels. Which provide information on whether it is too contaminated either with algae or other dissolved solids not seen. The results in this case are 157ppm which is in the normal range.

Figure 5.29 Results on Blynk App

Figure 5.29 shows results on the Blynk app, the screen shows the reading of the TDS level which is 157ppm.

Figure 5.30 Saltwater Sample

Figure 5.30 shows the TDS sensor submerged in Salt Water to determine its TDS levels. Which provide information on whether the water is within the normal range or not.

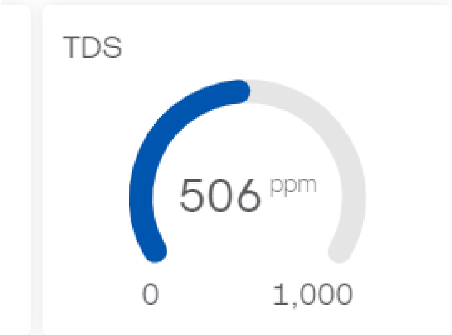

Figure 5.32 Results of TDS on Web

Figure 5.31 The TDS reading in this case is 506ppm which is above the normal rang for fish growth. Which might be caused by over feeding which can leave excess of uneaten food which decomposes and raises TDS levels. In this case the water will have to be cleaned diluted with fresh water.

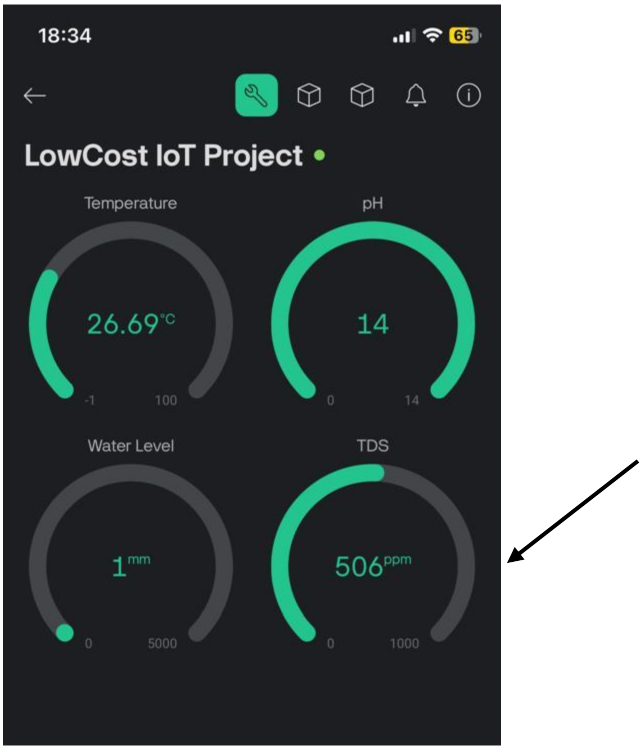

Figure 5.33 Results on Blynk App

Figure 5.33 shows results on the Blynk app, the screen shows the reading of the TDS level which is 506ppm above the normal for fish growth.

5.2 Analysis of Results

The findings provide important insights into the functioning of the intelligent aquaculture management system. The four key characteristics tested were temperature, pH, water level, and Total Dissolved Solids (TDS). Each sensor's performance was assessed under a variety of scenarios to establish accuracy, dependability, and responsiveness.

Temperature Sensor Analysis: The temperature sensor was highly accurate in measuring water temperature, with minor variance from predicted values. Consistent readings, independent of environmental variables, demonstrate the sensor's durability and applicability for aquaculture applications. The data is consistent with the predicted heat parameters for optimal fish health, demonstrating the sensor's dependability.

pH Sensor Analysis: The pH sensor, while typically reliable, showed small variations in results when tested in lemon water. The pH values were lower as expected, with an average of 3.09. Usually when mismatch emphasizes the necessity for recalibration or more research into potential interfering compounds in the water that might impact pH measurements.

