DEVELOPMENT OF A SMART ELECTRONIC SYSTEM FOR MAINTENANCE OF OPTIMUM WATER QUALITY IN WARMWATER FISH CULTURE

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A DISSERTATION PRESENTED TO THE DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING, POSTGRADUATE SCHOOL, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF DOCTOR OF PHYLOSOPHY (PhD.) DEGREE IN COMPUTER ENGINEERING

NOVERMBER 2023

CERTIFICATION

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DEDICATION

This work is dedicated to the almighty God and people who love research.

ACKNOWLEDGEMENTS

I would like to acknowledge the almighty God first, for giving me life, wisdom, knowledge and skills required for doctorate degree work.

I would like to acknowledge my main supervisor, Engr. Prof. F. K. Opara and co-supervisors, Engr. Dr. N. Chukwuchekwa and Engr. Dr. A. O. Akande for their immense contribution throughout the duration of my doctorate programme. I am greatly indebted to them for making this work to reach the standard it is today.

I also like to acknowledge the Dean, Post Graduate School, Prof. B. O. Esonu and Dean, Electrical Systems Engineering Technology of Federal University of Technology, Owerri, Engr. Prof. M. C. Ndinechi for their contribution towards the completion of this work.

I am indebted to the Head of Department of Electrical/Electronic Engineering, Federal University of Technology, Owerri, Engr. Dr. N. Chukwuchekwa and the lecturers of the department such as Engr. Prof. (Mrs) G. A Chukwudebe, Engr. Prof. E. N. C. Okafor, Engr. Prof. D. O. Dike, and Engr. Prof. (Mrs) I. E. Achmba, Engr. Prof. (Mrs) G. N. Ezeh, Engr. Prof. F. I. Izuegbunam, Engr. Dr. C. K. Agubor, Engr. Dr. O. Onojo. Engr. Engr. Dr. C. C, Mbaocha, Dr. O. C. Nosiri, Engr. Dr. I. O. Akwukwaegbu, Engr. Dr. J. C. Uzoegbu, Engr. Dr. L. O. Uzoechi, Engr. Dr. M. Olubiwe, Engr. Dr. S. O Okezi, Engr. Dr. E. S. Mbonu and Engr. R. O. Opara who helped in one way or the other in ensuring that this work is successful.

I also like to acknowledge Mr. F. Ibeamaka and the twelve fish culture experts and fish farm operators who assisted in the research work.

I am thankful to the authors whose work have been consulted, utilized and cited in this thesis.

Finally, I would like to acknowledge my wife and children and my mother and relatives whose support and contribution helped in the successful completion of this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

AC - Alternating Current

AFCD - Agriculture, Fisheries and Conservation Department

DC - Direct Current

DO - Dissolved Oxygen

DOD - Depth of Discharge

EEPROM - Electrically Erasable Programmable Read Only Memory

FAO - Food and Agricultural Organization

FH - Friction Head

GOK - Government of Kenya

GPH - Gallons per Hour

GPRS - General packet radio service

GSM   Global System for Mobile Communications

GUI - Graphical User Interface

IC - Integrated Circuit

ICSP - In-Circuit Serial Programming

IDE - Integrated Development Environment

IoT - Internet of Things IoT

ISP - Interrupt Service Protocol

LCD - Liquid Crystal Display

LED – Light Emitting Diode

LPH - Liters per Hour

MIT - Massachusetts Institute of Technology

MPa - Megapascal

OATA - Ornamental Aquatic Trade Association

PFG - Panel Generation Factor

PH - Pressure Head

Psi - Pound per Square Inch

PTFE - Polytetrafluoroethylene

PV - Photovoltaic

PWM - Pulse Width Modulation

PWQMR - Pond Water Quality Maintenance Record

RAM – Random Access Memory

SH - Static Head

SMS - Short Message Service

SRAM – Static Random Access Memory

TDH - Total Dynamic Head

TDS - Total Dissolved Solids

TSS - Total Suspended Solids

TTL - *Transistor–Transistor Logic*

UART - Universal Asynchronous Receiver-Transmitter

USB - *Universal Serial Bus*

ABSTRACT

This dissertation presents the development of smart electronic system for maintenance of optimum water quality in warmwater fish culture. The aim of the research work was to develop an efficient and reliable automation system for maintenance of optimum water quality required for optimal production and sustainable warmwater fish culture. The optimum water quality maintenance system was divided into four subsystems; optimum water temperature maintenance system, optimum water dissolved oxygen maintenance system, optimum water pH maintenance system and preventive maintenance system. The four subsystems where developed separately and then integrated to form the desired optimum water quality maintenance system for warmwater fish culture. Each of subsystems was developed via designing and simulation, calibration and validation of sensors, hardware implementation and software development. Top down design approach was adopted in designing the hardware and program while bottom up design approach was adopted in designing application for the system. Arduino Mega 2560 was used to control all the operations of the system. Other major components of the system include water quality monitoring sensors such as temperature, dissolved oxygen, pH and turbidity sensor, solenoid valves, ultrasonic sensor, water pump, servo motor, GPRS gateway, liquid crystal display and Smartphone. The subsystems were tested by subjecting each of them to various optimum limits of the water quality parameter it maintains in a 2m x 1.6m x 1.2m fish pond and observing the pond, liquid crystal display and Smartphone. The complete system was tested by installing its sensors in fish pond and switching it ON and allowing it to operate for two months. The results of the tests showed that the system maintained optimum water quality in warmwater fish culture by maintaining water temperature at a range of 20^{o}C to 28^{o}C, dissolved oxygen at 5mg/L to 7.5mg/L, pH at 6.8 to 8.5, turbidity at 10mg/L to 20mg/L and water level at 1.17m to 1.2m. The system was fully developed and performed its optimum water quality maintenance operation by using simple and low-power consuming components for exchanging portion of the water with appropriate water when any of the quad-essential water quality parameters reached optimum level and adequately prevented water quality problems with efficiency of 96%. The system also displayed the level of each pond water maintenance parameter on LCD and sent information about condition of the pond water and maintenance action taken to Smartphone via application and global packet radio service gateway.

Keywords: *Smart System, Optimum Water Quality, Warmwater Fish Culture, Maintenance, Parameter, Sensor.*

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Water is essential for the life of all living organism. It is the medium that must supply or support all their needs, including breathing, eating, reproducing and growing. All living organisms including fishes have tolerable limits of water quality parameters in which they perform optimally (Cline, 2019). A sharp drop or an increase within these limits has adverse effects on the body functions of fishes (Boyd, 2017; Kiran, 2010; Tumwesigye, Tumwesigye, Opio, Kemigabo., & Mujuni, 2022). So, good water quality is very essential for survival and growth of fish. Good water quality is characterized by adequate oxygen, proper temperature, pH and turbidity, limited levels of metabolites and other environmental factors affecting water in which fish lives (Bhatnagar & Devi, 2013: Uzukwu, 2020).

There has been sharp increase in demand of fish products due to increasing population pressure in the world (De Silva, 2016; FAO, 2016; Naylor *et al*., 2021) and the awareness that fish improves human health because of its protein content (FAO, 2020). Thus to meet the demand of present food supply, fishes are cultivated in ponds-lentic water (De Silva, 2012). A study by Naylor *et al*., (2021), revealed that freshwater fish account for about 75% of the global edible aquaculture volume in 2021 and this was justified as the global aquaculture development has steadily increased over the last two decades (Garlock *et al*., 2020). Water quality management in fish ponds is a necessary step that is required for achieving optimal production and sustainable fish culture (Little, Newton, & Beveridge, 2016: Sallenave, 2019).

Growth of fish is dependent on a wide range of positive or negative impacting factors. Studies showed that growth of fish in aquaculture mainly depends on abiotic factors such as water chemistry or pH, temperature, turbidity and oxygen level (Abedin, Bapary, Rasul, Majumdar, & Haque, 2017; Ariadi, Fadjar, & Mahmudi, 2019; Bhatnagar & Devi., 2013; Makori, Abuom, Kapiyo, Anyona, & Dida, 2017) in addition to feed consumption and quality; stocking density (Maucieri *et al*., 2019; Turner, Ngatunga, & Genner, 2019); biotic factors such as sex, age and genetic variance (Bhatnagar & Devi., 2013). Fish growth is generally greater in ponds with optimal levels of dissolved oxygen (DO) and temperature among other parameters (Bartholomew, 2010; Tumwesigye *et al.*, 2022), though different fish species have ideal levels of water quality parameters within which they grow optimally. For example, warmwater fishes need temperatures above 15°C to breed, grow best at temperatures over 20° C and can survive very high temperatures above 30 to 35°C (Coche, Muir, & Laughlin, 1996; Kleinholz, 2017). So the maintenance of all the factors becomes very essential for getting maximum yield in a fish pond. Successful fish culture therefore, requires stocking of good species of fish, feeding fish with good quality feed and controlling water quality. In order to achieve optimum production, water quality is maintained at optimum level. Optimum water quality maintenance is achieved by keeping the quad-essential water quality parameters (oxygen, temperature, pH and turbidity) in optimal levels (Cline, 2019: Coche *et al*,, 1996; GOK, 2016: Lamtane, Mgaya, & Bailey, 2017; Uzukwu, 2020).

Conversely, non-maintenance of optimum water quality can result to water quality problems and this hinders achievement of optimal production. Water quality problems are caused by environmental phenomena (heavy rains, pond overturn, hot weather and drought) and mismanagement (AFCD, 2009; Ssekyanzi, Nevejan, Kabbiri, Wesana, & Stappen, 2022; Wanja *et al.*, 2020). Water quality problems or suboptimal levels or concentrations of the water quality parameters can cause poor development and growth, weakness and poor health and death of fishes amongst others (Bhatnagar & Devi, 2013; Kleinholz, 2017: Tumwesigye *et al*, 2022). This is because fishes do not like any kind of changes in their environment; any change adds stress to the fishes and the larger and faster the changes, the greater the stress. Suboptimal levels or Low and high pH (e.g. below 6.5 and above 9.0) can cause *acidosis* and a*lkalosis* respectively when fishes are subjected to them for too long (Tucker & D'Abramo, 2008) and can lead to death of fishes. Similarly, higher temperature such as 35^{o}C increases the rate of bio-chemical activity of the micro biota, plant respiratory rate, and oxygen demand, decrease solubility of oxygen and increases level of ammonia in water. In addition, a relatively low water temperature can adversely affect fish by slowing down the development of their eggs; reducing the growth of juveniles and older fish; delaying and even preventing their maturation and spawning; decreasing their food intake and even stopping it completely and increasing their susceptibility to infections and diseases (Bhatnagar & Devi., 2013). Low oxygen level in pond water leads to poor feeding of fish, starvation, weakness reduced growth and more fish mortality (Makori *et al.*, 2017). Highly turbid water restricts penetration of light in pond water and causes reduction in rate of photosynthesis and oxygen production during the daytime and, this badly affects the growth of the fish and their natural food organisms (Uzukwu, 2020). In addition, a high mineral turbidity can affect fish directly by injuring their breathing organs, reducing their growth rate or preventing their reproduction (Coche *et al*., 1996). The resulting effect of poor water quality is poor performance or production (Boyd, 2017) and economic loss (Gayo, 2021). In addition, poor water quality of fish pond causes air pollution and contamination of land and crops when the water is discharged from ponds while controlling water quality (AFCD, 2009; Kleinholz, 2017: Tom, Jayakumar, Biju, Somarajan., & Ibrahim, 2021).

Solutions to fish pond water problems or control of water quality therefore, requires an understanding of the pond water since a special set of water chemistry requirements and optimal water quality is essential to a healthy, balanced, and functional (well managed) aquaculture system. Conventionally, water quality control or maintenance involves taking adequate precautionary measures, monitoring of important water parameters regularly using tools or through mere observation and performing tasks such as addition or subtraction of substances or removal and replenishment of portion of pond water (Uzukwu, 2020: Virapat, Wilkinson, & Soto, 2017). In case of temperature, high pond water temperature is lowered by addition of cooler, good quality water to the pond while low pond water temperature is normalized by addition of warmer good quality water. On the other hand, high or low pH pond water is corrected by replacing part of the water with neutral water (Lynn, 2018) while high turbid pond water is corrected by replacing part of the dirty water with good quality water or by filtration (Bhatnagar & Devi., 2013) or addition of or lime to the pond. Pond water with low DO is corrected by aeration (Coche et al., 1996) while high DO is corrected by introduction of the hot water gradually with pipes. Although the conventional method of water quality monitoring can be effective in solving fish pond water problems, observation method is prone to errors (Helfrich, 2021) and monitoring through testing of water parameters may be done on many samples and many times in a day, and this makes it to be strenuous, time consuming and prone to errors (Bokingkito & Llantos, 2017). In addition, measurement of the parameters may be inaccurate as a result of tools used and time of the day when the measurements are made and therefore are unreliable. In some cases, when there is sudden change in the parameters, measurements may not be made because there is no device fixed permanently in the pond to alert the owner when such change occurs. Additionally, many fish farmers in the world especially small scale farmers do not monitor pond water quality parameters as a result of their ignorance and cost of hiring workers who will monitor the pond quality daily (Obado, 2019). Some farmers monitor their pond quality but not regularly (Idachaba, Olowoleni, Ibhaze, & Oni, 2017) and this is as a result of inaccessibility of measuring equipment and lack of technical know-how in measuring the parameters. Low-cost automation system for solving fish pond water problems is therefore needed as it will allow the fish industry to improve environmental control, reduce catastrophic losses, reduce production cost, and improve product quality but investment and operating costs of automation systems are the biggest obstacles (Harun, Reda, & Hashim, 2018).

Furthermore, over the last two decades, global aquaculture development has steadily increased (Dickson, 2022; Garlock *et al*., 2020; Mzula, Wambura, Mdegela, & Shirima, 2021); advanced techniques and methods and electronic devices for fish pond water quality monitoring and control have been developed, and integration of aquaculture with other activities has emerged (Bouhali, Kouadri, Beya, & Imad, 2021; Goddard, & Al-Abri, 2018). Upon these developments, only few electronic systems have been developed and deployed to aid in solving fish pond water problems. Some of these systems only monitor water quality parameters and do not control water quality (McCann, 2015; Idachaba *et al*, 2017; Sutar & Patil, 2013) while very few of them monitor and control water quality (Harun *et al*., 2018; Mohammed & Al-Mejibli, 2018; Ujwala, Sunita, Yamuna, & Vandana, 2020). These electronic systems are inefficient and so have not been fully deployed in fish ponds. Moreover, the systems that monitor and control water quality do not maintain optimum water quality or perform adequate preventive maintenance on fish pond water and they are expensive.

This research employed the recent and new technologies of monitoring and controlling system to solve fish pond water quality problems. An electronic system which used several types of sensors, microcontrollers and other components to control pond water quality and maintains optimum water quality was developed. The system prevents fish pond quad-essential water quality parameters from increasing beyond or decreasing below optimum limits by taking adequate preventive measures, monitoring the parameters regularly, and taking control action whenever any of them reaches optimum limit.

1.2 Statement of the Problems

Fish production is affected by water quality problems. The problems are mainly recognized by problems of oxygen, temperature, pH and turbidity (quad-essential water quality parameters) and they cause poor development and growth, weakness and poor health of fishes and death of fishes amongst others thereby affecting production negatively (Boyd, 2017; GOK, 2016). Maintenance of optimum water quality is therefore, necessary for achieving optimal production and sustainable fish culture.

The conventional methods of water quality maintenance in warmwater fish culture which involve taking of preventive measures, regular monitoring of the essential water quality parameters using meters and test tools or through mere observation and taking of control action are strenuous, tiresome, time consuming (Bokingkito & Llantos, 2017) and prone to errors (Helfrich, 2021).

Conversely, many fish farmers in the world especially small scale farmers do not monitor water quality parameters in their ponds or tanks while some monitor but not regularly as a result of ignorance, cost of hiring workers for monitoring the water quality daily (Obado, 2019) and lack of knowledge and tools/equipment, and these cause poor maintenance of fish pond water quality (Idachaba *et al*, 2017) contended that inaccessibility of measuring equipment and lack of technical know-how in measuring the parameters are the causes of irregular monitoring of water quality.

On the other hand, few electronic automation systems have been developed for maintaining water quality in fish culture. The systems do not control all the quad-essential parameters nor maintain optimum fish pond water quality. More so, investment and operating costs of these systems are high (Harun *et al.*, 2018).These systems are inefficient, unreliable and have not been fully deployed/used in fish ponds (Mohammed & Al-Mejibli,. 2018).

There was therefore, the need for the development of an efficient, low-cost, automation system for maintaining optimum pond water quality in warmwater fish culture.

1.3 Aim and Objectives of the Study

The aim of this research work is to develop a smart electronic system for maintenance of optimum water quality in warmwater fish culture.

The specific objectives are to:

i. Develop a subsystem for maintenance of optimum water temperature in warmwater fish culture.

ii. Develop a subsystem for maintenance of optimum water DO in warmwater fish culture.

iii. Develop a subsystem for maintenance of optimum water pH in warmwater fish culture.

iv. Develop a subsystem for prevention of water quality problems in warmwater fish culture.

v. Integrate the optimum water temperature, DO and pH maintenance subsystems and preventive maintenance subsystem.

1.4 Justification of the Study

i. The smart electronic system helps fish farmers to achieve optimal production and sustainable warmwater fish culture

ii. The system also helps fish farmers to successfully produce fishes with less effort, energy and cost

iii. The development of the smart electronic system as regards to pond water quality control in warmwater fish culture encourages meaningful and advanced development in electronic systems for pond water quality control in fish culture.

iv. The process of designing fish pond water quality control system is now transparent and less susceptible to bias as the study has provided detailed information on fish pond water quality and problems, and conventional and electronic solutions to the problems.

v. The system provides recorded information on fish pond water quality parameters via an application which can help fish farmers know the trend of variation of the parameters with weather.

1.5 Scope of the Study

This work was limited to the development of an electronic system that takes adequate preventive measures against pond water quality problems, monitors the quad-essential water quality parameters regularly and takes control action when any of the parameters reached optimum limit in pond or tank with maximum area of $45m^2$ and depth of 2m.

The work focused on designing, simulation and implementation of the electronic system for optimum pond water quality maintenance, validation of instrument and testing of implemented system.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theory of Warmwater Fish Culture

The theories presented herein include theories on fish culture, water quality in fish culture and water quality maintenance in warmwater fish culture.

2.1.1 Fish culture

Fish culture is rearing or cultivation of fish in ponds (lentic water) or tanks. The vast majority of fish pond water is fresh water (or freshwater) and is any naturally occurring water except seawater and brackish water (FAO, 2005). Freshwater includes water in ponds, lakes, rivers, streams, ice sheets, ice caps, glaciers, icebergs, bogs and even underground water called groundwater (Maseke & Rao, 2018).

In fish culture, growth and survival of fish is dependent on a wide range of positive or negative impacting factors. These factors include abiotic factors such as water chemistry or pH, temperature , turbidity and oxygen level (Abedin *et al*., 2017; Ariadi *et al*., 2019; Makori *et al*., 2017) in addition to feed consumption and quality; stocking density (Maucieri *et al*., 2019), biotic factors such as sex, age and genetic variance (Bhatnagar & Devi., 2013). Maintenance of all these factors is very essential for getting maximum yield in fish culture (Tumwesigye *et al.*, 2022),

Good water quality for warmwater fish culture characterized by adequate oxygen (3.5mg/L - 8mg/L), proper temperature (20^{o}c - 30^{o}c), pH (6.5 - 9.5) and turbidity (30cm – 80cm), limited levels of metabolites and other environmental factors (Bhatnagar & Devi, 2013), is very essential for survival and growth of fish. Generally fish growth is greater in ponds with optimum levels of dissolved oxygen (DO) and temperature among other parameters (Tumwesigye *et al.*, 2022). Any change in environmental condition adds stress to the fishes and the larger and faster the changes, the greater the stress (Nocheski & Naumoski, 2018). In other words, maintenance of optimum water quality is very essential for getting maximum yield in fish culture.

2.1.2 Fish culture water quality

The fish pond water contains two major groups of substances; dissolved substances and suspended particles (Boyd, 2017; Coche *et al.*, 1996).

Dissolved substances are made of:

i. Gases: oxygen carbon dioxide and hydrogen sulphide.
ii. Minerals: salts of calcium, magnesium, sodium, potassium, iron and compounds of nitrogen and phosphorus.
iii. Organic compounds: proteins and carbohydrates.

Suspended particles are made of:

i. Non-living particles: minerals (such as silt and clay) and organic materials such as detritus, dead organisms and humus.
ii. Microscopic living organisms (the *plankton*): plant forms (*phytoplankton*) and animal forms (*zooplankton*).

The composition or characteristics of pond water depend both on the water that is used in filling the pond and on the characteristics of the soil. The composition of pond water changes continuously, depending on climatic and seasonal changes and on how a pond is used (Barange *et al*., 2018; Uzukwu, 2020).

Within the pond or tank water, some major chemical processes take place which usually change the water composition. The processes include:

i. Respiration (plants and animals): oxygen gas is consumed and carbon dioxideis produced.
ii. Photosynthesis (plants only): whenever sufficient light is available, carbon dioxide is used for the production of plant material, while oxygen gas is released from the plants.
iii. Decomposition: dead plants and animals decay under the action of minute organisms called *bacteria*, and oxygen is used to produce mineral and organic compounds.