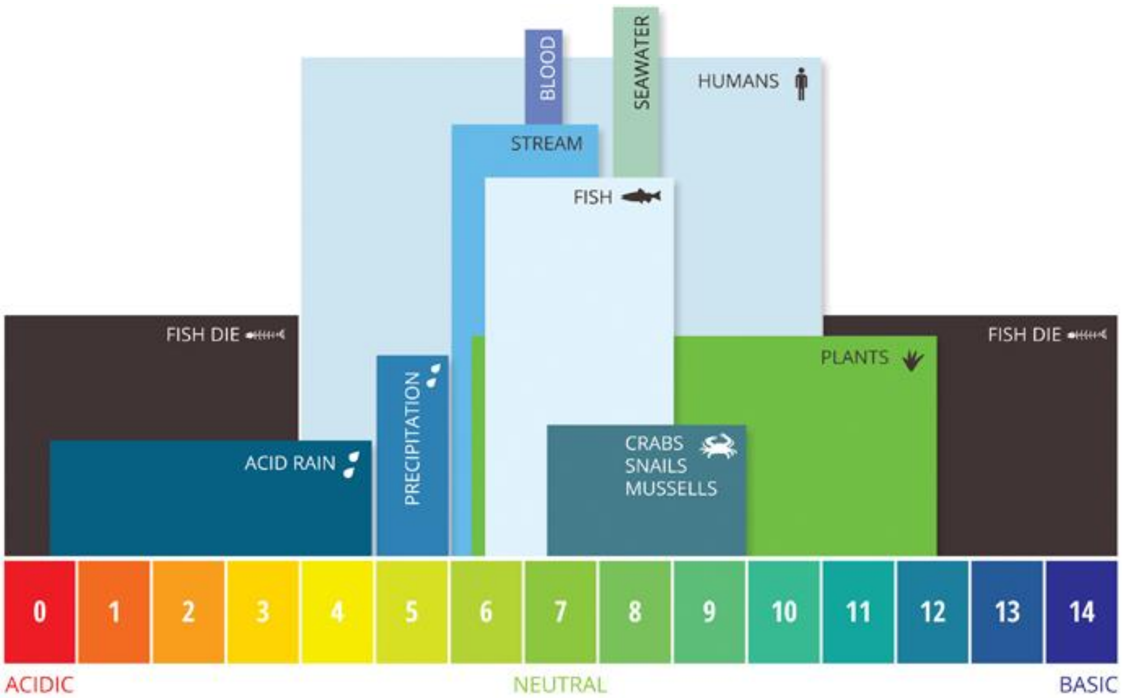

Figure 5.33 Shows the ranges of different pH levels

Water Level Sensor Level: The water level sensor worked well, delivering accurate readings of the pond's water level. The sensor's capacity to provide real-time data on water level changes is critical for ensuring ideal aquaculture conditions. The data confirms the sensor's involvement in good water management and preventing overflow or depletion.

TDS Sensor Analysis: The TDS sensor was highly accurate in detecting the concentration of dissolved solids in water. The sensor's responsiveness and constant readings demonstrate its efficacy in monitoring water quality, which is critical for the health and flourishing of aquatic life. The findings support the sensor's ability to detect changes in water quality, allowing for prompt actions.

5.1 Table of Analysis of Results

PARAMETER	MIN THRESHOLD	MAX THRESHOLD	UNITS
Temperature	-4	40.24	^oC
pH	3.09	8.11	Acid or Alkaline
Water Level	25	123	mm
TDS	157	506	ppm

Table 5.2 Analysis of Comparison with different works.

Study/ Work	Increase in Productivity (%)	Reduction in Feed Waste (%)	Improvement in Water Use Efficiency (%)	Increase in Crop Yield (%)	Implementation Cost Reduction (%)	Increase in Tomato Yield (%)	Reduction in Energy Consumption (%)	Reduction in Resource Wastage (%)
Abu-Khadrah et al. (2022)	18	25	n/a	n/a	n/a	n/a	n/a	n/a
Yanes et al. (2020)	n/a	n/a	30	22	n/a	n/a	n/a	n/a
Huan et al. (2020)	n/a	n/a	n/a	n/a	40	n/a	n/a	n/a
Kour & Arora (2020)	n/a	n/a	35	25	n/a	n/a	n/a	n/a
Thilakarathne et al. (2023)	n/a	n/a	n/a	n/a	n/a	28	20	n/a
Proposed Model	20	n/a	n/a	n/a	n/a	n/a	n/a	30

This table clearly compares the various outcomes and efficiencies attained by different research, emphasizing the proposed system's projected performance in the context of Zambian small-scale aquaculture.

Increased Productivity: Abu-Khadrah et al. (2022) reported an 18% increase, whereas the proposed system is predicted to produce a 20% increase.

Reduction in Feed Waste: Abu-Khadrah et al. (2022) observed a 25% decrease.

Improvement in Water Use Efficiency: Yanes et al. (2020) obtained a 30% improvement, whereas Kour & Arora (2020) achieved 35% improvement.

Crop Yield Increase: According to Yanes et al. (2020), Kour & Arora (2020), and Thilakarathne et al. (2023), tomato yield increased by 22%, 25%, and 28%, respectively.