The processes constantly change the water composition as follows:

i. During the day, by increasing the oxygen production and decreasing the carbon dioxide content through photosynthesis.
ii. During the night, by decreasing the oxygen content of the water and increasing the carbon dioxide content, through respiration in the absence of photosynthesis.

The greater the quantity of plants, animals and bacteria in the water, the more these processes change the water composition. In heavily stocked ponds or ponds that have water shortage problem, therefore, these changes are greater and need more careful management. All of these chemical processes are influenced by the water temperature (Barange *et al*., 2018; GOK, 2016). The warmer the water, the more these processes increase, and the more quickly the water composition can change. According to Coche *et al.* (1996) and Boyd (2017), change in water composition is recognized by changes in the water parameters such as chemical reaction of water (pH), temperature, turbidity and dissolved oxygen content of water.

So, fish pond water quality mainly changes with changes in the main characteristics of pond water or quad-essential fish pond water quality parameters (pH, water temperature and turbidity and dissolved oxygen content of water). Change in water composition can also be recognized by changes in other water parameters such as ammonia, salinity, alkalinity, hardness, (Bhatnagar & Devi, 2013; Cline, 2019), nitrite, carbon dioxide, hydrogen sulphide and Plankton (Banrie, 2012; Kleinholz, 2017). These other parameters directly affect animal health, feed utilization, growth rates and carrying capacities. Ammonia, nitrite, carbon dioxide and hydrogen sulfide are the principal toxic metabolites excreted by fish, bacteria and plankton in fish culture systems. While the whole solid material that is floating and dissolved, turbidity, color, odor, taste and temperature of water are the physical characteristics/parameters of water (they relate to the medium in which plants and animals live), pH, salinity, content of chemical compounds and hardness are the chemical parameters (Warish, Abdul, Adil & Najib, 2017).

Fish pond water quality problems are therefore, problems mainly associated with the quad-essential water parameters because problems of these other parameters are linked to problems of the quad-essential water parameters (Bhatnagar & Devi., 2013).

2.1.3 Water quality maintenance in warmwater fish culture

In fish farming, water quality control directly affects fish production. As mentioned in section 2.1, there are many water criteria (quad-essential parameters) that must be taken into consideration in order to maintain high quality of water. The quad-essential parameters influence fish production and each other and they are influenced by many other factors such as surrounding environment (Bhatnagar & Devi., 2013; Boyd, 2017).

Maintaining the essential water parameters within the acceptable ranges will prevent water quality problems and leads to achievement of sustainable fish culture.

The suggested acceptable, desirable and critical ranges of the criteria/water quality parameters for ponds used for warmwater fishes are depicted in Table 2.1.

Table 2.1: Acceptable, desirable/optimum and critical ranges of water quality parameters for the general warmwater fish culture

PARAMETER	ACCEPTABLE RANGE	DESIRABLE RANGE	CRITICAL LEVEL
Temperature (^{o}c)	15 – 35	20 – 30	<12, >35
pH	7 – 9.5	6.5 – 9.0	<4, >11
DO (mg/L)	3 – 5	5	<5, >8
Turbidity (cm)	20 - 80	30 – 80	<12, >80
Alkalinity (mg/L)	50 – 200	25 – 100	<20, >300
Hardness (mg/L)	>20	75 – 150	<20, >300
Ammonia (mg/L)	0 – 0.05	0 - <0.025	>0.3
Nitrite (mg/L)	0.02 – 0.2	<0.02	>0.2
Nitrate (mg/L)	0 – 100	0.1 – 4.5	<0.01, >100
CO_2 (mg/L)	0 – 10	5 – 8	<5, >12
H_2S (mg/L)	0-0.02	0.002	Any detectable level
BOD (mg/L)	3 – 6	1 – 2	>10
Calcium (mg/L)	4 – 160	25 – 100	<10, >250
Phosporous (mg/L)	0.03 – 2	0.01 – 3	>3

CO_2 = carbon dioxide; H_2S = hydrogen sulfide; BOD = biochemical oxygen demand

(Source: Bhatnagar & Devi., 2013)

The maintenance of pond water quality or solution to fish pond water quality problems for warmwater fishes therefore, involves measures that ensure the achievement of optimum water quality in the fish pond. The measures include taking of adequate precautions, monitoring and contingency response (Barange *et al*., 2018; AFCD, 2009). Generally, fish pond water quality problems can be prevented by taking precautionary measures and solved by performing tasks such as addition or subtraction of substances or removal and replacement of part of pond water. Water quality problems are prevented by taking precautionary measures mainly on pond design, water source and depth/volume, feeding style, and population of fishes and plankton in the pond.

The first precaution taken for proper management of pond water quality is the use of standard pond. Good pond water quality is achieved better in standard ponds than in substandard types. A standard pond is one with good design and filled with good quality water; with large pond area (not smaller than $2000m^2$ for large-scale commercial ponds); **w**ater depth of 1.2m to 1.8m (4ft to 6ft) deep; pond bottom made up of a layer of clay or concrete or butyl liners; have a good drainage system; strong pond bunds; good orientation and well located (AFCD, 2009). The actual size is decided with reference to the species to be stocked so that water quality and stocking are not affected negatively (FAO, 2005). Another precaution taken for prevention of pond water quality problems is use of good quality water in filling ponds and replacement of lost pond water to maintain a constant level or volume of water. Yet another precaution taken for prevention of pond water quality problems is maintenance of optimum number of fish and plankton population and fish feeding rate**.** Most water quality problems can be avoided by maintaining fish stocks less than 2,000 lbs/acre and feeding rates less than 30 lbs/acre (AFCD, 2009). Bhatnagar and Singh (2010) suggested that the optimum plankton population in pond fish culture is approximately 3000-4500 plankton per liter and is seen in the colour of pond water (light green colour).

The fish pond water quality problems for warm water fishes can be detected through monitoring of the essential water parameters. In general, monitoring of water quality involve detection of levels of the essential water parameters and comparing them with standard values/ranges such as the ones shown in table 2.1. Water quality is monitored through observation or use of meters/test tools or modern electronic systems. Water quality tests conducted using tools are usually expensive, complicated, and may be inconclusive (Bokingkito & Llantos, 2017). According to the conventional methods of water quality monitoring, samples of water are taken and transported to a chemical laboratory for analysis of hazardous substances or tested in the pond. A number of water samples from the surface and bottom waters and from the pond entrance and exit waters are usually required to identify a problem. Experienced fish farmers usually conduct water quality tests daily to establish the pattern of conditions in their ponds because pond water quality may change rapidly (within hours). The maintenance of the measurements and control process is manually influenced by the personal experience.

2.2 Fish Pond Water Temperature

The main source of heat for fish pond water is solar radiation. The amount and angle of incidence of sunlight decides the energy entering the pond and thus the temperature of pond. Much of heat mixing takes place by convection aided by wind action (Harun *et al.*, 2018). So, distribution of heat within the water by conduction is negligible because of very low heat conductivity of water especially in the tropics.

The growth and activity of the fish depend on its body temperature. Temperature is the degree of hotness or coldness in the body of a living organism either in water or on land. The body temperature of fish is about the same as the water temperature (0.5 to 1°C above or below the water temperature) and varies with it (Kleinholz, 2017)**.** This means that fish is a cold blooded (poikilothermic) animal and its body temperature changes according to that of environment and affecting its metabolism and physiology and ultimately affecting the production (Bhatnagar & Devi, 2013).

2.2.1 Fish pond water temperature problems

Water temperature problem is the most critical problem in fish pond. It affects fish level of activity such as feeding and reproduction because of their cold-blooded nature and the water DO and pH (Barange *et al*., 2018; Coche *et al.*, 1996).

(a) Causes of fish pond water temperature problems

Heat is lost in the pond water due to evaporation and also by direct exchange to air and substratum-the soil underneath (AFCD, 2009). So, the temperature of pond waters is greatly influenced by weather, pond size, location, design and materials used in building it or type of soil of the pond. Weather and small pond size or shallow water makes pond water more susceptible to temperature change. In artificial ponds with depth of 1m to 2m, there is only a minor temperature difference between the surface and water bed (Harun, *et al.*, 2018). The surface water temperature could be much higher in the afternoons and it is likely that fish take shelter in the cooler and deeper portions of the pond for comfort and probably to survive.

Decrease in the level/depth of pond water (pond water shortage) can also influence pond water temperature (AFCD, 2009). Pond water shortage is caused by water loss as a result of climatic change, human error and fish feeding. The main sources of water loss include: evaporation, seepage and intentional discharge (Barange *et al*., 2018; Troell, Metian, Beveridge, Verdegem, & Deutch, 2014; AFCD, 2009). Evaporative losses increase with pond surface area and with temperature (Barange et al., 2018), modified by wind movement and topography, and can be as high as $63m^3$ per hectare (Verdegem, Bosma, & Verreth, 2006). Decrease in the level/depth of pond water can make pond water to be shallow and this causes water temperature fluctuation.

(b) Effects of extremes of fish pond water temperature

Fish mortality due to temperature change is a rare phenomenon in the tropical plains. Quite often, fish mortality observed is not due to temperature, but a combination of factors e.g. temperature, low oxygen, metabolite load and salinity (Barange *et al*., 2018; Coche et al., 1996). Water temperature directly affects the reproduction, growth and survival of fish (Enders & Boisclair. 2016). In aquaculture, any fish species is adapted to grow and reproduce within well-defined ranges of water temperatures, but optimum growth and reproduction take place within narrower ranges of temperature. This range depends on whether the fish is *coldwater* or *warmwater fish a*nd temperature outside the range is critical. Coldwater fishes need water temperatures below 15°C to breed, grow best at temperatures below 18°C and rarely survive long at temperatures above 25°C (Coche *et al.*, 1996). On the other hand, warmwater fishes need temperatures above 15°C to breed, grow best at temperatures over 20°C and can survive very high temperatures above 30°C to 35°C. For example, water temperatures outside 25°C to 27°C for tilapia (Dewalle, Swistock, & Sharpe, 2011) is critical and thus, affects their reproduction, growth and survival.

Higher pond water temperature increases the rate of bio-chemical activity of the micro biota, plant respiratory rate, and so increase in oxygen demand (Barange *et al*., 2018). It further causes decreased solubility of oxygen and also increased level of ammonia in water (Bhatnagar & Devi., 2013). The water temperature also affects the breathing, or respiration, of the fish because the fish require sufficient dissolved oxygen in the pond water. The maximum quantity of dissolved oxygen present in water depends on its temperature: the warmer the water, the less dissolved oxygen it can contain. For this reason, if the pond becomes too warm, the fish can run out of oxygen.

On the other hand, under extended ice cover caused by low temperature, the gases like hydrogen sulphide, carbon dioxide and methane can build up to dangerously high levels affecting fish health. A relatively low water temperature can adversely affect fish by:

i. Slowing down the development of their eggs.
ii. Reducing the growth of juveniles and older fish.
iii. Delaying and even preventing their maturation and spawning.
iv. Decreasing their food intake and even stopping it completely.
v. Increasing their susceptibility to infections and diseases.

(c) Effect of temperature on water density.

Temperature also affects the density of water. The density of fresh water measured in mg/mL is at its maximum at 4°C and decreases at higher or lower temperatures as shown in figure 2.1.

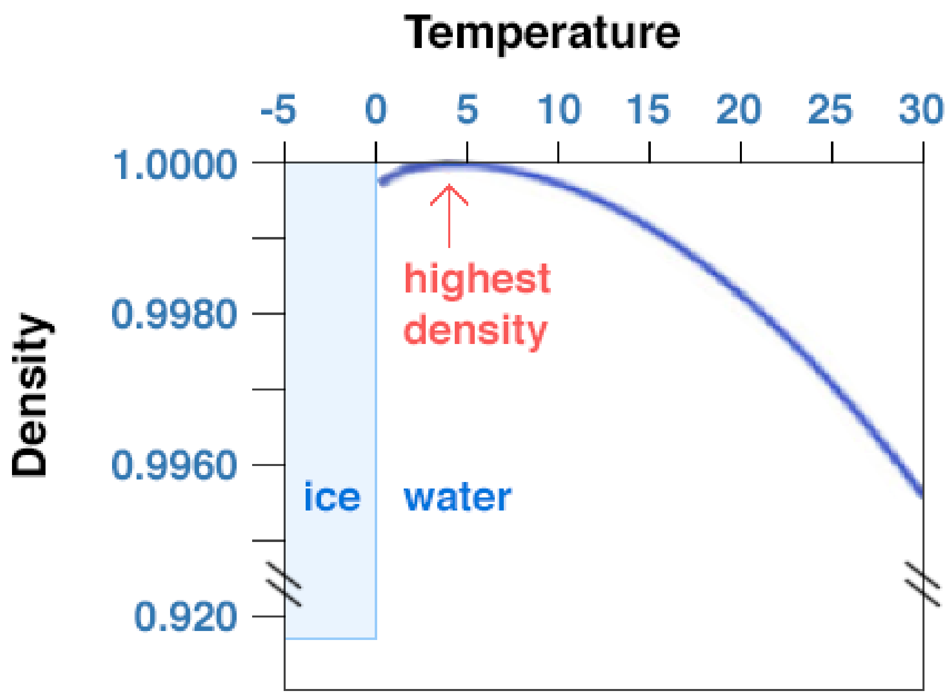


Figure 2.1: Effect of temperature on water density (Source: Arthur & Saffer, 2021)

The variation of temperature with the density of water has several consequences for fish ponds and they include:

i. Water becomes lighter as it cools down *below* 4°C. The ice which forms at 0°C will float on the surface of the pond water of temperature between 0°C and 4°C, and water below it will be warmer.

ii. Water becomes lighter as it warms up *above* 4°C. Therefore, the warmest water is always at the top of a pond and the coolest water at the bottom.

iii. Over longer periods of warm weather, the warmer and lighter surface waters tend to form a separate layer from the colder and heavier bottom waters. So the pond water *stratifies* into *distinct layers*.

iv. In deeper ponds (e.g. barrage ponds or ponds with depth greater than 1.2 or 1.5m), such stratification may establish itself for a long period. As shown in figure 2.2, The pond water then forms three different layers:

a) The upper, warmer and lighter *epilimnion*- in which the water temperature is relatively similar across the layer; the water is well mixed by wind, and usually has active photosynthesis and good oxygen levels.

b) The *thermocline*- in which the water temperature drops and the density increases rapidly, thereby forming a sort of barrier which separates the pond water into two distinct parts.

c) The lower, cooler and denser *hypolimnio*- in which the water temperature is relatively similar across the layer. The water cannot be mixed by wind any more, and in the absence of light and photosynthesis, dissolved oxygen gradually decreases, being mostly used for decomposition. Dissolved oxygen may even disappear completely from the bottom water, making life for fish and many other plants and animals impossible in this part of the pond..

Heavy cool rains or strong winds can cause this water stratification to break up in cooler weather. The whole water mass then *turns over*, bringing the cooler, oxygen-poor bottom waters to the surface of the pond and sometimes killing the fish. The nutrients and feed materials brought up from the bottom water can also cause excessive plankton growth in some cases which can restrict sun light penetration.

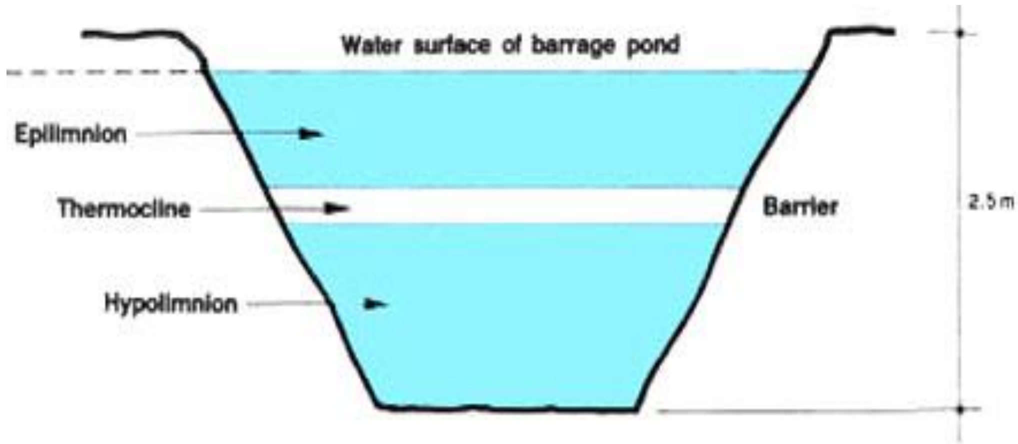


Figure 2.2: Thermal stratification of water in deeper ponds (Source: Coche *et al*., 1996)

Diurnal stratification of oxygen also occurs in shallow aquaculture ponds in cold region such as central Europe (Oberle, 2019).

2.2.2 Solutions to fish pond water temperature problems

Conventionally, water temperature problems are solved via monitoring, control action and adequate preventive measures.

(a) Monitoring of fish pond water temperature

Water temperature is monitored through observation or use of thermometer/meters or modern electronic systems. According to FAO (2005), the best time to monitor pond is immediately after sunrise (around 6.30an) when the air temperature is near its minimum value**,** and again shortly after midday (around 1.00pm)**,** when the air temperature is near its maximum value

Monitoring of pond water temperature through observation involves watching behaviour of fishes in the pond. The main behaviour of fish that can be used to detect temperature problem is decreased food intake (as a result of reduces appetite) caused by excessively high or low water temperature (Warish *et al*., 2017). Fish may stop eating completely due to total loss of appetite at a relatively low water temperature. Excessive high water temperature is detected when fishes avoid coming to the surface of water or upper part of pond water (AFCD, 2009). Fish mortality can also indicate temperature change and can be due to a combination of factors such as temperature, low oxygen, metabolite load and salinity (Helfrich, 2021), and therefore, cannot be used as a reliable method for detecting temperature problem.

The tools or devices used in monitoring water temperature are thermometers. Water temperature is measured with thermometer graduated in degrees celsius or centigrades (°C). The bulb of the thermometer is place under water, at a depth of about 15 to 20 cm when measuring the temperature of surface waters. The water temperature can also be measured in a bucket full of water from the pond. In this case, the temperature is measured immediately after the water is collected. The water temperature is measured in the morning around 6.30am and afternoon around 1pm and the average calculated. Experienced fish farmers calculate the average daily temperature of the water and list thermal fluctuations in a table and this enables them control water temperature. According to Coche et al. (1996), it is sufficient to measure the water surface temperature in a shallow pond not much more than 1 m deep, it is best to also measure the water temperature near the pond bottom in a pond deeper than 1.5 m.

Few devices such as digital monitors have been developed to monitor water quality parameters such as temperature, pH, turbidity and dissolved oxygen. These devices measure temperature and other water quality parameters regularly and displays or inform fish pond owners about the measured value (Harun *et al.*, 2018; Mohammed & Al-Mejibli., 2018; Ujwala et al., 2020).

(b) Fish pond water temperature control

The conventional methods of controlling pond temperature involve removing and replacing part of pond water depending on the type of problem, provision of shade and aeration among many others (Bhatnagar and Devi, 2013). While shades erected during summer can prevent thermal stratification, mechanical aeration can prevent formation of ice build-up in large areas of the pond.

Pond water high temperature is lowered by decreasing its average water temperature. According to Barange *et al*. (2018), the conventional methods of lowering pond water high temperature include:

i. **Replacing part of the surface water.** In shallow ponds, the warmest surface water is discharged and cooler water supplied.

ii. **Replacing the most deoxygenated water.** In deeper, stratified ponds, the most deoxygenated bottom water from the hypolimnion is discharged and cooler water supplied, making sure not to mix the layers while doing so.

Pond water low temperature is elevated by increasing its average water temperature. According to Coche *et al.*, (1996), the conventional methods of elevating pond water low temperature problem include:

i. **Planting of wind-breaks.** Planting of wind-breaks across the direction of seasonal cooling winds prevents heat loss due to evaporation of pond water and direct exchange to air. Heat is lost due to evaporation of pond water and also by direct exchange to air and substratum-the soil underneath.

ii. **Building of shallower ponds.** Shallower ponds warm up faster during sunny weather.

iii. **Supplying of warm water to pond.** Warming of a cold water supply and supplying it to pond helps in increasing the pond water temperature. This can also be achieved by replacing cooler bottom water by warm water. Heating of the water may also be necessary if the temperature of the water falls below the recommended range (Warish *et al*., 2017).

iv. **Use of deeper pond during cold season.** Using of deeper ponds during a cold season helps in maintaining pond water temperature because deeper ponds are less affected by sudden weather changes. If ice forms on the pond surface, bottom waters will remain warmer, at about 4ºC when density is the greatest.

v. **Reduction of shade.** Reduction of shade erected above pond can help increase pond water temperature. The main source of heat for fish pond water is solar radiation. So by reducing shade supports proper heating of pond water especially on a sunny day.

Fish pond temperature problems are best solved by removing and replacing part of pond water with water of higher or lower temperature depending on temperature of pond water.

(c) Preventive measures of temperature problems

The preventive measures for fish pond temperature problems involve actions taken in order to prevent high or low water temperature. These measures include:

i. **Use of standard pond.** Pond water quality problems are easily prevented and good water quality achieved better in well-designed ponds than in poorly-designed ponds. According to AFCD (2009), water quality problems are prevented by using pond that has large area and **w**ater depth of 1.2 to 1.8m (shallow large ponds), bottom made up of a layer of clay or concrete or butyl liners, good drainage system, strong pond bunds and good orientation and well located. Artificial ponds with depth of 1m - 2m have only a minor temperature difference between the surface and water bed (Harun *et al*., 2018); so stratification of pond water is not possible in such ponds. In addition, average water temperature in shallow large ponds is more stable than in deep ponds (AFCD, 2009; Coche et al., 1996). On the other hand, water lost by seepage is minimized and variations in water temperature and turbidity and competition for survival among the fishes caused by water shortage (Nocheski & Naumoski, 2018) are prevented with pond bottom made up of a layer of clay (Marine. 2015) or concrete or butyl liners (Boyd & Chainark, 2009; Mwato, 2021). Ponds are usually constructed with strong bunds, good drainage system and located on land with a gentle slope to prevents flood or run-off water that contain pollutants from entering ponds and damaging them. A well-orientated pond has good control of wind action on pond water. The long side of pond is usually constructed along the direction of wind so that it receives maximum air in area where wind does not cause extensive wave while the long side is at right angles to the prevailing wind where wind causes extensive wave. In standard pond, water quality problems caused by age and quality of pond bottom soil such as water shortage (Cole, Tulsankar, Saunders, & Fotedar, 2019) are easily prevented by maintaining the pond bottom soil at safe level and repairing damaged or cracked pond structure.

ii. **Erecting of a lightweight nylon screen above the fishpond.** According to AFCD (2009), erection of a lightweight nylon screen above the fishpond reduces exposure to sunlight in summer months when temperature is high and sunlight is strong. This measure can reduce the fishpond temperature by one to two degrees and prevent proliferation of algae.

iii. **Sheltering of pond.** Fishpond sheltered from wind in winter helps in slowing down temperature drop when there is strong wind. Water temperature of a sheltered pond may remain one to two degrees higher than that of an exposed fishpond (Barange *et al*., 2018).

iv. **Replenishment of pond water.** When some volume of water is lost in a pond through evaporation, seepage and feeding of fishes, the depth of water decreases and water temperature can easily change during afternoons and in cold weather. Temperature variations can be prevented by ensuring that the water depth is constant by replacing water lost in the pond.

v. **Other measures.** According to AFCD (2009), other measures for preventing fish pond temperature problems include feeding fishes sparingly and culturing fish species which can adapt to the local climate.

2.3 Fish Pond Water pH

Water is amphoteric; it can exhibit properties of an acid or a base, depending on the pH of the solution that it is in. It readily produces both hydrogen ion (H^+) and hydroxyl ions (OH^-). Related to its amphoteric character, it undergoes self-ionization. The self-ionization of water (also called autoionization of water, and auto-dissociation of water) is an ionization reaction in pure water or in an aqueous solution, in which a water molecule, H_2O, deprotonates (loses the nucleus of one of its hydrogen atoms) to become a hydroxyl ion (Westin, 2022)). The hydrogen nucleus H^+, immediately protonates another water molecule to form hydronium (H_3O^+) as shown in equation 2.1 (Westin, 2022).

$$H_2O + H_2O \leftrightharpoons H_3O^+ + OH^- \tag{2.1}$$

The product of the activities, or approximately, the concentrations of H^+ and OH^- is a constant, so their respective concentrations are inversely proportional to each other (Chalk, 2019).

The term "pH" is a mathematical transformation of the hydrogen ion (H^+) concentration; it conveniently expresses the acidity or basicity of water. The lowercase letter "p" refers to "power" or exponent, and pH is defined as the negative logarithm of the hydrogen ion concentration (Bhatnagar & Devi, 2013). Each change of one pH unit represents a ten-fold change in hydrogen ion concentration. The pH scale is usually represented as ranging from 0 to 14, but pH can extend beyond those values. At 25 °C, pH 7.0 describes the neutral point of water at which the concentrations of hydrogen and hydroxyl ions (OH^-) are equal; each at 10^{-7}moles/L (Tucker & Hargreaves, 2008). Conditions become more acidic as pH decreases and more basic as pH increases. The measure of the alkalinity or acidity of water is therefore, expressed by its pH value. Depending on pH value, water will react in different ways with the substances dissolved in it. It will also affect the plants and animals living in the water in different ways (Swain, Sawant, Chadha, Chhandaprajnadarsini, & Katare, 2020).

2.3.1 Fish pond water pH problems

The main pH (the chemical reaction of the water) problem encountered in fish ponds water is high pH. Low pH may also occur.

(a) Causes of pond water pH problems

The most important sources of pond water are underground water, waters of lakes and rivers. The pH of natural waters is greatly influenced by the concentration of carbon dioxide which is an acidic gas. Rain is slightly acidic (pH of about 5.6) because of the dissolved carbon dioxide in the air (AFCD, 2009). Carbon dioxide hydrates in water to form carbonic acid (H_2CO_3) which dissociates to hydrogen ion (H^+) and bicarbonate (HCO_3^-) as shown in equation 2.2 (RSC. 2022).

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \qquad (2.2)$$

Water as a powerful solvent, dissolves some of the gases or solids it contacts, and some of these dissolved substances affect the water's pH. So, natural waters are never pure. Bicarbonate and carbonate (CO_3^{2-}) are negatively charged ions (anions) common in most waters. These basic anions are derived from the dissolution of limestone and they increase the pH of water. Bicarbonate and carbonate are also the anions primarily responsible for alkalinity of water, which is the capacity of water to neutralize acid.

The pH levels for natural waters range between 5.0 - 10.0 (PHILMINAQ, 2008). In most natural waters, chemical interactions among carbon dioxide, hydrogen ions, and the anions that produce alkalinity buffer the pH in a range of about 6 to 8.5. The normal range for pH in surface water systems is 6.5 to 8.5, and the pH range for groundwater systems is between 6 and 8.5. In the absence of processes that add or remove carbon dioxide, the initial pH of water in contact with air depends on its alkalinity. Waters with low alkalinities have an initial pH at the low end of that range, while waters of higher alkalinities have higher pH. Although alkalinity establishes the initial pH of water, removing or adding carbon dioxide causes pH to rise or fall from that initial value. Adding carbon dioxide "pushes" the previously defined chemical reaction toward the right-hand side, forming carbonic acid and hydrogen ions and causing pH to decrease. The decrease in pH is because more hydrogen ions are added. Since pH is the negative logarithm of hydrogen ions concentration; the more the hydrogen ions concentration the lower the pH. Removing carbon dioxide "pulls" the reaction to the left, thereby removing hydrogen ions and causing pH to increase. The magnitude of variation from the initial pH depends on:

i. The amount of carbon dioxide added or removed and
ii. Alkalinity, which tends to buffer, or reduces the effect of changes in carbon dioxide concentrations.

(b) Cyclic fluctuation of pH

The original pH of the water may be affected by the pH of the soil. However, the pH of fish pond water varies throughout the day mostly as a result of photosynthesis, and through the night through respiration (Kleinholz, 2017). So, underwater biological activity controls carbon dioxide concentrations in aquaculture ponds. All living organisms continuously produce carbon dioxide as a product of respiration. During daylight, algae and underwater plants remove carbon dioxide from the water as part of the sunlight-driven process of photosynthesis. The relative rates of respiration and photosynthesis within the pond determine whether there is a net addition or removal of carbon dioxide, and therefore whether pH falls or rises. Respiration rates are affected by water temperature and the biomass of plants, animals and microorganisms in the water and bottom sediment. So, the rates of photosynthesis are controlled primarily by sunlight intensity, plant biomass and water temperature (Tucker & Hargreaves., 2008)**.**

At sunrise, the pH is lowest. Photosynthesis increases as the light intensity increases. More and more carbon dioxide is removed from the water by the plants causing the pH to increase. So, during the day, underwater photosynthesis usually exceeds respiration, so pH rises as carbon dioxide is extracted from the water. A peak pH value is reached in late afternoon. As the sun begins to set in late afternoon, light intensity then starts decreasing and photosynthesis also start decreasing as less and less carbon dioxide is removed from the water.

At sunset, photosynthesis stops, but respiration continues for the rest of the night. More and more carbon dioxide is produced, and pH keeps decreasing until sunrise, when it reaches its minimum. The next day, this cyclic fluctuation of pH starts again. The cyclic fluctuation of pH is shown in figure 2.3.

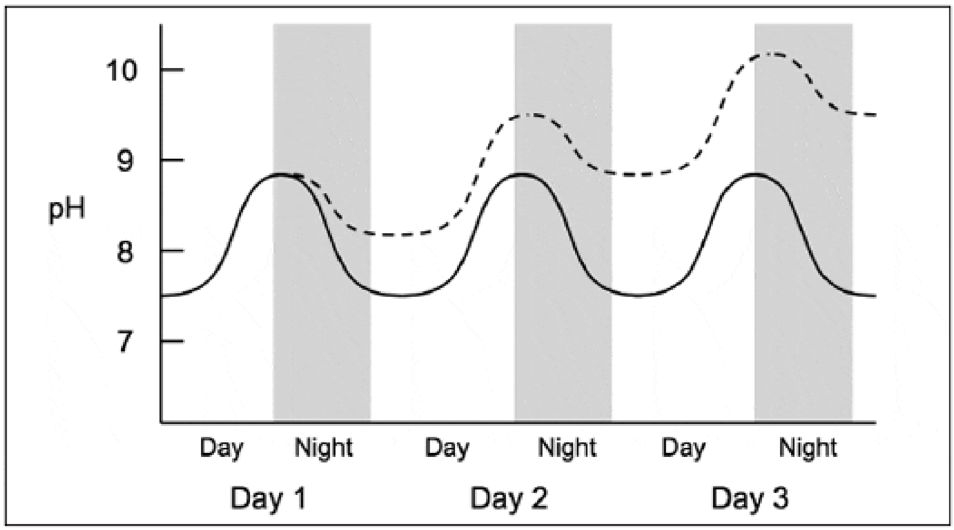


Figure 2.3: Cyclic fluctuation of pH during a 3-day period in two ponds (Source: Tucker & Hargreaves, 2008)

In both ponds, pH rises during the day as carbon dioxide is removed through photosynthesis and falls at night (shaded vertical bars) as carbon dioxide is added to the water through respiration. The solid line represents pH changes in a pond where carbon dioxide taken up in photosynthesis is offset by carbon dioxide respired at night. The dashed line represents pH changes in a pond where more carbon dioxide is fixed in photosynthesis than is produced at night, and pH values increase from day to day.

(c) High pH problem in fish pond

In most aquatic environments, daily photosynthesis is about equal to respiration and pH will usually remain within a range tolerated by most animals. However, when plants or algae are growing rapidly, more carbon dioxide is removed each day by photosynthesis than is added each night by respiration. As a result, pH may rise to abnormally high levels during the afternoon and may even remain high through the night. This condition may last for many days, until photosynthesis decreases or respiration increases.

Problems with high pH are common in fry nursery ponds because fertilization practices used to prepare ponds for stocking are designed to promote fast-growing phytoplankton blooms that rapidly take up carbon dioxide. High pH is most common in recently filled and fertilized ponds, ponds with established phytoplankton blooms (Kleinholz, 2017). Rapid carbon dioxide uptake in ponds where plants are growing quickly can cause high pH. Ponds with filamentous algae usually have clear water, allowing sunlight to penetrate deep into the water column and promoting intense photosynthesis by underwater or floating mats of algae thereby withdrawing more carbon dioxide than produced in pond water and this cause high pH (Tucker & Hargreaves, 2008).

(d) Low pH problems in fish pond

The source of water can cause low pH problem in fish pond. Water for freshwater pond fish farming can come from rain water harvesting (i.e. the interception and storage of water before it reaches the aquifer) or from diversion or abstraction of water from rivers or canals (Nagabhatla, Beveridge, Haque, Nguyen-Khoa, & Van Brakel, 2012). Rain is slightly acidic (generally about 5.6) because of the dissolved carbon dioxide in it (AFCD, 2009).

Occasionally during the winter, pond water pH may be low due to elevated carbon dioxide levels. Such a condition may arise after a period of extremely calm and cloudy weather, but quickly passes once sunny or windy weather returns (Hargreaves & Brunson, 1996). However, over an annual cycle, carbon dioxide concentrations are maximum during winter and minimum during summer. However, carbon dioxide is rarely a problem in winter because dissolved oxygen concentrations are usually well above saturation levels.

There are a few specific circumstances or scenarios in which carbon dioxide may be a problem, such as the period following the crash of an algae bloom or the application of an algicide, such as copper sulfate (Hargreaves & Brunson., 1996). Large quantities of organic material derived from dead plankton are quickly decomposed, reducing oxygen and increasing carbon dioxide.

In addition, carbon dioxide can cause low water pH in ponds deeper than 1.2 or 1.5 (4 or 5 feet), such as in so-called combined watershed/levee ponds under certain circumstances such as very low temperature (Hargreaves & Brunson, 1996).

(e) Effects of extreme levels of fish pond water pH

Fish production can be greatly affected by excessively high or low pH. Aquatic animals can, become stressed or die when exposed to pH extremes or when pH changes rapidly, even if the change occurs within a pH range that is normally tolerated (Tucker & Hargreaves, 2008).

In addition to the direct effects of pH on aquatic animals, the hydrogen ion concentration affects aqueous equilibrium involving ammonia, hydrogen sulfide, chlorine and dissolved metals. The interactions of pH with these variables are often more important than the direct effects of pH on aquatic animals.

Certain conditions may cause pond water pH to rise or fall outside the tolerable range, killing the animals being cultured. There are no precise guidelines for high pH tolerance, but pH values above 9.5 or 10 are generally considered undesirable in aquaculture ponds. According to Bhatnagar and Devi (2013), pH less than 4 or greater than 11 is lethal to fish/shellfish culture and 7.0-9.5 is acceptable limits. The critical pH values vary according to the fish species, the size of individual fish and other environmental conditions. Low and high pH level harm fish especially the young fish in immature stages because they are extremely sensitive to pH levels. The young fish may die when the pH level is below 5 (Yokogawa Electric Corporation, 2016) and a pH greater than 9 can already be detrimental to fish eggs and juveniles. Fish reproduction can also be greatly affected even at pH below 5.5. According to Ekubo and Abowei (2011),

Sudden changes in pH can stress or kill fish and other aquatic animals even when those changes occur within a pH range they normally tolerate. Fish will be killed when there is rapid change in pH such as 3-tenth within 24 hours (Lynn, 2018) or abruptly transferred to waters with pH values more than 1 unit higher than the water to which they were acclimated. Sudden transfer to waters 1.5 pH units higher will kill about 50 percent of the fish, and transfer to water 2.2 pH units higher will kill almost all the fish (Tucker & Hargreaves, 2008).

Water pH also has important impact on the toxic action of a number of other factors such as ammonia on fish (OATA, 2008). Acidic water (< pH 5) leaches metals from rocks and sediments and the metals have an adverse effect on the fish’s metabolism rates and ability to take in water through their gills, and can be fatal as well (Summerfelt, 1998). When water is very alkaline (>pH 9), ammonium in water is converted to toxic ammonia, which can kill fish (Lynn, 2018).

2.3.2 Solutions to fish pond water pH problems

Conventionally, water pH problems are solved via monitoring, control action and adequate preventive measures. In general, preventing or managing around pH problems will be more effective than trying to correct problems after they occur.

(a) Monitoring of fish pond water pH

Fish pond water pH is mainly monitored in the morning-at at sunrise through observation or using tools. The pH is expected to be approximately 6.5 to 8.5 at sunrise.

The pond water is monitored pH by observing fish behavior and perceiving odor. Fishes appear sluggish when water pH is low. Occasionally during the winter or cold weather, fish may appear to swim listlessly (with less energy) near the surface as if they were "under the influence," possibly due to elevated carbon dioxide levels. Such a condition may arise after a period of extremely calm and cloudy weather, but quickly passes once sunny or windy weather returns (Hargreaves & Brunson, 1996). Retarded fish growth can also indicate that pond water has low pH. When fishes are subjected to low pH **(**below 6) for a long period, their growth is inhibited because their feeding and digestive ability are weakened. Death of fishes is also a sign of very low pH (Kleinholz, 2017). Fish death is almost certain at a pH of less than 4.0 (AFCD, 2009)

Monitoring of pond water pH using tool or device involves measuring pH and comparing its value with safe pH range. Tools such as pH paper, Colour comparator, pH meter and monitor are mainly used. The pH meter provides the easiest way for determining the water pH, even in the field, but it is relatively expensive. The pH value is directly read from the meter after placing the glass electrodes in a water sample.

Few devices such as digital monitors have been developed to monitor water quality parameters such as pH. These devices measure pH regularly and displays or inform fish pond owners about the measured value.

(b) Fish pond water pH control

Generally, it is difficult to manage high pH in aquaculture ponds and no specific management practice is always successful. Difficulties arise because the term "high pH" describes not only a chemical property, but also the outcome of many interacting chemical and biological processes (Tucker and Hargreaves, 2008).

Fish pond water high pH problems can be solved by altering its biology so that the net daily carbon dioxide uptake is near zero (Pote, Cathcart, & Deliman, 1990). This can be done by reducing photosynthesis or increasing respiration. The conventional ways of managing high pH problems include:

i. **Exchange of whole pond water.** Some fish farmers drain their pond and refills it with new water in view to controlling pH problem. This is a bad practice because the pH of water will be affected later even if the pH of the water used for refilling pond is the same with the former pond water. There will be more carbon dioxide in the new water as there is little or no plankton to use carbon dioxide released by fishes during respiration and thus, a decrease in pH of water. In addition, fishes die when the pH of the water used for replacement is up to 1.5 times higher (Tucker & Hargreaves, 2008).

ii. **Addition of organic matter.** Carbon dioxide levels in pond can be increased by adding appropriate amount of organic matter (or acidic fertilizer) such as cracked corn, soybean meal or cottonseed meal to ponds (Bhatnagar & Devi, 2013; Coche et al., 1996). As organic matter decays, it releases carbon dioxide. This method does not reduce pH immediately, but it is a safer, longer lasting way to reduce high pH.

iii. **Addition of alum.** Alum (aluminum sulfate) is added in pond water to quickly reduce high pH. This is an emergency treatment for high pH. Alum is a safe, relatively inexpensive chemical that reacts in water to form an acid. Alum also flocculates and removes algae by sedimentation, thus decreasing algal biomass and reducing photosynthesis. It may also help to reduce pH indirectly by removing phosphorus (an important nutrient for plant growth). Alum does not have a permanent effect and it may need to be applied more than once until plant or algal growth decreases. A precise reduction of pH through the addition of alum is difficult because response is influenced by a number of conditions in the pond, especially the water's total alkalinity. In addition, overtreatment with alum can cause a dramatic decrease in pH, possibly to levels more dangerous than the original high pH problem. The pH can be reduced to dangerous levels if alum is used in waters with total alkalinities of less than 20mg/L.

iv. **Addition of herbicide.** In order to reduce pH quickly, the rate of plant growth must be slowed by adding herbicide. Using herbicides to kill algae and plants eliminate high pH problems, but the decomposition of plants killed by herbicides cause oxygen depletion and the accumulation of carbon dioxide and ammonia

(Tucker & Hargreaves, 2008). In addition, some herbicides are also relatively toxic to juvenile aquatic animals. Reducing plant growth to manage high pH also negatively affects fertilization.

v. **Reduction of sunlight intensity.** Restricting the amount of light penetrating the water column needed for photosynthesis can reduce pH quickly (Kleinholz, 2017). This method is a safer but less effective alternative to herbicides. Sunlight available in the pond can be reduced by either adding an approved aquaculture dye to the pond or keeping the pond water turbid (with suspended sediment) by using aerators or other devices to stir up mud from the pond bottom (Tucker & Hargreaves, 2008). Dyes are sold as weed-control agents and tint the water blue to reduce light penetration. Although dye may be effective for several weeks it may favor the growth of mat-forming filamentous algae that float high in the water column where there will be adequate light even in dye-treated water. On the other hand, turbid water negatively affects dissolve oxygen and respiration.

vi. **Balancing the hardness and alkalinity.** High pH problems occur most often in ponds where total alkalinity (the amount of bicarbonate and carbonate in the water) far exceeds water hardness (the amount of calcium and magnesium in the water). According to Mandal and Boyd (1980), groundwater with a hardness of about 30 mg/L as $CaCO_3$ and an alkalinity of about 90 mg/L will cause pH to rise. High pH problems caused by deficiencies in hardness relative to alkalinity can be corrected by adding gypsum (calcium sulfate-$CaSO_4$). The effectiveness of gypsum treatment in reducing pH is yet to be proved; at best, it is a preventive procedure rather than an emergency treatment. Although the amount of gypsum required is large, the result of treatment is long-lasting because calcium is lost from ponds only when waters are diluted by excessive rainfall or by the addition of water with low calcium content.

vii. **Addition of sodium bicarbonate.** One of the most frequently recommended treatments for high pH is addition of sodium bicarbonate (also called bicarbonate of soda or baking soda). This practice is the least effective. Sodium bicarbonate reduces high pH in water because it is *amphoteric*-it neutralizes either acids or bases (Ludwig, Hobbs, & Perschbacher, 2007). Sodium bicarbonate is, however, a weak acid and large amounts must be added to significantly reduce pH, especially in waters with high total alkalinities. Sodium bicarbonate is neither an effective emergency treatment for high pH nor a long-term solution.