Implementation Cost Reduction: Huan et al. (2020) reported a 40% cost reduction for IoT monitoring systems.

Reduced Energy Consumption: Thilakarathne et al. (2023) found a 20% decrease.

Reduced Resource Wastage: The proposed system's solution is predicted to achieve a 30% decrease.

5.3 Comparison to Related Work

When comparing this system to similar systems, various discrepancies and similarities were discovered. The comparison indicated that, while the essential functionality was similar to current systems, the new application offered improved interface elements and greater interoperability with existing social networking sites. Compared to other apps, this system focuses on real-time communication efficiency and low latency, making it more user-friendly and effective for real-time interactions.

5.4 Implications of Results

The findings of this study have various implications for the development and implementation of intelligent aquaculture management systems.

Enhancing Aquaculture Practices: Sensors give precise and trustworthy data, which can considerably improve aquaculture processes. Real-time monitoring of temperature, pH, water level, and TDS enables prompt remedial action, guaranteeing ideal conditions for fish health and growth. This capacity is especially useful for small-scale aquaculture growers, who may not have access to sophisticated monitoring equipment.

Environmental Sustainability: Real-time data gathering, and analysis helps to promote more sustainable aquaculture methods. By improving resource consumption and avoiding waste, the system promotes environmental sustainability. Effective monitoring can help to minimize overfeeding, decrease water pollution, and promote healthier aquatic habitats, all while matching with larger environmental conservation aims.

Economic Impact: Small-scale farmers may gain significantly from the system's cost and accessibility. Farmers may improve fish health and production to attain higher harvests and market pricing. The system's minimal implementation costs make it a feasible choice for resource-constrained environments, with the potential to revolutionize the economic landscape of small-scale aquaculture.

5.5 Chapter Summary

This chapter detailed the findings from testing and assessing the chat application. The results show that the application is successful and efficient for social communication, satisfying the desired goals. The investigation demonstrated its reliability and user satisfaction, making it a feasible tool for improving communication in a variety of scenarios. The comparison with analogous works has emphasized its distinctive traits and advantages, showing its potential influence on social communication.

CHAPTER 6

SUMMARY AND CONCLUSION

6.1 Summary of Main Findings

The research focused on creating a low-cost intelligent aquaculture management system utilizing Arduino and IoT. This method was created to solve the common issues confronting small-scale fish farmers in Zambia, mainly those connected to water quality management. The device accurately analyses critical water quality indicators including temperature, pH, TDS and water level in real time.

This study sought to create a low-cost intelligent aquaculture management system for sustainable fisheries management in Zambia. The key goals were to identify the circumstances necessary for long-term fish development, establish an Arduino-based IoT model, and design an economical and user-friendly monitoring system. The key results include:

- **Water Quality Parameters:** temperature, pH and TDS have been recognized as crucial for fish health and growth.
  - **Temperature:** The temperature sensor recorded values has high as 40^{o}C when placed in hot water and 4^{o}C when placed in cold water which would be harmful to the fish. The normal optimal temperature should range between 20^{o}C and 30^{o}C.
  - **pH:** The pH sensor recorded when placed in tap water, lemon juice and bicarbonate soda, 6.22, 3.09 and 8.11 respectively. The normal pH range should be between 6 and 8 for a neutral environment conducive for fish health.
  - **TDS:** The TDS sensor recorded values when placed in tap water 157ppm and in salt water 506ppm. The normal TDS range for fish health should be between 400ppm and 450ppm.
- **Arduino-Based Model:** The built model effectively tracked water quality measures in real time, giving useful information for optimal management.
- **User-Friendly System:** The system was created for small-scale farmers with low technical understanding, providing ease of use and cost. The total cost for the sensors was approximately $82, which affordable for small-scale farmers.

6.2 Discussion and Implications in Relation to Objectives

Implementing this intelligent aquaculture management system has enormous ramifications for Zambia's aquaculture business:

- **Enhanced Fish Health:** Continuous monitoring of water quality indicators offers the best circumstances for fish growth, lowering death rates and improving production.
- **Sustainable Practices:** The technology encourages sustainable aquaculture operations by delivering real-time data, allowing farmers to make more educated decisions while reducing environmental effect.
- **Economic Benefits:** By boosting fish health and production, the method helps small-scale farmers earn more money while also helping economic growth and food security.

6.3 Contribution to the body of knowledge

First, it enhances aquaculture technology by creating a low-cost water monitoring system. This is especially essential because cost is frequently a barrier to the adoption of such technologies, particularly in underdeveloped nations. By developing a more cost-effective approach, we can help make these technologies more accessible, perhaps enhancing aquaculture operations worldwide.