Low pH problems are normally solved by reduction of CO_2 concentration in pond water. The following are the conventional ways low pH problems are solved:

i. **Addition of lime**. Low pH problem is commonly solved by addition of lime to the water. According to Bhatnagar and Devi (2013), when the pH is below 6.5 at sunrise, adequate amount of lime or alkaline fertilizers are added directly to the pond. According to AFCD (2009) lime is added directly into the pond and the water pH measured making appropriate adjustment to avoid excessively high acidity or alkalinity.

ii. **Aeration.** Aeration is used to reduce carbon dioxide (CO_2) concentration in pond water with high humic turbidity caused by decomposing dead plankton and feeds (organic material). Aeration is any procedure by which oxygen is added to water. Vigorous aeration will drive off some proportion of the CO_2 produced in the pond and increasing pH. Aeration practices serve the dual role of supplying oxygen and reducing carbon dioxide. Aeration also reduces carbon dioxide concentration caused by daily stratification and destratification in deep ponds thereby increasing pH. Water currents established by aeration and wind blowing over the water surface usually keep the water column well-mixed and as a result, carbon dioxide problems rarely occur (Hargreaves & Brunson, 1996).

(c) Preventive measures of pH problems

The preventive measures for fish pond pH problems involve actions taken in order to prevent high or low water pH. These measures include:

i. **Use of standard pond.** Standard fish pond supports proper penetration of sun light needed for photosynthesis. With this the volume of CO_2 used during photosynthesis is controlled and this in turn prevents high pH caused by net withdrawal of CO_2 from pond water due to excess photosynthesis as a result high intensity of sun light. Standard fish pond also prevents low pH of water that may be caused by rain water or flood (acidic water) entering the pond. In addition, standard fish pond supports aeration of pond water by wind blowing over the water surface and this helps in removing some volume of CO_2 which may cause low pH in cold weather.

ii. **Water exchange**. According to (Lynn, 2018), weekly water changes of 10 to 20 percent, where 10 to 20 percent of the dirty water is removed and replaced with clean water treated with a dechlorinating additive, will prevent pH problems in a pond. Removal of portion of the dirty water containing decomposed organic matter will prevent pond water from becoming acidic. In general, removal of the dirty water from pond will normalize pond water that is about becoming acidic or alkaline.

iii. **Replenishment of pond water.** When some volume of water is lost in a pond through evaporation, seepage and feeding of fishes, the depth of water decreases and water pH can easily change. Shortage of water can cause pond water to be turbid and replenishing it helps in preventing low pH of water that may result when the turbidity is humic or hinders photosynthesis will be prevented. On the other hand, high pH that may result when water is not turbid in the pond that has lost part of its water is prevented by replacing the lost water.

iv. **Other measures.** High pH can be prevented by addition of organic matter or acid fertilizers to the pond water (Bhatnagar & Devi, 2013). Adding small amounts of easily decomposable organic matter can be an effective preventive measure because its decomposition produces carbon dioxide and reduces pH for a longer period (Tucker & Hargreaves, 2008). Another way to prevent high pH problems is to prepare ponds as early as possible, preferably several weeks before stocking (Bhatnagar & Devi, 2013),

2.4 Fish Pond Water Dissolved Oxygen

The most important gas dissolved in water is oxygen (O_2). Dissolved oxygen (DO) is essential to most living organisms for their respiration. Dissolved oxygen affects the growth, survival, distribution, behaviour and physiology of fish and other aquatic organisms (Sallenave, 2019). The oxygen dissolved in water has two sources; atmospheric oxygen and photosynthesis. The atmospheric oxygen in contact with the water surface is an unlimited source of oxygen; unfortunately, its passage into water, its diffusion and its subsequent dissolving into water is a very slow process. So, photosynthesis is the major source of dissolved oxygen in ponds. Photosynthesis depends on the amount of light available to the plants. This implies that oxygen production decreases during cloudy days; completely stops at night; gradually decreases as water depth increases.

The oxygen requirements of fish are determined by three basic factors (Coche *et al*., 1996; EPA, 2014):

i. Fish species
ii. Size of the fish and
iii. Water temperature.

Coldwater fish require higher oxygen levels than warmwater fish. Fish such as catfish, which are used to slow-moving water bodies, can tolerate lower levels than fish used to fast-moving water. For a particular species, younger fish require higher oxygen levels than adults. Usually, when individual weight of fish is increasing, oxygen required per unit weight is significantly declining (EPA, 2014).

2.4.1 Fish pond water DO problems

The main fish pond DO problem is low DO. High DO problem rarely occur. Obtaining sufficient oxygen is a greater problem for fish and other aquatic organisms than terrestrial ones, due to low solubility of oxygen in water. Solubility of oxygen in water decreases with factors like-increase in temperature; increase in salinity; low atmospheric pressure, high humidity, high concentration of submerged plants and plankton blooms (AFCD, 2009).

(a) Fish pond low DO problem

Low dissolved oxygen is the most common stress for cultured fish and can be caused by many factors. Changes in pond water temperature are the major causes of DO problems. At higher water temperatures, the fish will consume more oxygen for their respiration. This factor can be very important, because when temperature rises, water holds less oxygen and fish will also require much more oxygen than usual when actively feeding and later, when digesting their food (Bhatnagar *et al*., 2004). According to AFCD (2009), there may be some variation due to other physiological factors such as activity, sexual maturation and spawning (deposition of eggs or sperm directly into the water).

Oxygen is also necessary for dead organic matter to be broken down during the process called decomposition. Not only is dissolved oxygen important for fish respiration, it is also important for the survival of phytoplankton-the organism which breaks down toxic ammonia into harmless forms.

(b) Daily fluctuations of DO level

In surface water, the daily fluctuation of the DO content is related to the 24-hour cycle of day and night. As shown in figure 2.4, daily fluctuations are as follows:

i. Photosynthesis increases the DO level from sunrise to sunset. On clear days, DO production is higher than on cloudy days. The higher the phytoplankton population, the higher the DO production.

ii. Respiration reduces the DO content at night until sunrise. Photosynthesis does not take place at night. The higher the plankton population, the faster the DO will fall.

iii. High respiration may cause very little oxygen to be left by the end of the night in surface water of very rich ponds as a result of super saturation by midday. This may lead to death of fishes in the pond.

iv. The daily fluctuation of the DO content is related to the plankton turbidity in deeper water: the higher the turbidity, the smaller the amount of light penetrating deeper in the water, and the less the production of DO through photosynthesis in deeper water. The DO content decreases with depth.

v. The DO content of the lower depths of the water may become very low even during the day in very rich ponds where there is dense plankton population and high turbidity. The fish may concentrate at the surface of the pond to survive and greater problems are to be expected after sunset.

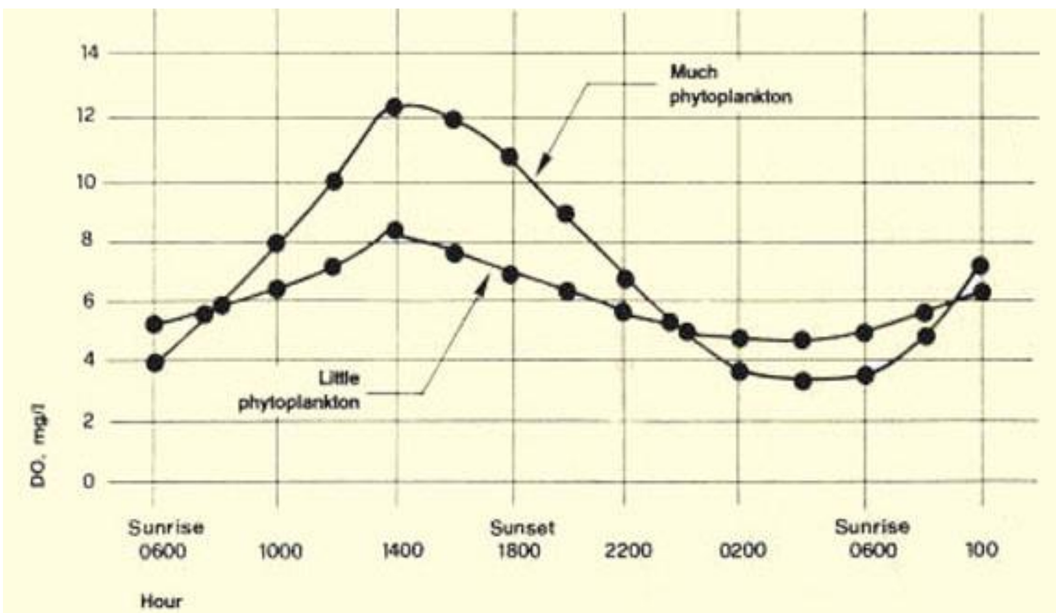


Figure 2.4: DO content in the surface water of a shallow pond during a 24-hour cycle (Source: Coche *et al*., 1996)

(c) Seasonal fluctuation of DO level

The seasonal fluctuation of the DO content is essentially related to the thermal stratification of the water. As the thermocline establishes itself and restricts exchanges between the upper and lower layers, the DO content of the bottom water decreases, mainly because of the decomposing organic matter. It is only after the pond water has turned over that DO is brought back from the pond surface to the bottom through the general mixing of the water.

In deep ponds rich inorganic bottom mud, the bottom water may become totally devoid of oxygen (anoxic) within a few weeks, and fish will not be able to live there. Later, when the pond water turns over, this anoxic water may reach the surface, together with decomposed organic material; many fish may die as a result of this (Coche *et al*., 1996).

(d) Sudden drops in the DO content of pond water

Apart from the fluctuations of the DO content which take place regularly, every day or seasonally, the DO content of pond water may also decrease suddenly for several other reasons (Kleinholz, 2017). Causes of sudden drop in DO content include:

i. The water supply. The incoming water may have a very low DO content. Water from a well or deep water from a reservoir may be low in DO; respiring or decomposing algae upstream in a surface water supply may reduce DO. Water inflow that is too small can also cause sudden drop in DO content.

ii. The weather. Turning over of pond water (by bringing the deoxygenated bottom water to the surface) in a stratified pond water by a *cool rain or a strong wind* can cause sudden drop in DO content of pond. Several days of cloudy skies or rainy weather can also cause reduced oxygen production through photosynthesis. Very hot days can increase the water temperature, reduce DO saturation and increase fish requirements of oxygen.

iii. The fish pond. Sudden drop in DO content can be caused when plankton turbidity is too high, and too much oxygen is consumed at night for respiration. Sudden drop in DO content can be caused when there is too much decaying organic matter, and too much oxygen is used up for its decomposition.

iv. Fish stock management. Sudden drop in DO content can be caused when there are too many fish in the pond. Overfeeding of fish can result in fish wastes (faeces), and the wastes and unconsumed food decays on the bottom of pond with the help of DO.

(e) Fish pond high DO problem

Problem of high oxygen levels occur less in fish ponds. Problem of high oxygen levels can be caused by excessive phytoplankton in pond due to abundant organic matter or fertilizer in newly stocked pond (Bhatnagar & Devi, 2013). Ponds stocked with low number of fishes can also cause pond high oxygen problem.

(f) Effects of extreme levels of fish pond water DO

Low dissolved oxygen concentration is recognized as a major cause of stress, poor appetite, slow growth, disease susceptibility and mortality in aquaculture animals (Mwegoha, Kaseva, & Sabai, 2010). Dissolved oxygen less than 1mg/L leads to death of fish, less than 5mg/L-fish survive but grow slowly (Bhatnagar & Devi, 2013). Tropical fishes have more tolerance to low DO than temperate fishes. Infrequent exposure to low oxygen water leads to fish swimming sluggishly and weakened and coming to the water surface in an effort to breathe with its mouth, poor feeding of fish, starvation, reduced growth and more fish mortality, either directly or indirectly (Kleinholz, 2017) and an odor of rotten egg rising from the water. Oxygen deficiency in pond water causes asphyxiation (suffocation) and death of fish. According to AFCD (2009), fish will come to the surface to breathe with their mouths and will die when exposed to low DO. Fish feeding activity will also drop, and with a low assimilation rate, fish growth will slow down accordingly when dissolved oxygen of water is low.

Nighttime oxygen depletion (ecological hypoxia) in the summer can cause sudden, large fish kills or fish die-off in ponds often as a result of fish suffocation (Wikipedia. 2021). Fish kills from oxygen depletion usually occur in the early morning hours (at dawn) in very rich (green water) ponds (Helfrich, 2021).

2.4.2 Solutions to fish pond water DO problems

Conventionally, water DO problems are solved via monitoring, control action and adequate preventive measures.

(a) Monitoring of fish pond water DO

Fish pond water DO problem can be detected by physical observation or use of oxygen meter. Physical observation may be misleading because the result of the observation may be similar to results of other pond water problems. The best time to monitor DO is during the time of the day when it is highest (evening) and when it is lowest (around 6.30am), and should be done on daily bases. According to (Banrie, 2012), dawn (sun rise or set) is a critical time for monitoring DO.

Monitoring DO through observation involve watching pond water and fish behavior. In an already stocked fishpond, if a farmer noticed the fish always struggling at the pond water surface to get oxygen, then there is low DO content in the water. Infrequent exposure to low oxygen water leads to fish swimming sluggishly and weakened and coming to the water surface in an effort to breathe with its mouth, poor feeding of fish, starvation, reduced growth and more fish mortality, either directly or indirectly (Kleinholz, 2017; Mwegoha, Kaseva, & Sabai, 2010). Symptoms of oxygen depletion may also include an abnormal distribution of fish gulping at the water surface or at the pond inlet or edges. This symptom of oxygen depletion (fish kill) is not a sure proof of DO depletion since fish may die of old age, starvation, body injury, stress, suffocation, water pollution, diseases, parasites, predation, toxic algae, severe weather, and other reasons.

Dissolved oxygen is measured either by chemical methods (e.g. use of simple kits) or by electrical methods (e.g. use of oxygen meter) and its unit is milligrams per litre (mg/L) or grams per cubic metre (g/m^3) or parts per million (ppm), where 1 ppm = about 1 mg/l or millilitres per litre (ml/L). The oxygen saturation value is also a measure of DO. Dissolved oxygen is commonly measured with a probe, attached to a battery-powered meter. In chemical method, dissolved oxygen is determined by titration of water samples from culture ponds (Kleinholz, 2017).

(b) Fish pond water DO control

Low DO problem can be solved by:

i. **Aeration.** Emergency aeration can be used to increase DO. Aeration is any procedure by which oxygen is added to water. Mechanical aerators such as paddlewheel aerators are the most efficient systems currently used to increase DO (Kleinholz, 2017). Increasing the inflow of well-oxygenated and/or cooler water through inlets with perforated screen place high above the pond and wind blowing over the water surface are other common methods of aerating pond water (Coche et al., 1996). According to AFCD (2009), aeration is achieved in smaller ponds by increasing the mixing of air and water by splashing the water with hands or with a broad stick or paddle.

ii. **Water exchange.** Discharging less oxygenated bottom water, by using the pond outlet, and filling pond with better oxygenated water also increases DO (Coche *et al*., 1996; Kleinholz, 2017). This method is more effective for problems caused by high temperature and cool weather. On the other hand, problem of fluctuation in oxygen levels can be solved by draining off some of the surface water and replenishing pond with fresh water. This water exchange reduces the existing phytoplankton population that is causing oxygen levels to fluctuate too strongly slightly.

iii. **Reduction of stocking density.** Reducing the number of fish present in the pond reduces DO consumed and making the oxygen produced during photosynthesis and on water surface to be sufficient for the remaining fish population.

iv. **Reduction of phytoplankton population.** Phytoplankton population is reduced slightly in a pond were they are over populated in order to increase the depth of sunlight penetration which in turn increases production of oxygen through photosynthesis. This also reduces night-time respiration through the control of submerged plants and algae that also consume oxygen (Coche *et al*., 1996).

v. **Reduction of feeding rates.** Reduction of feeding rates may also be used to increase DO. Reducing or even stopping supplementary feed helps in reduction of oxygen requirements of fish (Kleinholz, 2017). It also helps in reduction of oxygen consumption from decomposition of feed/organic matter (AFCD, 2009).

vi. **Controlling shady trees.** Oxygen production is increased through photosynthesis by increasing sunlight availability by keeping shady trees under control (Coche *et al.*, 1996).

vii. **Fertilization of pond.** Ponds with low oxygen due to phytoplankton mortality can be fertilized with phosphorus to encourage re-growth of the plankton population. Kleinholz (2017), According to Coche *et al.* (1996), low oxygen pond water can be treated by liming to increase phytoplankton only when it is necessary.

High pond water oxygen occur less and can be reduced by:

i. **Water exchange.** Problem of high oxygen levels can be solved by draining off some of the surface water and replenishing pond with fresh water. This water exchange reduces the existing phytoplankton population that is causing oxygen levels to increase.

ii. **Increment of stocking density.** Increasing the number of fish present in the pond increases DO consumed thereby reducing the high DO pond water.

iii. **Injection of the hot water into the pond.** Introduction of the hot water gradually with pipes reduces high level DO (Bhatnagar & Devi, 2013).

(c) Preventive measures of DO problems

DO problems can be prevented by proper water management and can be achieved by:

i. **Use of standard pond.** Standard pond supports proper production of DO on water surface and its circulation via wind action. It also prevents rain water or flood containing livestock waste and other organics that may cause overturning of pond water which will result in DO problem. Standard pond don't support stratification of pond water because of its shallowness and it contains outlets on its upper part, just at the top of the required water level through which rain water falling into the pond can flow out of pond.

ii. **Water exchange.** Water exchange helps in increasing DO in ponds especially when water used in replenishing pond has lower temperature and turbidity and more oxygen than the pond water. This method helps in controlling/reducing water temperature thereby preventing oxygen depletion caused by low dissolution of oxygen and high oxygen demand by fishes (when actively feeding and later, when digesting their food)/biomass in high temperature pond water. Water exchange also reduces zooplankton and phytoplankton population that reduces DO through their respiration and turbidity that makes oxygen to dissolve less.

iii. **Replenishment of pond water.** Replenishing pond water after portion of it is lost through evaporation, seepage and feeding of fishes helps in preventing DO problems. Water loss may cause pond water shortage which in turn, causes low DO and high turbidity and temperature that further reduce oxygen dissolution in water. Replenishing of pond water helps in preventing reduction of water depth, high turbidity and temperature that cause DO problems.

iv. **Other measures.** DO problems can also be prevented by avoiding over application of fertilizers and organic manure to manage DO level, physical control of aquatic plants and also management of phytoplankton biomass, recycling of water and use of aerators and avoidance of over stocking of fishes (Bhatnagar &

Devi, 2013). Herbicides are also used to kill weeds that may cause oxygen depletion in order to prevent DO problems.

2.5 Fish Pond Water Turbidity

Turbidity is the optical property of water which reflects the water ability of transmitting the light; it is a measure of the water clarity (FAO, 2005). It is the resultant effect of several factors such as suspended clay particles, dispersion of plankton organisms, particulate organic matters and also the pigments caused by the decomposition of organic matter (Bhatnagar & Devi, 2013).

2.5.1 Fish pond water turbidity problems

High turbidity is the major turbidity problem encountered in fish ponds. High turbidity of water can decrease fish productivity, as it will reduce light penetration into the water and thus oxygen production by the water plants. Low turbidity problem may occur occasionally in newly fertilized ponds and is corrected mainly by the fish farmer or fish pond owner. According to Coche *et al.* (1996), water turbidity is caused by the presence mineral turbidity, humic turbidity and plankton turbidity.

(a) Mineral turbidity

Mineral turbidity is caused by a high content of silt and/or clay particles which turn the water a light brown, sometimes reddish colour (GOK, 2016). It may occur when the water supply is turbid or a bottom feeding fish, such as the common carp, stirs up the bottom mud.

(b) Humic turbidity

Humic turbidity is caused by the presence of *humus* (dark organic material in soils, produced by the decomposition of vegetable or animal matter), which turns the water a dark brownish colour. Its origin is usually the water supply, although it can also be caused by an excess of organic matter entering the pond

(c) Plankton turbidity

Plankton turbidity is caused by a high content of minute plants and animals which colour the water in various shades of brown, green, blue-green or yellow-green, depending on which plankton species is dominant. Planktons are those aquatic pelagic organisms, which are carried about by the movement of the water rather than their own ability to swim and they serve as fish food organisms. The water color in pond reflects the predominant phytoplankton species. Phytoplankton is free-floating microscopic algae (Kleinholz, 2017). Phytoplankton often tint the water green, but may also cause the water to appear blue-green, red or brown because any change in phytoplankton flora or densities will change the water color or its intensity. Excessive phytoplankton populations are indicated if pond water becomes dark green, red or brown within a 7 to 10 day period. Surface scums of algae also indicate excessive populations and often occur 1-3 days before an algal crash. The color of water can change suddenly and this is attributed to mass phytoplankton mortality which can occur when the phytoplankton reaches the reproductive cycle peak, or when suddenly the physicochemical environment conditions change and become disadvantageous to phytoplankton. This is caused by a drastic salinity or change in water temperature, shortage in nutrients, or vast grazing of zooplankton (Neospark, 2012). Populations may "bloom" 7 to 10 days after large inputs of nutrients (e.g. fish feed), or "crash" when nutrients are depleted, or if toxic chemicals are added to the water.

(d) Effects of high turbidity

Mineral and humic turbidity reduce the amount of light that penetrates the water. In highly turbid waters, light penetrates only a short distance (light will reach the bottom of a pond with 10% turbidity while it will not reach the bottom of a pond with 40% turbidity), and photosynthesis is reduced. Thus, oxygen production during the daytime will be relatively small. Both the growth of the fish and of their natural food organisms can be badly affected. A high mineral turbidity can affect fish directly by injuring their breathing organs (Carballo, Eer, Schie, & Hilbrands, 2008), reducing their growth rate or preventing their reproduction. In the same way, it can harm the minute animals called cladoceres and copepods (*zooplankton*), which are very important food for young fish. It also affects algal photosynthesis resulting in a lower dissolved oxygen level in water (AFCD, 2009).

Dense scums formed by blue green algae in surface waters, cause shallow thermal stratification, less availability of soluble phosphate on the top layer and prevents the penetration of light for photosynthesis to depths below 1m so leading to anoxic conditions in the deep areas (lack of oxygen and high concentration of free carbon dioxide) resulting in fish kills (Bhatnagar & Devi, 2013). According to Kleinholz (2017), phytoplankton respiration may be nearly 80% of oxygen consumption in water, and respiration by large phytoplankton populations may deplete oxygen in ponds during sustained periods of cloudy weather or at night and this in turn negatively affects fish production.

High turbidity value for pond water can be any value less than 30cm (Coche *et al.,* 1996). Clay turbidity in water 30cm to 60 cm is generally adequate for good fish production, 30 cm or less may prevent development of plankton blooms, and there is an increase in the frequency of dissolved oxygen problems when values are above 60 cm. With turbidity of 30 cm or less, light penetrates to greater depths and encourage underwater macrophyte growth, and so there is less plankton to serve as food for fish.

2.5.2 Solution to fish pond water turbidity problem

Conventionally, water turbidity problems are solved via monitoring, control action and adequate preventive measures.

(a) Monitoring of fish pond turbidity

The method used for measuring turbidity in order to monitor turbidity varies according to the kind of turbidity present. Turbidity of pond water varies from almost zero to highly turbid, depending on the amount of suspended particles.

Turbidity can be monitored through observation or perception. Muddy water (that is water showing a lot of clay particles) indicates mineral turbidity (Coche *et al.*, 1996). Deep green water indicates over-production of planktons (plankton turbidity). Fish may come to the surface of water and may swim sluggishly and weakened as a result of muddy water.

Humic turbidity can also be monitored through observation. According to Kleinholz (2017), if the bottom soil becomes black and a rotten egg odor is recognized when sediment is disturbed, it indicates anaerobic conditions and the presence of hydrogen sulphide (H_2S) and indicates humic turbidity.

In order to measure mineral turbidity (brownish water) using tool, a laboratory is required to determine the weight of material suspended in a given volume of water (sample). This figure is called the total suspended solids (TSS), which is usually expressed in milligrams per litre (mg/L). Samples are carefully collected to avoid disturbing the water too much which can increase the TSS very easily. Samples are collected from different levels of pond water. Boyd (1998) recommended 30mg/L - 200mg/L as optimum range. On the other hand, Davis (1993) recommended 10 mg/L - 20mg/L as optimum range for TSS defined as a specific measurement of all suspended solids, organic and inorganic, by mass.

In order to measure plankton turbidity (greenish water), simple method which involve human arm or Secchi disc is required. Measurement of plankton turbidity using Secchi disc which is a very simple tool that can give a better estimate of turbidity is based on transparency (Coche *et al.,* 1996). This measurement is called the Secchi disc transparency. Measurement of transparency is best done between 09.00 hours and 15.00 hours (i.e. when the sun is out), not behind a cloud on calm days.

(b) Fish pond high turbidity control

The conventional methods of controlling high turbidity in fish pond water partly depend on the kind of turbidity present. The methods include:

i. **Addition of lime or gypsum.** Addition of lime or gypsum to the pond reduces high turbidity. According to Bhatnagar & Devi, (2013), addition of lime at a rate of 20 mg/L or gypsum (magnesium sulphate) on the entire pond water at rate of 200 Kg/1000m^3 of pond can reduce turbidity.

ii. **Addition of more water.** According to Bhatnagar and Devi (2013), addition of more water to the pond reduces turbidity. Addition of more water to the pond reduces the concentration of the dissolved particles and thereby reducing turbidity.

iii. **Addition of organic matter**. According to Coche *et al.* (1996), spread of organic matter throughout the pond at the rate of 20 kg/100 m^2 (two to three treatments may be necessary) can reduce mineral turbidity.

iv. **Water exchange.** The plankton turbidity problem can be solved by maintaining plankton turbidity at the acceptable range. This is simply done by flushing of algae by partially draining water from pond bottom and refilling with clean water. If water is removed from the pond bottom, some of the nutrients causing the algal bloom will be removed during draining.

(c) Preventive measures of turbidity problems

The real long term method for preventing turbidity problem is to divert muddy water away from the pond and draining turbid portion of pond water, and it can be achieved by:

i. **Use of standard pond.** Standard pond prevents flood containing livestock waste, other organics and none organic substances and planktons that can make pond water to be turbid to enter pond.

ii. **Water exchange.** Water exchange helps in decreasing turbidity in ponds because the water used for the replacement of portion of the pond water usually has turbidity less than the replaced water. Pond water exchange done at the appropriate time helps in controlling/reducing water turbidity thereby preventing problems associated with it.

iii. **Replenishment of pond water.** When some volume of water is lost in a pond through evaporation, seepage and feeding of fishes, the depth of water decreases and turbidity increases. So, replenishment of lost pond water helps in preventing turbidity problems and associated problems.

iv. **Other preventive measures.** Mineral turbidity can be prevented by use of settling basin or silt catchment basin (Carballo *et al*., 2008). The catchment basin is in the form of a small reservoir at the inlet of the pond. The water flows into this reservoir and is kept there until the mud settles on the bottom. Then the clear water is let into the fish pond. Plankton turbidity can be prevented by use of filtrate on the water inlet, adequate liming and fertilization (Coche *et al*., 1996).

2.6 Other Fish Pond Water Quality Parameters

The other fish pond water quality parameters include ammonia, salinity, alkalinity, hardness, nitrite, carbon dioxide and hydrogen sulphide (Banrie, 2012; Dickson, 2022; Kleinholz, 2017). The alkalinity, ammonia, nitrite, salinity, hardness, carbon dioxide and hydrogen sulphide problems are solved by one or combination of the methods used in solving temperature, dissolved oxygen, pH and turbidity problems.

2.6.1 Fish pond water alkalinity

Alkalinity is the water's ability to resist changes in pH (i.e. the buffering capacity of water) and is a measure of the total concentration of bases in pond water including carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), hydroxides, phosphates and borates, dissolved calcium, magnesium, and other compounds in the water. Alkalinity takes the role of buffer (lowers the level of pH). Alkalinity can affect the potential for primary productivity and also the water pH (Banrie, 2012). Ideal alkalinity range for general warmwater fish culture is 50 mg/L - 200 mg/L (Bhatnagar & Devi, 2013).

Alkalinity problems can be solved by maintaining pH at the acceptable.

2.6.2 Fish pond water hardness

Hardness is the measure of alkaline earth elements (positive ions in the water) such as calcium (Ca^{2+}) and magnesium (Mg^{2+}) in an aquatic body along with other ions such as aluminum, iron (Fe^{+}), manganese, strontium, zinc, and hydrogen ions (AFCD 2009). Calcium and magnesium are essential to fish for metabolic reactions such as bone and scale formation. These positive ions do not exist in the atmosphere and so rainwater has low water hardness. High concentration of hardness exists in water sources like limestone-based aquifers. Low hardness values causes stress and high hardness is lethal to fish life as it increases pH, resulting in non-availability of nutrients (Swain *et al*., 2020).

Hardness problems can be solved simply by water exchange and replenishment of pond water.

2.6.3 Fish pond water ammonia

Ammonia is the by-product from protein metabolism excreted by fish and bacterial decomposition of organic matter such as wasted food, faeces, dead planktons, sewage and the reduction of nitrates and nitrites by bacteria in anoxic waters. Other sources of ammonia include industrial effluents from gas works, coking plants and power generator stations. Pond water ammonia problem needs to be avoided as ammonia is a very important parameter for good fish and shrimp production. Ammonia in water exists in two forms; ammonium ions (NH_4^+), which are non-toxic, and the un-ionized or molecular (non-dissociated) toxic ammonia (NH_3). Ammonia reacts with water to form the ammonium ion (NH_4). The relative proportion of one or the other depends on water temperature and pH. The NH_3 is more toxic to fish than dissociated because it can readily diffuse across the tissue barriers (Levit & JD, 2010). Measurements of ammonia in water are the sum of NH_3 and NH_4 and are called total ammonia nitrogen (TAN).

Although ammonia is passively excreted through fish gills, toxic NH_3 concentrations may occur in the body when environmental levels of NH_3 are high. As little ammonia concentrations as 0.6 ppm (mg/L) of NH_3 can be toxic to many kinds of fish, causing gill irritation and respiratory problems. Safe level of ammonia concentration for aquatic fishes is 0.00 mg/L - 0.05 mg/L (Bhatnagar & Devi, 2013). In addition, ammonia may be very toxic to catfish in cold water of less than 4.44^{o}C.

Ammonia problems can be solved by maintaining pH and temperature of pond water at the acceptable range-simply by regular water change out or reduction of feeding rates.

2.6.4 Fish pond water nitrite

Nitrite (NO_2^-) is another form of nitrogenous compound that results from feeding of fish. Nitrite (NO_2^-) is a product of bacterial reduction of ammonia. So it is an intermediate product of the aerobic nitrification bacterial process, produced by the autotrophic *Nitrosomonas* bacteria combining oxygen and ammonia. In the pond water, nitrite concentration is associated with ammonia concentration (Boyd, 2017). Nitrite replaces oxygen in the blood to form methemoglobin which is harmful to fish when present in high concentrations.

At 2 ppm (mg/L) and above, nitrites are toxic (injurious or lethal) to many fish and shrimp (Banrie, 2012). Nitrite oxidizes haemoglobin to methemoglobin in the blood, turning the blood and gills brown and hindering respiration; also damages nervous system, liver, spleen and kidneys of the fish. When the level of methaemoglobin in fish blood is more (70–80%), they lose their orientation and become unable to response to stimuli (Tilak, Veeraiah, & Raju, 2007). Nitrite toxicity is influenced by pH, dissolved oxygen, and water temperature. The ideal and normal measurement of nitrite is zero in any aquatic system. According to Bhatnagar and Devi (2013), 0.02 - 0.20 ppm is ideal for many fish species.

The level of nitrite can be reduced by maintaining pH, dissolved oxygen and temperature of pond water at the acceptable range simply by regular water change out (Bhatnagar *et al*., 2004)

2.6.5 Fish pond water carbon dioxide

Carbon dioxide (CO_2) in ponds is primarily produced through respiration by fish and the microscopic plants and animals that constitute the pond biota. So it is a byproduct of aerobic respiration. It is free carbon dioxide, highly soluble in water and main source of carbon path way in the nature. Carbon dioxide can exist in water as bicarbonate or carbonates in the dissolved or bound form in earth crust, in limestone and coral reefs regions. When carbon dioxide dissolves in water, it forms carbonic acid which decreases the pH of any system, especially insufficiently buffered systems, and this pH drop can be harmful for aquatic organisms. Carbon dioxide levels (and toxicity) are highest when DO levels are lowest. Carbon dioxide levels in fish culture ponds cycle daily, with highest levels near dawn and lowest levels in mid-afternoon Kleinholz (2017).

The carbon dioxide in water has direct and indirect toxic action on fish. In the indirect action, it influences the water pH, causing its values to rise to toxic levels. In addition to changes in pH, it influences the toxicity of dissociated and non-dissociated forms of H_2S and ammonia. When CO_2 is in excess or less than required, a direct adverse effect occurs.

High CO_2 concentrations inhibit the ability of fish to extract O_2 from the water, reducing the tolerance to low O_2 conditions and inducing stress comparable to suffocation (Banrie, 2012). Fish affected by CO_2 becomes listless, and then lie motionless on the pond bottom (Hargreaves & Brunson, 1996; OATA, 2008). Bhatnagar and Devi (2013) suggested that CO_2 level from 5 mg/L - 10 mg/L is safe for warmwater fishes.

Carbon dioxide problems can be solved by maintaining pH at the acceptable range-simply by replacing portion of the dirty water from pond bottom with more oxygenated water making sure the whole water is properly mixed or by vigorous aeration (Bhatnagar *et al*., 2004).

2.6.6 Fish pond water hydrogen sulphide

Hydrogen sulfide (H_2S) is a colorless and toxic gas excreted by bacteria during anaerobic decomposition of waste products on the pond bottom. Any detectable level should be considered detrimental to fish production since it hinders their respiration.

Anaerobic soils with moderate to high organic concentrations can be a significant source of H_2S (Boyd, 2017). If the bottom soil becomes black and a rotten egg odor is recognized when sediment is disturbed, it indicates anaerobic conditions and the presence of H_2S. Hydrogen sulfide is highly toxic in the unionized form (comparable to ammonia). However, the unionized form is predominant at low pH (< 8) and high temperature. At pH 7.5 approximately 14 % of the sulfide is in the toxic H_2S form and at pH 6.5 about 61 %. The impact of hydrogen sulphide ranges from high to very high toxic on fish. According to (Banrie, 2012), sulfide concentration above 0.002 ppm is high in fish pond.

Hydrogen sulfide problems can be solved by maintaining humic turbidity at the acceptable range (Banrie, 2012)-simply by frequent water exchange.

2.6.7 Fish pond water salinity

Salinity or Total Dissolved Solids (TDS) represents the total concentration of dissolved inorganic ions, or salts, in water (El-Leithy *et al*., 2019). It is defined as the total concentration of electrically charged ions such as cations – Ca^{++}, Mg^{++}, K^{+}, Na^{+} ; anions– CO_3^-, HCO_3^-, SO_4^-, Cl^- and other components such as NO_3^-, NH_4^+ and PO_4^- (Shemsanga *et al*., 2017). According to Groundwater Glossary (2006), pond water contains dissolved salts less than 500 parts per million (ppm). Salinity affects the concentration of dissolved oxygen. Dissolve oxygen (DO) decreases as salinity increases (Rairat *et al*, 2022). Salinity is a major driving factor that affects the density and growth of aquatic organisms' population (Rairat *et al*, 2022). It plays a significant role for the growth of culture organisms through osmoregulation of body minerals from that of the surrounding water.

Fishes are sensitive to the salt concentration of their waters and have evolved a system that maintains a constant salt ionic balance in its bloodstream through the movement of salts and water across their gill membranes. When salinity is too high, fish and shrimp start to lose water to the environment (Banrie, 2012). Drastic changes of salinity may also alter the phytoplankton fauna and their population densities and lead to instability of the ecosystem **(**Hassan, 2017**)**. Salinity problem can be solved by maintaining DO at the acceptable range (Bhatnagar et al., 2004)- simply by exchange of portion of water, making sure that the salinity is not lowered by more than 5 ppm, at each time of water exchange.

2.7 Electronic Method of Controlling Water Quality in Fish Culture

Electronic method of controlling water quality in fish culture involves using electronic system in maintaining water quality at an acceptable/optimal range. The maintenance involves preventing occurrence of problems, monitoring and controlling water quality parameters. The water quality parameters monitored and controlled include the quad-essential parameters (temperature, dissolved oxygen, pH and turbidity) and other important water quality parameters (hardness, salinity, ammonia, hydrogen sulfide, nitrite, nitrate, carbon dioxide). The water quality parameters are monitored through their respective sensors. A typically electronic system for monitoring and controlling water quality senses the level of the parameters and processes the signals from the sensors, displays or sends the values to fish pond operator/farmer or computer/mobile phone for analysis and then takes action to control water quality when the level of any parameter is out of range (Mohammed & Al-Mejibli, 2018; Ujwala et al., 2020). So, the system monitors and records water quality around the clock providing continuous data that can be used to identify trends and improve production.

An electronic system takes action to control water quality through devices such as valve, pump, mechanical aerator, heater, axial fan, chemical injectors, and other devices. Alarms may be sent via pager, radio, or phone when the level of any parameter reach presets danger level or when amp sensors indicate controller (e.g. aerator) failure. So a typical electronic system for monitoring and controlling water quality consists of power supply, input/sensing unit, processing/control unit, output unit (contingency response unit and communication unit). The typically electronic system also performs functions such as replacement of pond water lost through evaporation and seepage amongst others in order to maintain appropriate fish pond water quality.

The methods applied by the electronic systems are based on the conventional methods of maintaining fish pond water quality which involve monitoring and controlling of fish pond water quality parameters and taking precautionary measures (AFCD, 2009). The use of the electronic systems may lead to the achievement of high-quality, high yield, improvement of the basic environmental conditions and high productivity in fish farming (Lee, Ibey, Coté, & Pishko, 2008; Wang, Qi, & Pan, 2012), but systems which could carry out real-time water quality monitoring continuously have limited applications since most of them are under development and have not been fully deployed in fish ponds (Mohammed & Al-Mejibli, 2018).

2.8 Review of Related Works

Some published works on the different electronic systems for monitoring and controlling fish pond water quality parameters were reviewed in this section.

Harun *et al*, (2018) developed a real time fish pond monitoring and automation system using Arduino microcontroller. The objective of their work was to eliminate the need for hiring worker for monitoring water quality parameters, consequently drive down operating costs and improve efficiency. The automation system is powered from solar panels. In the design, three essential water quality parameters (temperature, pH and DO levels) were used as measures for monitory pond water quality. Water level sensor was also integrated in the system. So, four sensors were integrated in the system. The sensors were a temperature sensor (DS18B20) for measuring water temperature, dissolved oxygen (DO) sensor (Atlas Scientific Kit), pH sensor (Analog pH Meter Kit SKU:

SEN0169) and water level sensor. The system also contains a temperature sensor to measure atmospheric temperature, an aerator, a submersible pump (to pump water from the creek) and a suction pump (to extract water from the well). The integrating devices are comparatively not expensive and consist of Arduino board, internet and relay frames and display system. The readings of the sensors were collected via an Arduino Mega 2560 microcontroller. The data was then sent via the existing, domestic Wi-Fi network to an online Google spreadsheet. To send data via Wi-Fi, an extra Arduino shield (Cytron ESP8266) was fitted to the main board. The data passed through an [Arduino – PushingBox – Google Form – Google spreadsheet] chain. Data from all sensors were captured and uploaded online at a rate of one set per minute. The Google spreadsheet was shared between the research team and farm owner. Data was also monitored in-situ via a 16×2 LCD. The system was tested in one of the typical aquaculture farms located in Malacca in Malaysia. The pond has a length of 24m, width of 13m and depth of 1.2m (typical water level). The pond produced tilapia and two of local Malaysian catfish favorites called patin and keli. Water was supplied to the pond from an abandoned well using suction pump and from a nearby creek using a submersible pump. The DO sensor, pH sensor and one of the temperature sensors were packed together and dipped in the water 1.5m away from one side of the pond. The second temperature sensor was left in the atmosphere, just outside of the water. The system monitored temperature, pH, DO and water levels and pumps water into the pond when water level dropped and operated mechanical aerator when DO levels fell outside acceptable range and pH was low. User could receive information on four most important water parameters at predetermined intervals on preferred communication or display gadgets as long as they had internet.

With this system, farmer needed not to hire worker at their site for monitoring water, temperature, pH and DO levels, consequently drive down operating costs and improve efficiency. The system did not monitor turbidity nor controlled water temperature and turbidity and high DO and pH.

Mohammed and Al-Mejibli (2018) developed a smart monitoring and controlling system to enhance fish production with minimum cost. Mohammed and Al-Mejibli (2018) employed the recent technologies of remote monitoring and controlling system to increase the fish farm production. The system developed used several types of sensors and controllers. In addition, it implemented an application which may be applied on mobile phone or personal computer. The system has the abilities of remote monitoring and controlling fish farm to maintain its healthy conditions. The system offered seamless approach to the fish farmer in order to monitor and control fish farm. The development was aimed at maintaining healthy life conditions of fish farm or pond by offering remote monitoring and controlling facilities. In this design, three essential water quality parameters (temperature, pH and DO), total dissolved solids (TDS) and water levels were used as measures for monitory pond water quality. Six sensors were integrated in the system and they included temperature sensor (DS18B20) used for measuring water temperature, ultrasonic ranging module (HC-SR04) for measuring the water level, dissolved oxygen (DO) sensor (Atlas Scientific Kit), pH sensor (Analog pH Meter Kit SKU: SEN0169), TDS sensor of type (SKU: SEN0244) and turbidity sensor (SKU: SEN0189). GSM module used was SIM900. The SIM900 was connected to microcontroller by using Arduino board to enable it send and receive SMS on fish farm condition based on collected and processed data. The system maintained healthy life conditions of fish farm or pond by offering remote monitoring and controlling facilities. In monitoring process, it periodically reads the sensed data from the six sensors. In controlling process, the system continued gathering, calculating and testing the sensors readings regularly, in order to perform the required action(s) based on the sensed data. It took the required action via heater, axial fan, water pump or TDS filter when pond water quality parameter was critical (went out of the required range). A heater and axial fan were used to increase and decrease the water temperature respectively. When the sensed value was larger of acceptable level (28^{o}C), the microcontroller switches on axial fan via relay and when it was lower than 18^{o}C, it switches on heater. When the sensed TDS value was out of required range, the microcontroller switched *on* TDS filter via relay. On the other hand, when the oxygen value was reduced in pond, the microcontroller energized the air pump (via relay) to supply ponds with the oxygen. When the amount of suspended solid (turbidity) was larger than the required range the microcontroller switched *on* filter via relay. Again, when the water level was less than the required level (for instance less than 3cm) the microcontroller switched *on* a water pump via relay in order to increase the water level. When pH value was out of the required range the microcontroller sends SMS warning massage to ponds operator via GSM to enable him interfere immediately and when it was required. The system controlled temperature and DO, water and TDS levels and did not monitor or control pH levels.