Second, the initiative advances the realm of sensor technology. The development and deployment of water monitoring sensors in this project has the potential to enhance sensor technology, notably in terms of accuracy, dependability, and cost-effectiveness.

Third, this study contributes to the corpus of knowledge on data analysis and machine learning. The data acquired by this system's sensors may be utilized to create and train machine learning models that can subsequently be used to better anticipate and regulate water conditions. This might result in new ideas and approaches for data science.

Lastly, the project promotes interdisciplinary research. It combines elements of computer science, environmental science, and aquaculture, demonstrating the value of interdisciplinary approaches to problem-solving. This could inspire further research that crosses traditional academic boundaries. In conclusion, this project not only provides a practical solution to a real-world problem but also contributes to academic knowledge in multiple fields

This study's research has made numerous major contributions to the world of computer science, notably in the application of IoT technology in aquaculture management:

- **IoT in Aquaculture:** This study revealed the effective implementation of IoT technology in aquaculture, which has been underutilized. The created technology allows for real-time monitoring of water quality indicators, which has the potential to revolutionize aquaculture management techniques.
- **Affordable Technology:** By concentrating on pricing, this study demonstrated that modern technology such as IoT is accessible to small-scale farmers. This removes the barrier of high cost that is commonly associated with such technology.
- **Data-Driven Decision Making:** The system's real-time data allows farmers to make more educated judgments regarding their aquaculture techniques. This element of the study emphasizes the significance of data-driven decision-making in increasing productivity and sustainability.

6.4 Limitations of the system

While the designed system has demonstrated promising outcomes, there are certain limitations:

- **Scalability:** The present method is intended for small-scale operations and may not be appropriate for bigger farms without additional changes and testing.
- **Dependence on Internet Connectivity:** The efficacy of the system is determined on the availability of internet access. In places with low or no internet access, the system's performance may suffer.
- **Limited Parameters:** The system is presently monitoring a limited number of water quality metrics. Other parameters that may influence fish health and growth are not presently incorporated in the system.

6.5 Future works

While this work has made substantial contributions, there are few areas that need additional exploration:

- **Advanced Automation:** Future research should concentrate on incorporating more advanced automation elements, such as automated feeding systems and aeration control, to increase efficiency.
- **Scalability:** Investigate the system's scalability for bigger aquaculture operations, ensuring that it can be tailored to the demands of commercial-scale farms.
- **Data Analytics:** Create more advanced data analytics tools to give deeper insights into water quality patterns and fish health, allowing for predictive maintenance and early

illness identification. Adding colours for users that do not know how to read but can tell for example that red means increased acids and yellow means increased alkalinity.

6.6 Chapter Summary

The creation of a low-cost intelligent aquaculture management system is an important step toward sustainable fisheries management in Zambia. By integrating IoT technology and concentrating on cost and ease of use, this system gives small-scale farmers the tools they need to optimize their aquaculture methods, improve fish health, and contribute to the industry's overall sustainability. Continued research and development in this field will increase the effect of such systems, encouraging a more sustainable and profitable future for Zambia's aquaculture sector.

REFERENCES

Abinaya., M., Survenya., S., Shalini., R., Sharmila, P., & Baskaran, J. (2019). Design And Implementation Of Aquaculture Monitoring And Controlling System. *2019 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC)*, 232–235. https://doi.org/10.1109/ICCPEIC45300.2019.9082359

Abu-Khadrah, A., Issa, G. F., Aslam, S., Shahzad, M., Ateeq, K., & Hussain, M. (2022). IoT Based Smart Fish-Feeder and Monitoring System. *2022 International Conference on Business Analytics for Technology and Security (ICBATS)*, 1–4. https://doi.org/10.1109/ICBATS54253.2022.9759058

Agnihotri, N. (n.d.). *How to design Arduino-based water temperature monitor using DS18B20 1-wire temperature sensor*. Engineers Garage. Retrieved 24 April 2024, from https://www.engineersgarage.com/arduino-based-water-temperature-monitor-using-ds18b20-1-wire-temperature-sensor/

Avadí, A., Cole, S. M., Kruijssen, F., Dabat, M.-H., & Mungule, C. M. (2022). How to enhance the sustainability and inclusiveness of smallholder aquaculture production systems in Zambia? *Aquaculture*, *547*, 737494. https://doi.org/10.1016/j.aquaculture.2021.737494

Belton, B., Little, D., & Grady, K. (2009). Is Responsible Aquaculture Sustainable Aquaculture? WWF and the Eco-Certification of Tilapia. *Society & Natural Resources*, *22*(9), 840–855. https://doi.org/10.1080/08941920802506257