Obado (2019) developed Internet of Thing (IoT) based real time fish pond water quality monitoring model. The purpose of the development was to enable the stakeholders using the model to take proactive action when the thresholds for the various parameters were achieved in order to avoid losses such as fish kills and feed wastage. The model utilized

IoT concept which enabled information gathering about water quality through the corresponding sensors. The status of the water quality aspects was then relayed on a real time basis through a cloud platform via a microprocessor to a graphical user interface (GUI) on the farmer's Smartphone. The farmer would then act as per the information relayed or the model automatically acts on behalf of the farmer based on predefined actions. The real time information enabled timely intervention by the farmers which eventually helps in minimizing or eliminating wastages. The research focused on developing a model for real time monitoring of fish ponds. The crucial parameters in fish pond culture in Kenya were identified as temperature, water level and turbidity. So, the model used temperature sensor (DS18B20), ultrasonic ranging module (HC-SR04) and turbidity sensor (SKU: SEN0189) to monitor the water quality parameters. The model used the sensors for capturing water quality state through virtual pins while actuators which were in the form of relays, were responsible for manipulating devices such as the water pump and Smartphone application cable of remote monitoring by displaying the water state. The microcontroller used in this model is Arduino UNO R3. Arduino UNO microcontroller was responsible for executing the programmed sequence of instructions embedded in it and issues user commands on the actuators. A cloud infrastructure that contains a RESTFUL API was also integrated in this model. Its function was to execute instructions obtained from the Smartphone application. The status of the water quality aspects were relayed on a real time basis through a cloud platform via a microcontroller to a graphical user interface (GUI) on the farmer's Smartphone. The farmer then acted based on the information relayed or the model automatically acted on behalf of the farmer based on predefined actions. The actions taken included water exchange through water pump connected to a reservoir tank and outlet for temperature and turbidity problems and replenishment of water when pond water level dropped. The system did not monitor or control DO and pH levels.

The work done by Abinaya, Ishwarya, and Maheshwari (2019) explained the importance of monitoring and controlling water quality parameters. Based on that, the researchers designed an Internet of Thing (IoT) based system for monitoring and controlling water quality parameters in the aquaculture. The system was able to detect and control parameters such as temperature, pH value, dissolved oxygen, water level, foul smell and ammonia in the pond water. Sensors nodes gathered the real time data from the water and sent it to Aurdino microcontroller for processing and initiating control action when any of the measured parameter exceeded the desired range. The measured values from the sensors were also sent to the cloud using wi-fi modem and can be viewed in the control room and short messages (SMS) sent to the concern person using GSM modem. The system was compatible and was used for any type of aquaculture system. The developed system used multiple sensors commonly used to continuously monitor the parameters. The system consists of Arduino microcontroller, ammonia, water level, pH, foul smell, temperature and dissolved oxygen sensors. It also has Wi-Fi connectivity and GSM module. The sensors were the common sensors used in monitoring water quality parameters except foul smell sensor. MQ4 Electronic Nose was used as a foul smell detector/sensor. The system detected and controlled ammonia, water level, pH value, foul smell, temperature, dissolved oxygen level in the water. The real time data was collected from the sensor nodes and sent to Arduino for processing. The processor activated the corresponding controller to take necessary action when the parameters exceeded the threshold. If temperature was low, the heater would be turned *on* till the temperature reached prescribed level and if water level decreased, the water pump should be turned *on* till the water level was normal. If dissolved oxygen level or pH level was low, aerator was turned *on* till the level normalized. The sensed values were also sent to the cloud using Wi-Fi and could be accessed in the control room. These values in the form of short messages were sent through GSM to aqua farmer to inform him of the present situation in the farm. The system does not monitor nor control turbidity level.

This research by Azhra1 and Anam (2020) developed a system which is a real time fish pond water quality controlling model which utilized a Smartphone. The objective of this work was to design a system that will enable fish farmers monitor and control fish pond water quality easier and in real time. In this model, fish pond water quality was monitored through seven parameters namely salinity, ammonia, conductivity, dissolved oxygen, temperature, pH and turbidity of water via their respective sensors and the system can control water quality in real time from phone and can activate automatic responses directly and through applications on mobile phones if there is an indication that the water quality is outside normal limits. The system was designed by installing seven sensors with the consideration that the more parameters used, the analysis and decision making would be closer to valid. The dissolved oxygen, temperature, pH, turbidity and salinity level sensor modules used were not specified in this design. The conductivity module consisted of a sensor module circuit and a TDS sensor signal conditioning circuit while ammonia sensor used was MQ-135 module. Arduino microcontroller was also integrated in the design to control the activities of the system. Actuators were integrated in the design through which control actions were taken. The actuators included axial fan, pump, and aerator and salinity injectors. Actuators function to control several indicators in response if there were indications that water quality was beyond normal limits. Actuators were activated automatically or manually. This tool was also connected to the application that was installed on mobile phones so that users could control water quality even if they were far from fish ponds. The design also included screen which was installed in the fish pond for displaying of several menus including, calibration-to change the sensor value into general units, set point-to set the maximum limit of the value of each allowed indicator, monitoring-to display the value of each indicator in real time, and control-to activate the actuator on the appliance. The system was connected to the application that was installed on mobile phones so that users could control water quality even if they were far from fish ponds. Actuators functioned to control several indicators in response if there were indications that water quality was beyond normal limits. So any water quality parameter was controlled by activating the actuator on the corresponding appliance. Cooling actuator was activated in response if the water temperature was high. The pump was activated to drain water from pond to hydroponic and refill the water. The methods of controlling pH, ammonia and turbidity were not clearly stated by the authors and may be done through water drainage to hydroponic. Aerator was activated to add oxygen in the pool if DO was low while salinity injectors were activated in response if water salinity was not normal. Actuators could be activated automatically or manually and remotely since the system was also connected to the application that could be installed on mobile phones. The system in the work monitored the quad-essential fish pond water parameters and other parameters such as salinity and ammonia. The authors did not specify parameters that were controlled by activating pump to drain water from pond to hydroponic.

2.9 Research Gaps

The water quality control systems for fish culture reviewed in this work have the following limitations:

i. The systems did not maintain optimum fish pond water quality. They allow the parameters to reach critical levels before taking control action.

ii. The systems did not perform adequate preventive maintenance on fish pond water.

iii. Most of the systems did not control all the essential water quality parameters; only the last system controlled all the parameters but it did not control water level.

iv. The systems provided temporary solutions to fish pond water low DO and pH and high temperature. These systems controlled water quality problems via mechanical aerator/air pump, axial fan, heater or water pump when pond water quality parameter was critical. Mechanical aerator used in controlling low DO and pH problems provided temporary solutions as it did not eliminate or reduced the root causes of the problems (high temperature, cloudy weather, excessive plankton population, rain storm). Axial fan provided temporary solution to high water temperature as it does not eliminate or reduce the root causes of the problem (harsh weather or low volume/depth of water). Use of heater in controlling low pond water temperature is challenged by mixing of the water.

v. The systems consumed much electric power because of the multiple controllers (such as 230v water pump, mechanical aerator/air pump, axial fan and heater) used in their operations.

vi. Only one electric power source was integrated in each of the systems. So, when the power source of any of the systems has problem, the system would not operate and this made it unreliable.

vii. The systems were expensive as the multiple controllers (such as 220V water pump, mechanical aerator/air pump, axial fan and heater) used in their development make them to be expensive.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials used in the development of smart electronic system for maintenance of optimum water quality in warmwater fish culture include hardware and software components and tools respectively. The materials were sourced locally except Arduino-based sensors such as dissolved oxygen sensor, and turbidity sensor that were ordered from China.

3.1.1 Hardware components

The hardware components include:

1. Arduino Mega microcontroller board
2. Temperature sensor
3. Dissolved oxygen sensor
4. pH sensor
5. Turbidity sensor
6. Ultrasonic sensor
7. GSM module
8. Smart phone
9. Liquid crystal display (LCD)
10. Water pump
11. Solenoid valve
12. Servo motor
13. Solar panel

14. Battery
15. Charge controller
16. Transformer
17. Diode rectifier
18. Capacitor
19. Circuit breaker
20. Regulator
21. Relay
22. Transistor
23. Resistor
24. Light emitting diode (LED)
25. Plastic pipe and adapter

3.1.2 Software tools

The software tools include:

1. Arduino Integrated Development Environment (IDE)
2. Proteus Professional Simulation Software
3. MIT App Inventor

3.2. Hardware Design of Smart Electronic System for Optimum Water Quality Maintenance in Warmwater Fish Culture

The hardware system was designed via specification of design, drawing of pictorial diagram, conversion of the specification into a block diagram and drawing of circuit diagram.

3.2.1 Design specification

Function: The smart electronic system for optimum water quality maintenance in warmwater fish culture is an automation system that maintains optimum water quality in fish ponds and tanks. The system maintains optimum level of each of the quad-essential water quality parameters by taking smart action.

Target users: The target users are fish farmers, fish farm operators and aquaculture research institutes.

Materials: Low-cost, efficient and durable materials are required for the development of the system. The materials include sensors, processor, actuators, display system and wireless communication system.

Ergonomics/overall size: The system is an automation module, which consists of four sub-modules or subsystems: optimum water temperature maintenance system, optimum water DO maintenance system, optimum water pH maintenance system, and preventive maintenance system. The standard optimum levels of the quad-essential water quality parameters (temperature: 20 - 28^oC, DO: 5 – 7.5mg/L, pH – 6.9 – 8.5, turbidity: 10 – 20mg/L) presented in literature review is used in the design. The system is efficient, reliable, durable, user-friendly, scalable and fairly cheap. The smart system is used in fish ponds and tanks having depth of 2m or less (shallow pond or tank), maximum area of 45m^2 and an overflow pipe. The system requires a regular 24V 300W DC power supply and operates regularly (24 hours a day). Part of the system (sensors) is immersed in the fish pond or tank and is water resistant and protected against contact with fishes. The remaining part of the system is installed outside the fish pond or tank and protected against theft and damage. The system communicates water quality conditions and maintenance operations performed to fish pond owner or operator.

Development process: The system is a prototype and requires developing by hand. Development process including calibration and validation of sensors, software system development, hardware system implementation and testing is applied in the development.

Equipment/tools-requirements: Hardware tools such as multimeter, screw drivers, hammer and soldering iron and software tools such as Arduino Integrated Development Environment (IDE), Proteus professional simulation software and MIT App Inventor are required for the development of the system.

System life span: The system lasts for 20 to 30 years and needs maintenance every 6 months. It is required that the processor/controller is selected with this purpose in mind. All other components are of high quality materials.

Quality assurance: Quality assurance is required to ensure that all the materials and procedures are in place to ensure the development of a quality piece of system. The potential users are constantly updated and consulted on all aspect of the development.

Quality control: The system check is required for quality and imperfections/damage at every stage of the development. Corrections/repairs or replacements of faulty components are required to ensure development of system with highest possible quality. A final quality check takes place before the deployment of the system in fish pond or tank.

Cost: The system is fairly cheap (no more than ₦600,000). This price includes materials only and excludes labour costs, tools and equipment requirements. This means that simple design and low-cost, efficient and durable materials is required in its development.

Time scale and planning: Three to 6 months is required for designing and construction of a prototype system. Approximately half of the time is required for the design work and half for development of the prototype, which includes model making.

Health and safety: Adherence to health and safety regulations is required during the development process. When implementing the system, vigorous testing is required for leakage current and stability. Assurance of safety of user and fishes is also required

3.2.2 Pictorial diagram of smart electronic system for optimum water quality maintenance in warmwater fish culture

The pictorial diagram of smart electronic system for optimum water quality maintenance in warmwater fish culture is as shown in figure 3.1. The pictorial diagram was drawn based on the design specification and on the fact that any system for maintenance of optimum water quality in fish culture should take adequate preventive measures (replacement of lost water, exchange of bottom dirty water, erection of sun screen/shade or windbreak and discharging of excess water caused by rain or run-off water), monitor the essential water quality parameters regularly and adjust level whenever any of the parameters reaches optimum level.

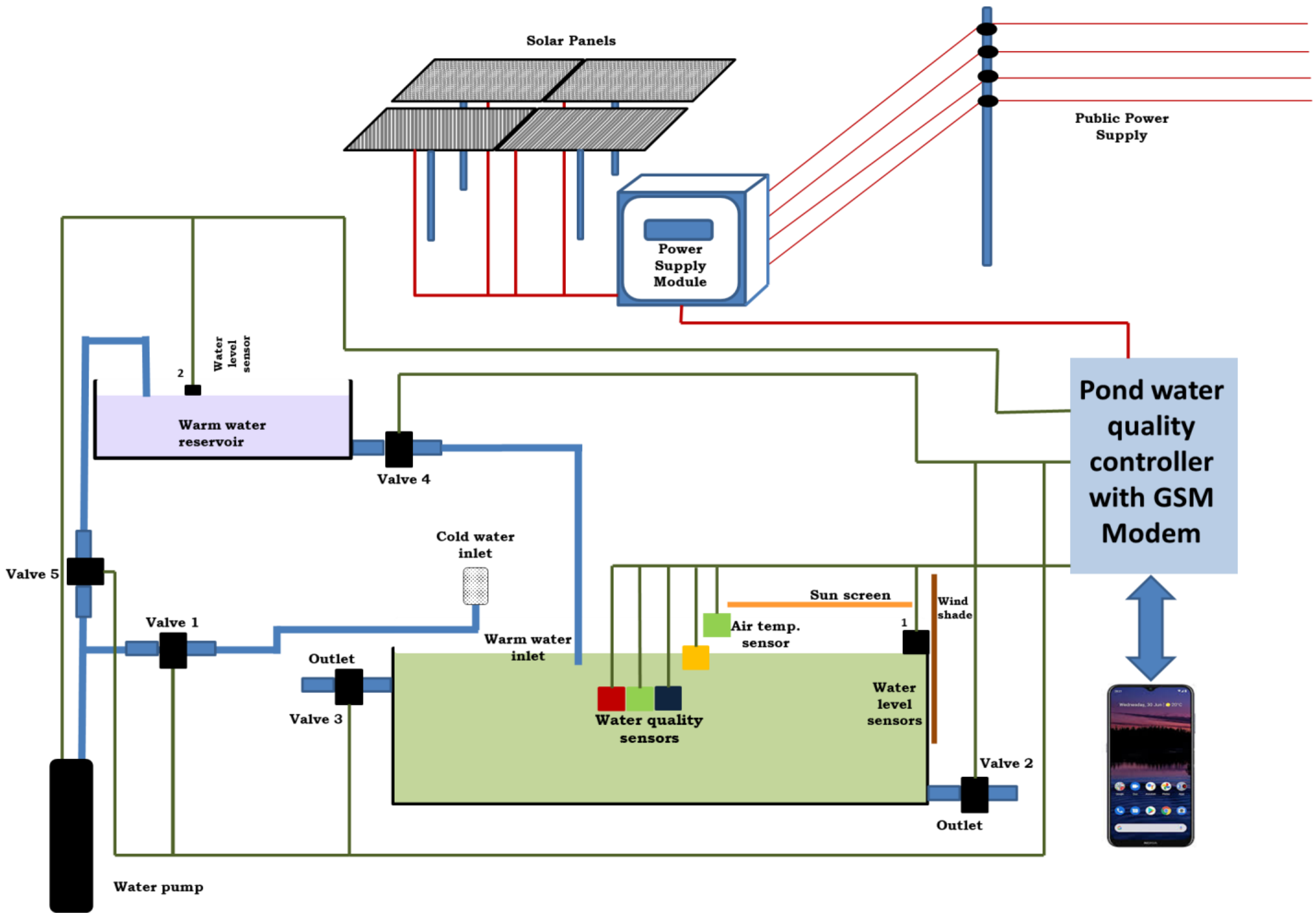


Figure 3.1: Pictorial diagram of the smart electronic system for optimum water quality maintenance in warmwater fish culture

The system has dual electric power source, controller for controlling the operation of the entire system, sensors for monitoring the quad-essential water quality parameters, air temperature and pond and reservoir water levels, inlets filling pond and outlets for discharging water from pond via solenoid valves, water pump for supplying water, actuators (relay circuits) for activating valves and pump, liquid crystal display (LCD), GPRS gateway and Smartphone for transmission and recording of water quality condition.

3.2.3 Block diagram of the smart electronic system for maintenance of optimum water quality in warmwater

The block diagram of the smart electronic system for maintenance of optimum water quality in warmwater fish culture is as shown in figure 3.2.

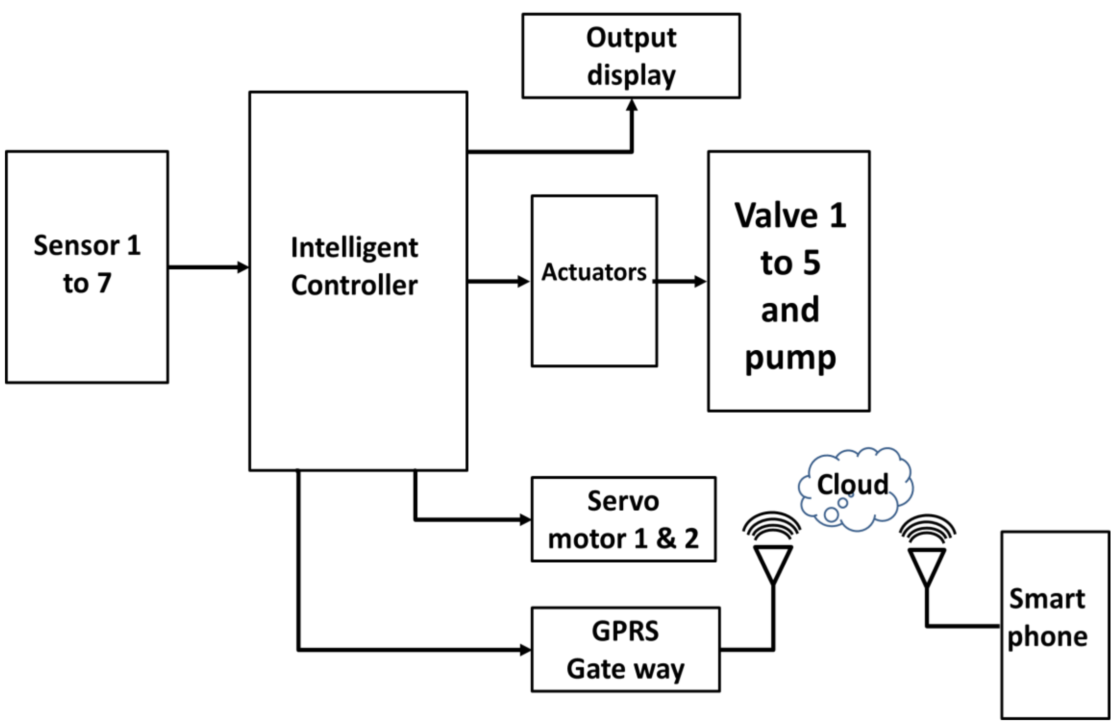


Figure 3.2: Block diagram of smart electronic system for maintenance of optimum water quality in warmwater fish culture

The block diagram was drawn based on the conceptual model of the optimum water quality maintenance system. The system consists of 7 sensors (4 for monitoring quad-essential water quality parameters (input system), 1 for monitoring air temperature and 2 for monitoring pond water and reservoir water level respectively), 5 valves and 1 water pump and their actuators, 2 servo motors, 1 output display system, 1 general packet radio service (GPRS) gateway and 1 Smartphone (output system) and 1 intelligent controller (processing unit).

3.2.4 Design and analysis of the input system of smart electronic system for maintenance of optimum water quality in warmwater fish culture

The input system consisted of power supply unit, pond water and air temperature sensors, DO, pH and turbidity sensors, pond and reservoir water level sensors and signal conditioners. The signal conditioners (analog to digital converters) were inbuilt in the Arduino Mega 2560 (microcontroller board) used as the processing unit in this design. The input unit is as shown in figure 3.3.

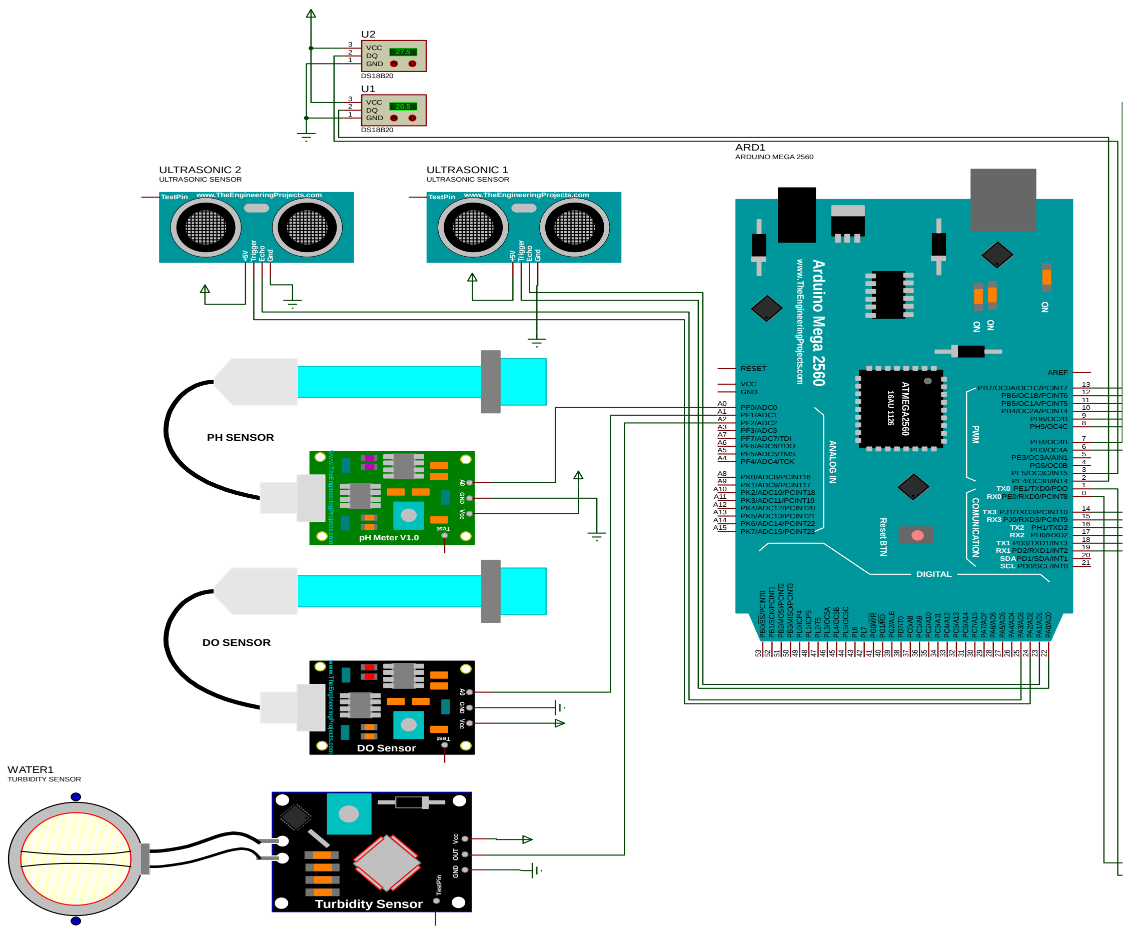


Figure 3.3: Design of the input system of the smart electronic system for optimum water quality maintenance

(a) Power supply unit

Power supply unit provided electric power required by the components of the entire system. This unit supplied constant 24V DC power to water pump, 12V DC to six relay circuits and five solenoid valves and a 5V DC to microcontroller, liquid crystal display (LCD), GSM module, seven sensors and two servo motors. Only one solenoid valve and two relays used the 12V DC supplied at a time. The 5V DC supply came from two regulators; one for the servo motors in which only one used the power at a time and the other supply was for the other components that use 5V DC. This unit is a dual power supply system and its input power of 24V was supplied to the system either by solar power system or public power supply via transformer through the help of automatic change-over switch. The unit also have switch for switching OFF the system when its operation was not needed or when it was not in use. The circuit diagram of the power supply unit is as shown in figure 3.4.

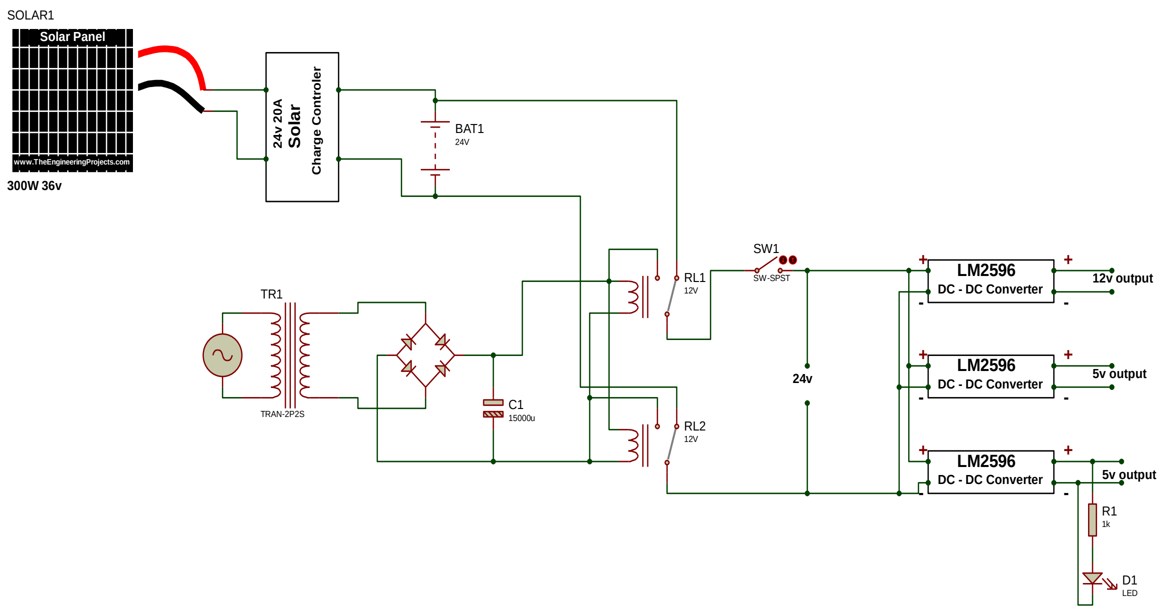


Figure 3.4: Circuit diagram of power supply unit

The choice of components for the power supply unit were made based on the power requirements of pump, valves, relay drivers, servo motors, sensors and processor of the smart system for optimum water quality maintenance. The analysis of the power supply unit design is as presented in subsections 2.3.4a to 2.3.4c.

(b) Solar power system

The solar power system provided 24V DC supply to the power supply unit and it consists of solar panel or photovoltaic array (PV array), battery, battery charge controller and interconnections. The solar power system was designed for the worst-case scenario (for the day when the energy demand was highest). In the design, an automatic change over switch was directly connected to the charge controller and was fed up by two power sources. The required sizes of solar power system components were determined based on guidelines from Electrical Technology (2020) and Phansopkar (2020).

Solar panel: The solar panel used in this system was 300W 24V Mono Solar Panel (4183197) while the required size was 300W 24V. The panel has high efficiency toughened glass material to withstand any weather condition and ability to absorb light (even low light) into the cells and has life span of up to 20years. The solar panel had current rating of 8.24A and short circuit current of 8.76A. The size of solar panel used was determined using the expected highest total DC load and lowest mean daily solar irradiance in peak sun hours (worst case). It was assumed that the system made two water exchanges within 24 hours (rare case since each water exchange tends to maintain a water quality parameter and prevents water quality problem), so the highest total DC load was experienced. With the assumption, the water pump takes halve an hour to refill portion of the pond water drained while two valves and a level sensor are involved in the water exchange. Other components involved in each of the water exchange assuming pH reached its lower optimum limit two times in a day include Arduino Mega, pH sensor and relay drivers. The DC loads of the valves, Arduino Mega, sensors were calculated using their power rating accessed from their manufacturer's datasheets and the expected time each component operates during the water exchanges and the rest of the day.

The total load was calculated as follows:

Let the total load or power consumed by the entire system be P_T, and let the power consumed by each component be P_{ni}

Where n is the total number of components.

i is number assigned to component.

Mathematically, the entire system load was represented as in equations 3.1, 3.2 and n 3.3 (Theraja & Theraja, 2002).

$$P_T = \sum_{i=1}^{n} P_{n_i} \tag{3.1}$$

$$P_T = P_1 + P_2 + P_3 \dots + P_n \tag{3.2}$$

Let P_1 be the power consumed by pump.

$$P_1 = \int_{t=0}^{t} IV dt = IV \int_{t=0}^{t} dt = IVt \tag{3.3}$$

Where V is the voltage rating of pump in volt

I is the current rating of pump in ampere

t is the operation time in hours

The voltage rating of pump ass 24V while current rating was 8.75A and for the worst case, it was expected to operate for 2h (1h for each of the two water exchange).

So,

$P_1 = 8.75A \times 24V \times 2h = 420Wh$

The calculated load for each of the other components involved in the two water exchanges is shown in Table 3.1.

Table 3.1: Maximum load calculation of the system

S/N	COMPONENT	ENERGY CALCULATION	MAXIMUM ENERGY CONSUMPTION(Wh)
1	Pump	P_1= 8.75A x 24 x 2h	420
2	Valve 2, 4 and 5	P_2= 3(416.7mA x 12V x 2h)	30
3	Relay 2, 4, 5 and 6	P_3 = 4(150mA x 12V x 2h)	14.4
4	Ultrasonic sensor 1 Ultrasonic sensor 2	P_4 = 15mA x 5V x 22h P_5 = 15mA x 5V x 2h	1.65 0.15
5	Pond temp. sensor and air temp. sensor	P_6= 2(5.5mA x 5V x 20h)	1.1
6	DO sensor	P_7 = 13.5mA x 5V x 20h	1.35
7	pH sensor	P_8 = 20mA x 5V x 20h	2.0
8	Turbidity sensor	P_9 = 30.25mA x 5V x 20h	3.025
9	LCD active LCD sleep	P_{10} = (21mA x 5V x 20s) + (480µA x 4.2V x 340s)	0.0248
10	GSM module	P_{11} = 2.0015A x 5V x 20s	0.56
11	Arduino Mega Vcc pin 25 used pins	P_{12} = (50mA x 5V x 24h) + 25(20mA x 5V x 24h)	66
Total maximum load			539.7≈540

The total load $= 540Wh$

The lowest mean daily solar irradiance in peak sun hours of a month per year or Panel Generation Factor (PFG) in USA was 3.22 and it was used in determining the total size of solar panel for the system because it was seen as one of the lowest; PFG in Nigeria is about 3.596 (Onwuzuruike and Aminu, 2019).

The required size of solar panel in watt was calculated using equation 3.4 (Electrical Technology, 2020).

$$S_P = (P_T \div T_{PH}) \times 1.25 \quad (3.4)$$

Where S_P is the required size of solar panel in watt

T_{PH} is the lowest daily average peak sun hours

P_T is the total load

1.25 is the scaling factor.

So, $S_P = (540 \div 3.22) \times \quad 1.25 \; = 209.63W$

The number of solar panels required was calculated using equation 3.5 (Electrical Technology, 2020).

$$N_P = S_P / P_P \tag{3.5}$$

Where N_P is the total size of the solar panels

P_P is the rating of selected panel in peak-watts.

$$N_P = 209.63/300 \; = 0.699$$

The solar panel required was one 300W panel since the number 0.699 was close to 1.

Battery: The battery selected for this system was 24V, 200Ah battery while the required size was 24V, 106.1Ah. The battery has the capability of supplying the required power without being discharged (depth of discharge) more than 70%. The battery has 3 to 4 days backup capacity and this allows for days with low sunlight and reduces the daily depth of discharge resulting in longer battery life. The parameters taken into consideration while sizing the battery include Depth of Discharge (DOD) of the battery, voltage and capacity of the battery in ampere-hour (Ah). Another parameter considered was the number of days of autonomy- number of days required to power up the whole system (backup power) without solar panels in case of full shading or rainy days.

The required battery size in ampere-hour (Ah) using the 24V battery with 70% DOD and 3 days backup capacity was calculated using equation 3.6 (Phansopkar, 2020).

.

$$S_B = \frac{(P_T \times B_B / V_B)}{D_B} \times E_B \tag{3.6}$$

Where S_B is the battery size in ampere-hour

B_B is the battery backup capacity in days

V_B is the battery voltage in volt

D_B is the battery discharge depth in percent

E_B is the battery efficiency factor

The efficiency factor of 1.1 was used in this formula because batteries were generally only about 90% efficient.

So, $B_S = \frac{(540 \times 3/24)}{0.7} \times 1.1 = 106.1$Ah

Therefore, one 24 V, 200 Ah battery was selected for the solar system.

Solar charge controller: The charge controller chosen for this system was 20A charge controller while the required size was 10.95A**.** The rating of the selected charge controller was 125% of the solar panel short circuit current. It is 25% greater than the short circuit current of solar panel.

The size of solar charge controller was calculated using equation 3.7 (Electrical Technology, 2020).

$$S_c = I_{SC} \times 1.25 \tag{3.7}$$

Where S_c is thesize of the charge controller in ampere

I_{SC} is the short-circuit current of solar panel in ampere

The short-circuit current of the 300Wsolar panel was 8.76A.

So**,** $C_S = 8.76 \times 1.25 = 10.95A$

The size of selected charge controller was 20A as its rating was close to the calculated size of charge controller. The charge controller was therefore, suitable for the 24V, 300W solar panel.

(c) Public power supply system

The public power supply system consisted of 220V AC power source, 220V/50Hz to 24V 15A transformer (step-down transformer), 24V, 20A bridge rectifier and 15000µf/63V capacitor, change-over switch and their interconnection. The transformer was selected for this design because the required rating of transformer was 220V/50Hz to 24V 9.2A. The power output of the transformer was adequate for the pump which was the only component that uses 24V power. The pump drew a maximum of 8.75A and made use of 210W of the 360W supplied by the transformer. The 24V, 20A bridge rectifier was suitable for this design because a maximum of current of 9.2A flowed through it. The 15000µf was suitable for this design because as a general guide, the capacitor should be rated at a minimum of 1000µf for each ampere of current drawn and at least twice the input voltage. The required size of capacitor was 9200µf since the maximum current drawn from it is 9.2A. The 15000µf capacitor used was therefore, suitable for the design. The 15000µf capacitor filtered the 24V DC and removed surges that appear on either the input or output of the supply after ratification. The change-over switch made up of two 24V DC (SPDT) relays ensured that there was regular supply of electric power to the system. The 24V relays were suitable for this design since each of them can withstand load of 1000W while the maximum load connected to them was 220W.

(i) 12V DC power source: The 24V DC from solar power system or the 24V DC output of the public power supply system was converted to 12V DC by 12V regulator connected after automatic change over switch and 24V 100A circuit breaker (switch). The circuit breaker was used for switching the system when its operation was not needed or when it was not in use. The 24V 100A circuit breaker was suitable for this because the required size was 24V, 10A (max). LM2596 voltage regulator was used in this design for converting 24V DC from battery or transformer to 12V DC required for powering valves and relays. The voltage regulator was chosen because it can convert DC voltages ranging from 4.5V to 35V to 12V DC and has maximum output current of 3A. The regulator provided regulated and stable DC voltage. The regulator was suitable for the design because a maximum of 2 relays and 1 valve can operate at a time and they draw a maximum of 0.816A. A valve draws a maximum of 416mA while each relay consumes a maximum of 200mA (a total of 816mA or 0.816A).

(ii) 5V DC power source: Two LM2596 voltage regulators were used for converting 24V DC from solar power system or public power supply system to 5V DC sources. The first 5V DC power source was used for powering microcontroller, sensors, LCD and GSM module. The regulator was suitable for this design because a maximum of one sensor operates at a time and the highest current was drawn from the regulator when turbidity sensor was active. The total current drawn in this case was 0.55A or 550mA (30mA current was drawn by turbidity sensor plus 520mA drawn by 26 pins of microcontroller), which was far less than the 3A current rating of the regulator.

The second 5V DC power source was used for powering two 5V servo motors. The regulator was suitable for this design because only 1 servo motor operated at a time. The total current drawn by the two servo motors was 0.26A (250mA drawn by the active servo motor plus 10mA drawn by the idle servo motor), which was far less than the 3A current rating of the regulator.

An LED was connected across the second 5V DC output with 1KΩ connected to it in series. The LED indicated when the power was ON. The value of the resistor was calculated using equation 3.8 (Theraja & Theraja, 2002),

$$R_S = \frac{V_S - V_D}{I_F} \quad (3.8)$$

Where V_S is the input voltage in volt

V_D is the voltage across LED in volt

I_F is the forward or circuit current in ampere

For an infra-red LED with V_D of 1.4V and I_F of 50mA,

$$R_S = \frac{5-1.4}{50\times10^{-3}} = 72\Omega$$

So, the 1K resistor used was adequate to protect the LED.

The summary of the design analysis of the power supply unit is depicted in Table 3.2.

Table 3.2: Summary of power supply unit design analysis

S/NO	COMPONENT	SPECIFICTION	REQUIRED VALUE
1	4183197 Solar panel	Rating 300W, 24V	24V, 0.699 of 300W
2	Battery	Rating 24V, 200Ah	24V, 106.1Ah
3	Charge controller	Rating 20A	10.95A
4	Transformer	Rating 24V, 15A (360W)	220W (max)
5	Diode rectifier	Rating 24V, 20A	24V, 9.2A (max)
6	Capacitor	15000µf/63V	9200µf/48V
7	LM2596 Regulator (3)	24V to 12V/5V Max output current- 3A	Current drawn - 0.816A (max)
8	Switch (Circuit breaker)	24V, 100A	24V, 16A (max)
9	Relay (2)	24V DC (SPDT) Max load power- 1000W Coil Power- 360 mW	24V DC 220W (max)

(d) Temperature sensors

Two DS18B20 temperature sensors were used in this design for sensing pond and reservoir water temperatures in view to monitoring them. Generally, each sensor was selected for the design based on its measurement range, operating temperature, power requirement and compatibility with the processor, durability and availability. The DS18B20 sensor was chosen for this design because it was Arduino-based sensor with measurement range (from -55°C to 125°C), low power requirement (3.0V to 5.5V), precision, accuracy of ± 0.5 °C and compatibility with Arduino based controller used in the system. This measurement range and power requirement of the sensor made it suitable for this system that monitored and maintains water temperature between 20°C and 28°C. The DS18B20 temperature sensor was a 1-Wire digital temperature sensor from Maxim Integrated Circuit (IC) that reports temperature in digital form in degree Celsius with 9 to 12-bit precision.

(e) Dissolved oxygen sensor

The DO sensor used in this development is Atlas Scientific Gen 2 Dissolved Oxygen Probe. The DO probe/sensor was chosen for this development because it can measure DO ranging from 0 to 100 mg/L with accuracy of ±0.5 mg/L and therefore suitable for this system that monitored DO ranging from 5 to 9 mg/L. The DO probe was Arduino-based sensor that can operate at water temperature of 1 to 60°C, has low power requirement of 3.3V to 5V, response time of about ~0.3 mg/L/s and maximum pressure of 3,447 kPa. The sensor has life span of above five years and can be fully submerged in ponds at depth up to 343m. These features made the sensor suitable for this optimum water DO maintenance system. The DO sensor consists of Epoxy and Noryl (highly resistant to corrosion) body, Male SMA Connector and PTFE membrane (polytetrafluoroethylene membrane). The circuit of the sensor has a flexible calibration protocol, allowing for single point or dual point (optional) calibration.

(f) pH sensor

The pH sensor used in this design was pH meter (SKU: SEN0169). The SKU: SEN0169, a pH meter pro was chosen for this design because it was Arduino-based sensor that has low power requirement (5V), measuring range of 0-14, response time of ≤ 1min, accuracy of ± 0.1pH (25^oC) and good thermal stability. The sensor operates efficiently at temperature between 0^oC and 60^oC and this made it suitable for this design where pond water temperature level was from 20^oC to 28^oC. In addition, the sensor used an industrial electrode and has a built-in simple, convenient, practical connection, and has long life. This pH meter pro was very suitable for long-term monitoring and it measures pH by measuring the amount of H_3O^+ ions in solution. The sensor's output signal is in analog form.

(g) Turbidity sensor

The turbidity sensor used in this design was SKU: SEN0189 (gravidity arduino turbidity sensor). The turbidity sensor was selected for this work because it was Arduino-based sensor that can sense turbidity from 0 to 3000mg/l (or 0 to 3000 NTU) accurately, has low operating voltage (5V DC) and operating current (40mA maximum), response time of less than 500ms, operating temperature of 5^oC~90^oC and senses Total Suspended Solids (TSS). The turbidity range for the water quality maintenance system was 10 to 20 NTU. The turbidity sensor system gives a specific measurement of all suspended solids, organic and inorganic, by mass and this made it suitable for this. SKU: SEN0189 provides analog and digital signal output modes; the threshold is adjustable when in digital signal mode. In this design, analog signal output mode was used.