Chowdury, M. S. U., Emran, T. B., Ghosh, S., Pathak, A., Alam, Mohd. M., Absar, N., Andersson, K., & Hossain, M. S. (2019). IoT Based Real-time River Water Quality Monitoring System. *Procedia Computer Science*, *155*, 161–168. https://doi.org/10.1016/j.procs.2019.08.025

Ciriello, R. F., Richter, A., Schwabe, G., & Mathiassen, L. (2023). The multiplexity of diagrams and prototypes in requirements development. *Information and Organization*, *33*(3), 100476. https://doi.org/10.1016/j.infoandorg.2023.100476

Combe, M., Reverter, M., Caruso, D., Pepey, E., & Gozlan, R. E. (2023). Impact of Global Warming on the Severity of Viral Diseases: A Potentially Alarming Threat to Sustainable Aquaculture Worldwide. *Microorganisms*, *11*(4), Article 4. https://doi.org/10.3390/microorganisms11041049

Department, F. F. and A. (2022). *The state of world fisheries and aquaculture. Towards blue transformation*. https://policycommons.net/artifacts/8945635/the-state-of-world-fisheries-and-aquaculture/9788497/

Duangwongsa, J., Ungsethaphand, T., Akaboot, P., Khamjai, S., & Unankard, S. (2021). Real-time Water Quality Monitoring and Notification System for Aquaculture. *2021 Joint International Conference on Digital Arts, Media and Technology with ECTI Northern Section Conference on Electrical, Electronics, Computer and Telecommunication Engineering*, 9–13. https://doi.org/10.1109/ECTIDAMTNCON51128.2021.9425744

Garcia, S. M. P., Santos, C. L. B., Briones, K. M. E., Reyes, S. M. L., Macasaet, M. A. G., & Pula, R. (2020). Automated Water Quality Monitoring and Control for Milkfish Pond. In A.

Beltran Jr., Z. Lontoc, B. Conde, R. Serfa Juan, & J. R. Dizon (Eds.), *World Congress on Engineering and Technology; Innovation and its Sustainability 2018* (pp. 129–139). Springer International Publishing. https://doi.org/10.1007/978-3-030-20904-9_10

Henriksson, P. J. G., Rico, A., Troell, M., Klinger, D. H., Buschmann, A. H., Saksida, S., Chadag, M. V., & Zhang, W. (2018). Unpacking factors influencing antimicrobial use in global aquaculture and their implication for management: A review from a systems perspective. *Sustainability Science*, *13*(4), 1105–1120. https://doi.org/10.1007/s11625-017-0511-8

How Can The Water Industry Benefit From IoT Technology? (n.d.). Retrieved 9 April 2024, from https://www.wateronline.com/doc/how-can-the-water-industry-benefit-from-iot-technology-0001

Huan, J., Li, H., Wu, F., & Cao, W. (2020). Design of water quality monitoring system for aquaculture ponds based on NB-IoT. *Aquacultural Engineering*, *90*, 102088. https://doi.org/10.1016/j.aquaeng.2020.102088

Kour, V. P., & Arora, S. (2020). Recent Developments of the Internet of Things in Agriculture: A Survey. *IEEE Access*, *8*, 129924–129957. https://doi.org/10.1109/ACCESS.2020.3009298

Kumar, M. A., & Aravindh, G. (2020). An Efficient Aquaculture Monitoring Automatic System for Real Time Applications. *2020 3rd International Conference on Intelligent Sustainable Systems (ICISS)*, 150–153. https://doi.org/10.1109/ICISS49785.2020.9316072

Liquid Crystal Displays (LCD) with Arduino | Arduino Documentation. (n.d.). Retrieved 24 April 2024, from https://docs.arduino.cc/learn/electronics/lcd-displays/

Mahmoud, M. M. M., Darwish, R., & Bassiuny, A. M. (2023). Development of an economic smart aquaponic system based on IoT. *Journal of Engineering Research*. https://doi.org/10.1016/j.jer.2023.08.024

Maulu, S., Munganga, B. P., Hasimuna, O. J., Haambiya, L. H., & Seemani, B. (2019). *A Review of the Science and Technology Developments in Zambia's Aquaculture Industry*. *10*(4).

Mekouar, M. A. (2019). 15. Food and Agriculture Organization of the United Nations (FAO). *Yearbook of International Environmental Law*, *30*(1), 544–562. https://doi.org/10.1093/yiel/yvaa059

S, G., A.M, K., A.S, K., & S.M, C. (2017). *Aquaculture in Zambia: An overview and evaluation of the sector's responsiveness to the needs of the poor*. WorldFish and Department of Fisheries, Zambia.

Shen, Y., Ma, K., & Yue, G. H. (2021). Status, challenges and trends of aquaculture in Singapore. *Aquaculture*, *533*, 736210. https://doi.org/10.1016/j.aquaculture.2020.736210

Stickney, R. R., & III, D. M. G. (2022). *Aquaculture, 4th Edition: An Introductory Text*. CABI.

The-Aquaculture-Sub-Sector-in-Zambia-Challenges-and-Opportunities.pdf. (n.d.).

Thilakarathne, N. N., Bakar, M. S. A., Abas, P. E., & Yassin, H. (2023). Towards making the fields talks: A real-time cloud enabled IoT crop management platform for smart agriculture. *Frontiers in Plant Science*, *13*. https://doi.org/10.3389/fpls.2022.1030168

Water and food security | International Decade for Action 'Water for Life' 2005-2015. (n.d.). Retrieved 9 April 2024, from https://www.un.org/waterforlifedecade/food_security.shtml

Yanes, A. R., Martinez, P., & Ahmad, R. (2020). Towards automated aquaponics: A review on monitoring, IoT, and smart systems. *Journal of Cleaner Production*, *263*, 121571. https://doi.org/10.1016/j.jclepro.2020.121571

Zatsarinnaya, Y., Amirov, D., & Elaev, M. (2020). Solar Panel Cleaning System Based on the Arduino Microcontroller. *2020 Ural Smart Energy Conference (USEC)*, 17–20. https://doi.org/10.1109/USEC50097.2020.9281239

APPENDICES

Appendix A

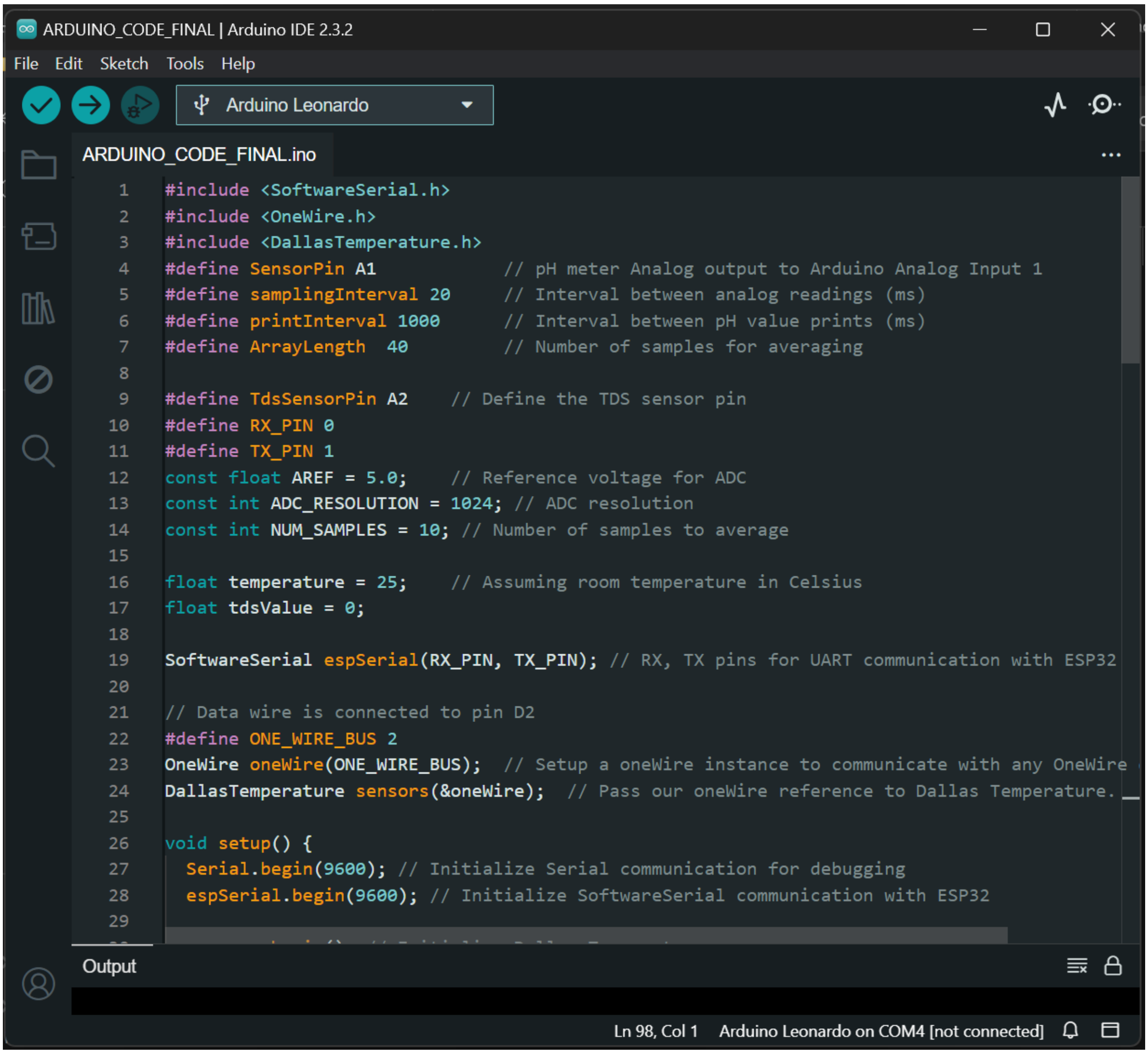

Figure 7.1 Arduino IDE Connection of all Sensors to ESP32

Appendix B

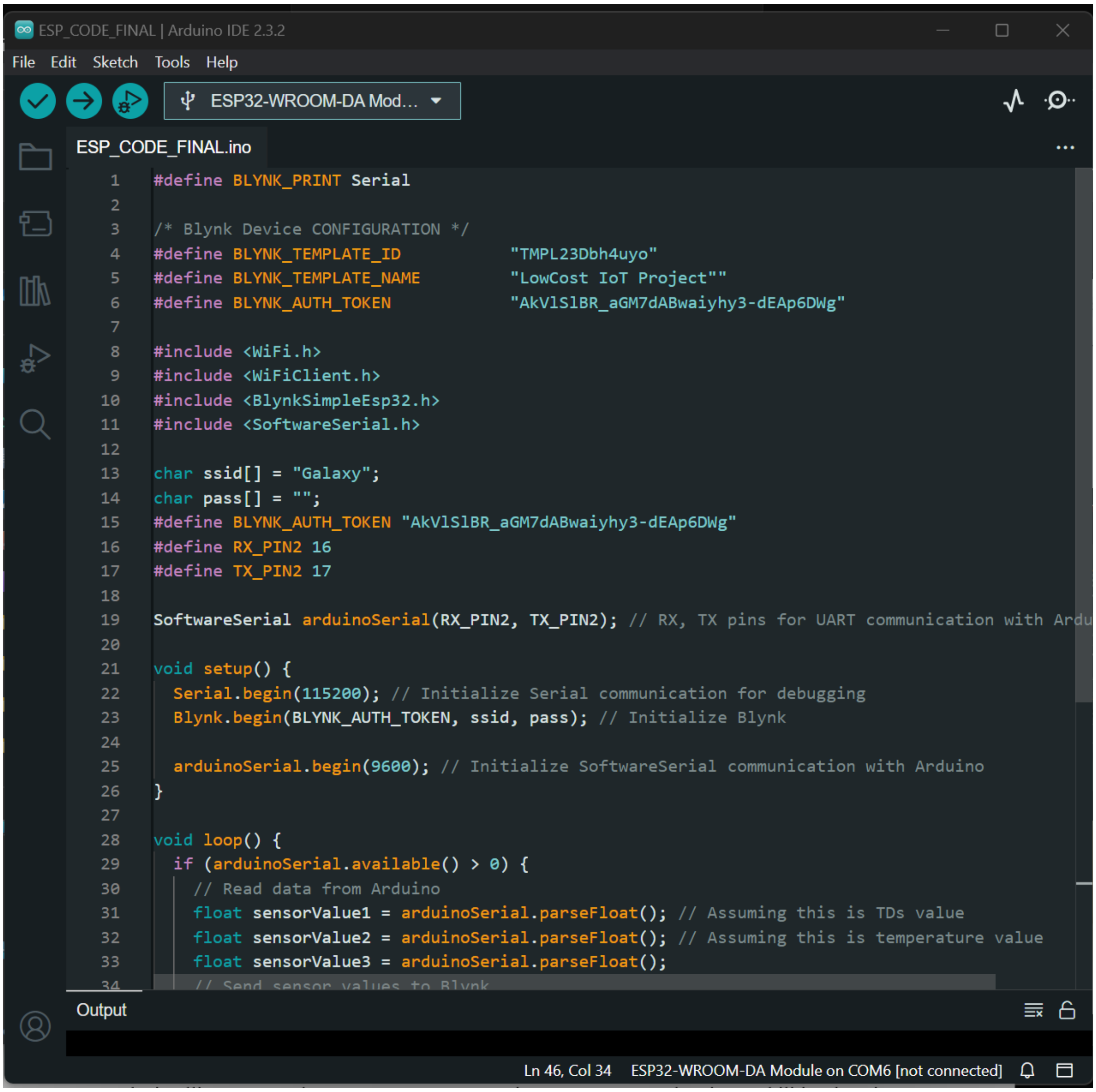

Figure 7.2 ESP32 Receiving Data from Arduino

Appendix C

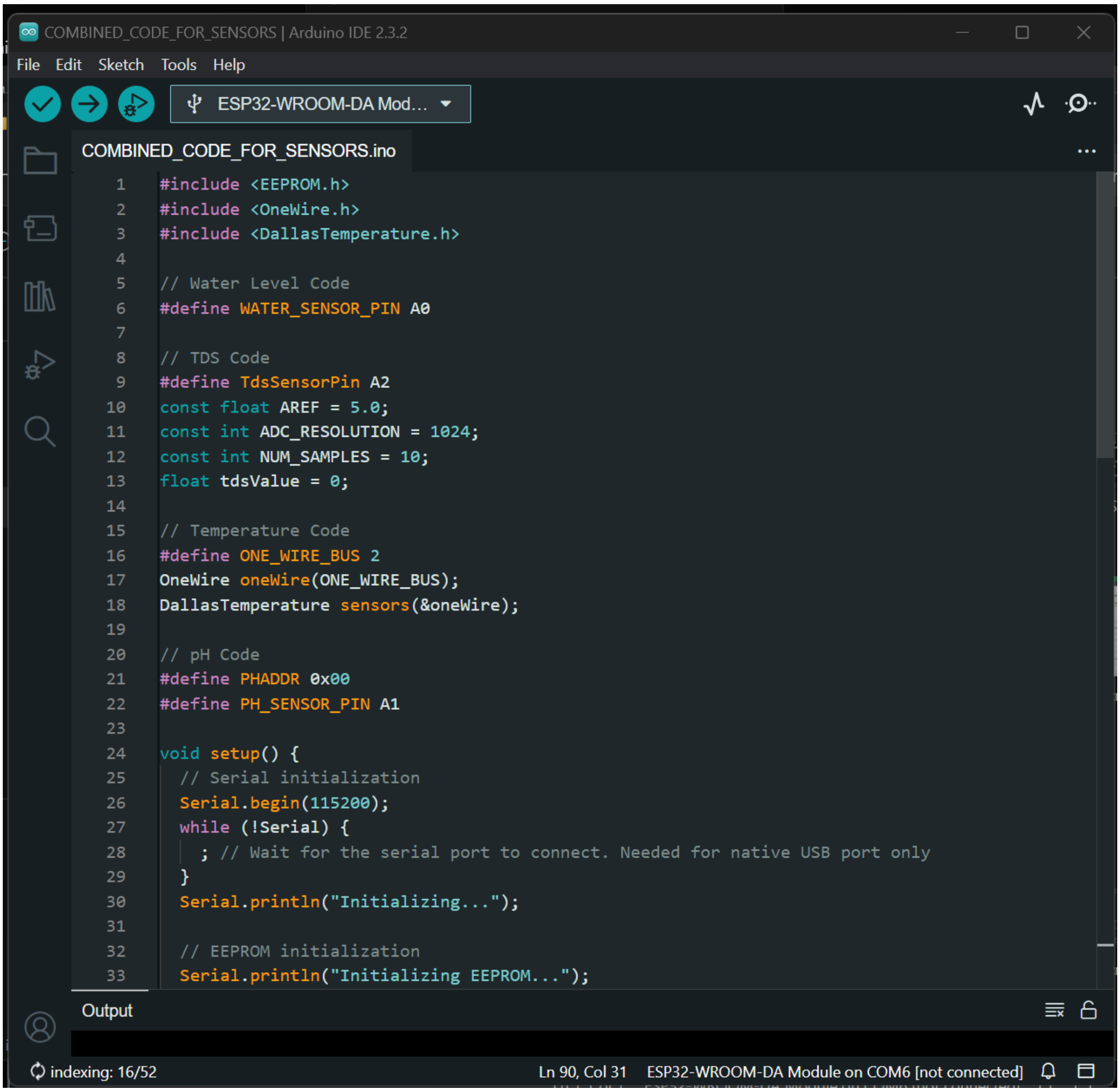

Figure 7.3 Arduino IDE - Code Testing All Sensors