(h) Water level sensors

Two HC-SR04 ultrasonic sensors were used in this design for measuring water level in pond and reservoir respectively. The sensor was selected for this work because it was Arduino-based sensor that can read distance from 2cm to 400cm (0.8inch to 157inch or 13feet) with an accuracy of 0.3cm (0.1inches), has low operating voltage (5V DC), offers excellent non-contact range detection with high accuracy and stable readings and its operation is not affected by sunlight or black material. The sensor was suitable for this design in which the depth measured ranged from 96cm to 120cm. The ultrasonic sensor uses sonar to determine the distance to an object. In addition, this sensor comes with ultrasonic transmitter and receiver modules and gives out signal in analog form.

The summary of the analysis of measurement ranges and operating temperatures of the sensors is depicted in Table 3.3.

Table 3.3: Summary of analysis of sensors' measurement ranges and operating temperatures

S/NO	COMPONENT	SPECIFICATION		REQUIRED VALUE	
		Range	Operating temperature	Range	Operating temperature
1	DS18B20 Temp. sensor (2)	-55^{o}C to 125^{o}C	-55^{o}C to 125^{o}C	20^{o}C to 28^{o}C	20^{o}C to 28^{o}C
2	Atlas Scientific Gen 2 DO sensor	0 to 100 mg/L	1^{o}C to 60^{o}C	5 to 7.5 mg/L	20^{o}C to 28^{o}C
3	SKU: SEN0169 pH sensor	1 to 14	0^{o}C to 60^{o}C	6.8 to 8.5	20^{o}C to 28^{o}C
4	SKU: SEN0189 Turbidity sensor	0 to 3000mg/L (NTU)	5^{o}C to 90^{o}C	10 to 20mg/L	20^{o}C to 28^{o}C
5	HC-SR04 Ultrasonic sensor (2)	2cm to 400cm	0^{o}C to 60^{o}C	96cm to 120cm	20^{o}C to 28^{o}C

3.2.5 Design and analysis of processing unit of smart electronic system for maintenance of optimum water quality in warmwater fish culture

Arduino Mega 2560 was used as processing unit in this design. This unit processed signals from input components and controlled all the activities of the entire system. The processing unit is as shown in figure 3.5

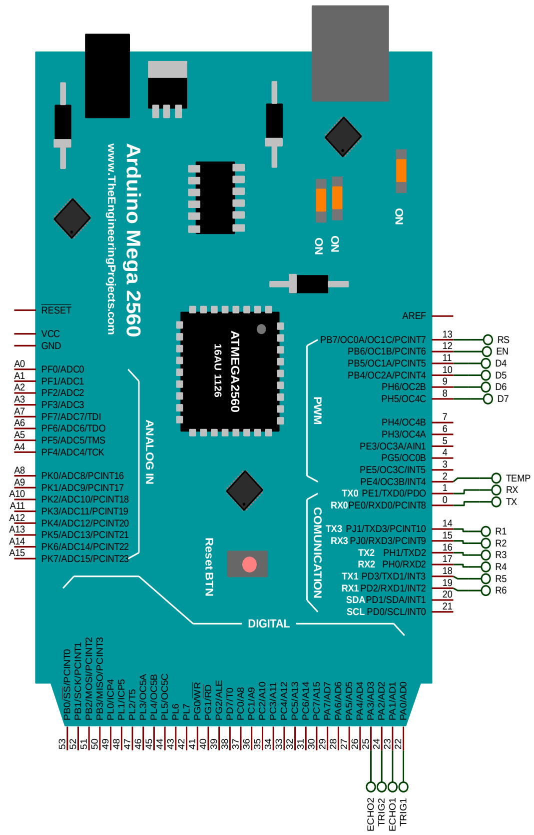


Figure 3.5: Processing unit of the smart electronic system for maintenance of optimum water quality in warmwater fish culture

The Arduino Mega 2560 was chosen for this design because it has the required number of input/output pins, serial communication port which enables simulation and calibration processes to be viewed by system developers, virtual communication port for viewing simulation and calibration processes, pulse width modulation output, adequate memory, and its compatibility and durability. The Arduino Mega 2560 is a microcontroller board based on the ATmega 2560. Arduino Mega 2560 had 54 digital input/output pins of which 16 can be used as analogue inputs, 15 as Pulse Width Modulation (PWM) outputs and 4 as UARTs (hardware serial ports) while the optimum water quality maintenance system for warmwater fish culture requires 9 input pins (3 analog pins and 6 digital pins) and 16 output pins (Table 3.4); a total of 25 pins.

Table 3.4: Microcontroller pin requirement of the system

S/NO	COMPONENT	MICROCONTROLLER PIN REQUIREMENT
1	Water temperature sensor	1 Input pin
2	Air temperature sensor	1 Input pin
3	Dissolve oxygen sensor	1 Analog input pin
4	pH sensor	1 Analog input pin
5	Turbidity sensor	1 Analog input pin
6	Water Level Sensor 1	2 Input pin
7	Water Level Sensor 2	2 Iinput pin
8	Pump	1 Output pin
9	Valve 1	1 Output pin
10	Valve 2	1 Output pin
11	Valve 3	1 Output pin
12	Valve 4	1 Output pin
13	Valve 5	1 Output pin
14	GSM module	2 Output pins
15	Servo motor 1	1 Output pin
16	Servo motor 2	1 Output pin
17	LCD	6 Output pins
TOTAL		25 Pins

The pins of Arduino Mega 2560 operate at low voltage (5V) and each pin can provide or receive 20mA (operating current) and has an internal pull-up resistor (disconnected by default) of 20-50 kΩ. In addition, the Arduino Mega 2560 has a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. The ATmega 2560 processor on the Mega 2560 board has 256 KB of flash memory for storing code (of which 8 KB is used for the bootloader), 8 KB of SRAM and 4 KB of EEPROM (which can be read and written with the EPROM library). The ATmega 2560 has a bootloader that allows one to upload new code to it without the use of an external hardware programmer. The processor communicates using the original STK500 protocol (reference, C heard files).

3.2.6 Design and analysis of output system of smart electronic system for maintenance of optimum water quality in warmwater fish culture

The output system consisted of a water pump and 5 solenoid valves and their drivers (actuators), 2 servo motors, LCD and GSM module and Smart phone. The output system is as shown in figure 3.6.

The components of the output system of the smart electronic system for optimum water quality maintenance in warmwater fish culture were chosen because they had the required parameters (e.g. operating voltage, operating current), are compatible with the processor, durable (last long) and available.

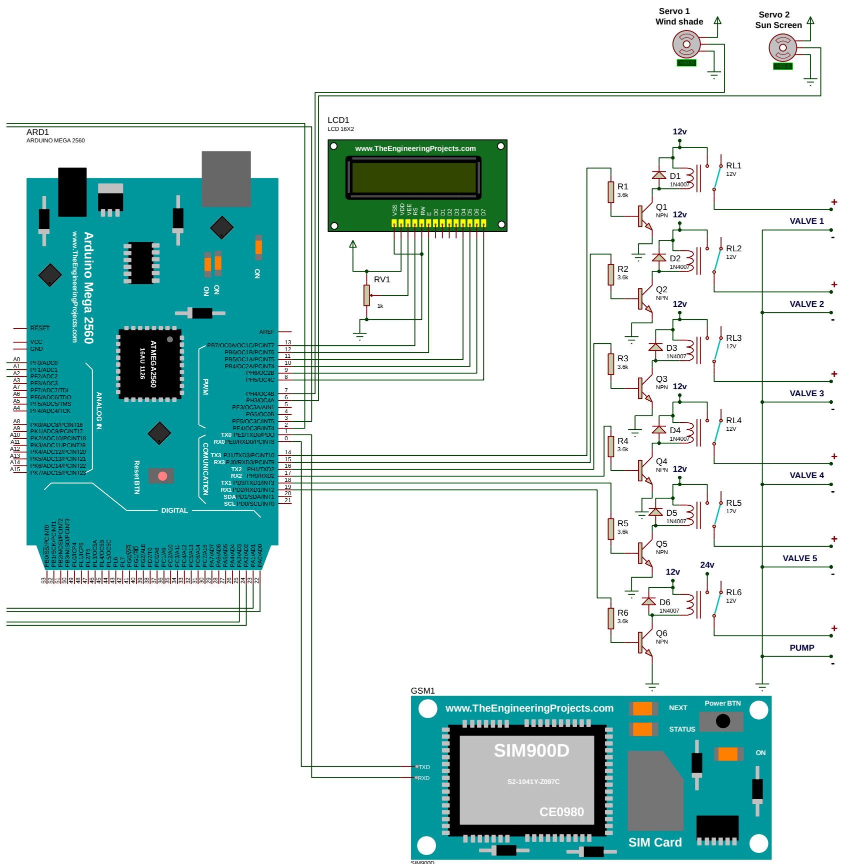


Figure 3.6: Output system design of smart electronic system for optimum water quality maintenance in warmwater fish culture

(a) Water pump

The water pump used in this design was 210W 24V DC solar power-based borehole pump with model 3FLS1.8/80-D24/210. The pump has maximum flow of 1.8m^3/h (6480L/day), maximum head of 80.00m (suitable for 50m borehole and deep well) and pumps water for 6 hours on daytime and these qualities makes it suitable for the optimum water quality maintenance system which requires pump maximum flow of 1.514m^3/h (maximum water flow 480L/day), maximum head of 77.88m and operates a maximum of two hours a day.

The pump was chosen after calculating the size of the pump required. The size was calculated by finding the flow rate and head height of pump needed using guidelines by Chris (2019). Flow rate is the volume of water moved per unit of time and is usually given in gallons per hour (GPH) or liters per hour (LPH) or cubic meter per hour (m^3/h). A pump's flow rate varies based on head height, or just head. Head is the height that a pump lifts water above the surface of a pond. Every 0.305m (1 foot) of vertical distance between the surface of the pond and the highest point the water is pumped to counts as 0.305m (1 foot) of head. This distance is sometimes called static head. The normal/cool water discharge outlet of the optimum water quality maintenance system is a fountain (also serves as aerator) and the reservoir inlet which is connected to the pump is a water flow system. These water systems are not operated at the same time. So, pump size is determined by fountain flow system which operates more and has higher head height.

The fountain flow rate was determined by applying equation 3.8 (Chris, 2019).

$$F_F = D_O \times 59.606 \tag{3.9}$$

Where F_F is the flow rate in cubic metre per hour

D_O is the outlet's diameter in metre.

The outlet's diameter is 0.025m (4inches).

So, $F_F = 0.025 \times 59.606$

$= 1.514 \text{ m}^3/\text{h}$

In order to determine the required head height of the pump, the overall head height of the fountain called its Total Dynamic Head (TDH) was calculated**.** The TDH comprised of Static Head (SH), Friction Head (FH) and Pressure Head (PH).

The SH of fountain is the vertical distance from the outlet to the height at which the pump sits, and it is 45.415m (43.891m pump depth and 1.524m distance from ground to fountain position).

The FH describes how pipe size and material affects resistance to flow and was accounted for by adding 0.305m of head for every 3.050m of horizontal piping between the pump and feature and 0.305m of head for every 90° turn in the piping. The horizontal piping between the pump and fountain is 5.741m (19ft) and four 90° turns in the piping. So, the horizontal piping contributes about 0.609m (2ft) and 90° turn in the piping contributes about 1.219m (4ft). Therefore, FH is 1.829m (6ft)**.**

The PH is the resistance from devices such as valve that use pressure to operate. Pressure head was estimated by using the conversion factor 0.704m (2.31ft) equal to 1Psi, which means that every one unit of pressure in pound per square inch (Psi) gives 2.31 feet head height. The valve used applied pressure of about 0.30 Megapascal (0.30MPa**)** for water flow greater than 16L/min and less than 28L/min (between 0.016m^2/min and 0.028m^2/min). The fountain's flow rate of 1.514m^2/h is equivalent to 0.02523 m^2/min and this value lies between 0.016 m^2/min and 0.028m^2/min. So the valve applied about 0.30Mpa and this pressure was equivalent to 43.51 psi (i.e. 0.30 x 145.03773773 psi). Applying the conversion factor, PH is 30.635m (43.51 x 0.704m = 30.635m).

$$TDH = SH + FH + PH \quad (3.10$$

$TDH = 45.415 + 1.821 + 30.635 = 77.879m$

The pump was suitable for the water exchange system since its head height is 80m and the required head height is 77.879m.

(b) Solenoid valves

The water valve used in this design was 12V DC, 3/4 inch diameter solenoid water valve. The valve was chosen for this design because of its low power requirement (12V DC and maximum power of 5W), minimum fluid pressure of 0.02Mpa (3 psi) and temperature of liquid (0-100^{o}C) allowed flow from its input to the output. The 12V DC valve is normally closed (NC) and opens when transmitting voltage is applied to it. A total of five valves (valve 1, 2, 3, 4 and 5) were integrated in the design. Valve 1 was used for letting in normal/cool water into the pond; valve 2 was used for draining water from the pond bottom; valve 3 was used for draining water from the upper part of the pond; Valve 4 was used for letting in warm water into the pond; Valve 5 was used for letting in water from pump into the warm water reservoir.

(c) Relay circuits

Relay circuits were used for interfacing the valves and pump to the microcontroller in the system. These components cannot be interfaced directly to microcontroller because the operating voltage of valves (12V) and pump (24V) are different from that of the microcontroller (5V). In this design of figure 3.6, a relay circuit consists of a 12V DC relay, a 1N4007 diode connected across it, a BC337 transistor and a 10kΩ resistor connected to the base of the transistor.

BC337 transistor was chosen for this design because it can carry the load (12V relay) comfortably. The collector continuous current of the transistor was 800mA and the load trigger current (nominal current) of the relay was 53.3mA (from the relay specification) and therefore, adequate for it. In addition, the 5V of any output pin of the ATMega 2560 microcontroller (V_{in}) was adequate for switching BC337 transistor because a minimum of 0.7V was required to bias it.

In this design, base resistor method of biasing was used. A high resistor of 10KΩ was connected between the base and output pin of the microcontroller (the positive end of supply) for each of the NPN BC337 transistor.

The base current required to cause zero signal flow (I_B) was determined using equation 3.13 (Toshiba, 2018), and base resistance determined using equation 3.12 derived from equation 3.11 (Toshiba, 2018).

$$I_B = \frac{V_{in} - V_{BE}}{R_B} \quad (3.11)$$

$$R_B = \frac{V_{in} - V_{BE}}{I_B} \quad (3.12)$$

Where R_B is the value of the base resistor of the transistor in ohm.

V_{in} is voltage across the resistor (microcontroller's pin voltage).

V_{BE} is voltage drop across the base and emitter in volt.

But $$I_B = \frac{I_C}{h_{FE}} \quad (3.13)$$

Where h_{FE} is the forward current gain of the transistor.

I_C is the maximum collector current in ampere.

V_{BE} is $0.7V$, I_C is 800mA and h_{FE} is 630 (maximum rating of BC337 from datasheet) and V_{in} is $5V$.

$$I_B = \frac{600\ x\ 10^{-3}}{630} = 1.2698\ \times\ 10^{-3}$$

So, $R_B = \frac{5-0.7}{1.2698 \times 10^{-3}} = 3386\Omega$

The 3600Ω (3.6KΩ) resistor used was therefore suitable for the design.

1N4007 was used in this circuit to protect the switch from high voltage spike that may be produced by the relay coil when the relay was switched off as a result of self-inductance. So, it serves as a fly back or flywheel diode. The 1N4007 diode is a 1000V, 1A general purpose type. The diode was chosen for each of the relay circuits because it has voltage rating of 1000V and maximum average forward rectified current of 1A. The reverse voltage of 12V (power supply voltage) required to be blocked was less than the voltage of the diode (1000V) used for blocking it and the peak current which is equal to the relay coil current (53.3mA) was less than the maximum average forward rectified current. So, the diode was suitable for this circuit of figure 3.6.

The 12V SPDT relay was chosen for this design because it can be triggered by 12V DC and its normally closed (NC), normally open (NO) or Common (COM) terminal can withstand maximum load of 30V and 10A. The load connected to each of the first five relays was 12V DC valve and the load connected to the sixth relay was 24V DC borehole water pump. These loads fall into this range.

The solenoid valves and pump were connected to 12V DC relays in a normally open mode. A wire was connected between 12V supply and NO terminal of the 12v relay. Another wire was joined between COM terminal of relay and appliance/device to be controlled. The other terminal of the device/appliance was connected to ground. When a relay was energized, the COM and NO terminals made contact with each other thereby switching ON the device connected to the relay.

(d) Servo motors

Two DS3218MG servo motors were used in this design for preventing water quality problems caused by temperature variations. One of the servo motors was fixed to a sun shade system while the other motor was fixed to a windbreak system. The servo motor was selected for this work because it is a digital motor that has stall torque of 20.5kg-cm (torque load that causes a servo motor to "stall" or stop rotating) and operating voltage of 4.8V to 7.2V, high precision, good heat dissipation and rotation angle of 270°. In this design, a servo motor rotated 90° to set sun shade or windbreak and the weight of sun or wind control system on which the servo motor was fixed at about 1.6kg. The motor draws only 100-250mA during movement.

The size of the servo motor was determined by using equation 3.14 (Khan Academy, 2022).

$$\tau = m \times g \times r \tag{3.14}$$

Where m is the mass the servo motor has to lift in kg.

g is the acceleration due to gravity in metre per second square.

r is the radial distance in metre.

The mass the servo motor has to lift is the weight of frame with tarpaulin which is about 1.6kg. The radial distance is the horizontal distance between the point at one end of the frame where the servo motor arm is fixed and the other end and it is equal to 98cm (0.98m).

$\tau = 1.6 \times 9.80665 \ \times 0.98 = 18.26Nm = 18.26kg - cm$

The 20kg-cm 12V servo motor used was suitable because the required stall torque (18.26kg-cm) was less than the rating of the servo motor.

(e) Liquid-Crystal Display (LCD)

The display system used in this design was 2x16 LCD module. The unit displays levels of water quality parameters and water level. The 2x16 LCD was chosen because it has an interface IC (HD44780) used for receiving commands and data from the microcontroller, processing them and displaying meaningful information onto its screen, requires +5V power supply and can display 16 characters in each of the 2 rows at any instance of time. The display unit converts all the output of the control unit into human readable form and was easier to connect.

(f) GSM Module

The GSM module used for communicating information about pond water quality and maintenance from the microcontroller to Smartphone is SIM900D. This GSM module was chosen for this design because it has baud rate configurable from 9600-115200 with AT command and supported by Arduino Mega, has internal TCP/IP stack for connecting SIM with the Internet via GPRS, suitable for SMS, Voice as well as DATA transfer applications in the M2M interface and delivers quad band (850; 900; 1800 and 1900 MHZ) that enables it work in all countries with GSM (2G) networks. The SIM900D has low power requirement (3.4 to 4.5V DC) and supports 1.8V and 3.3V SIM cards.

(g) Smartphone

Smartphone with Pond Water Quality Maintenance Record Application (PWQMR App) installed in it was used in this design for communicating information on pond water quality and maintenance to fish farm owner or operator. Smartphone was chosen for this design because fish farm owner or operator needs to be notified in real time about the pond water quality and have record of the pond water quality variation and maintenance operation performed on fish pond water. The PWQMR app comprises of a mobile application designed to enable recording of the pond water quality parameters and maintenance operation in warmwater fish culture.

The summary of the analysis of the output system design is depicted in Table 3.5.

Table 3.5: Summary of the output system design analysis

S/NO	COMPONENT	SPECIFICATION	REQUIRED VALUE
1	Relay Circuit		
	BC337 Transistor (6)	Ic = 800mA, H_{FE} = 630, V_{BE} = 0.7	Ic = >53.3mA
	Resistor (6)	3.6kΩ	3.386Ω
	12V SPDT Relay (6)	Coil current = 53.3mA Max load- 30V and 10A	<800mA <24V and <8.75A
	IN4007 Diode (6)	1000V, 1A	>12V, >53.3mA
2	3FLS1.8/80-D24/210 Water pump	210W, 24V DC Flow- 1.8m^3/h (max) Head- 80m operating hours- 6h (max)	>210W, 24V DC 1.514m^3/h 79.48m 2h (max)
3	5W, 12V DC Solenoid valve (5)	Diameter- 3/4 inch Fluid pressure- 3 psi (min) Liquid temp.- 0-100°C	3/4 inch <3 psi 20°C to 28°C
4	DS3218MG Servo motor (2)	Stall torque- 20.5kg-cm Operating voltage- 4.8V to 7.2V Operating current- 100- 250mA Rotation angle- 270°	18.26kg-cm 5V <1A 90°
5	2x16 LCD	Display size-16 characters Operating voltage- 5V Operating current- 21mA (max)	<16 characters 5V 21mA (max)
6	SIM900D GSM module	Baud rate- 9600-115200bps Operating voltage- 3.4V – 4.5V Operating Temp.- 30°C to 80°C Supports 2G & 3G	9600-115200bps 5V 0°C to 40°C 2G & 3G
7	Mobile phone	Android phone	Android phone

3.2.7 Schematic circuit diagram of the smart electronic system for maintenance of optimum water quality in warmwater fish culture

The circuit diagram of the smart electronic system for maintenance of optimum water quality in warmwater fish culture is as shown in figure 3.

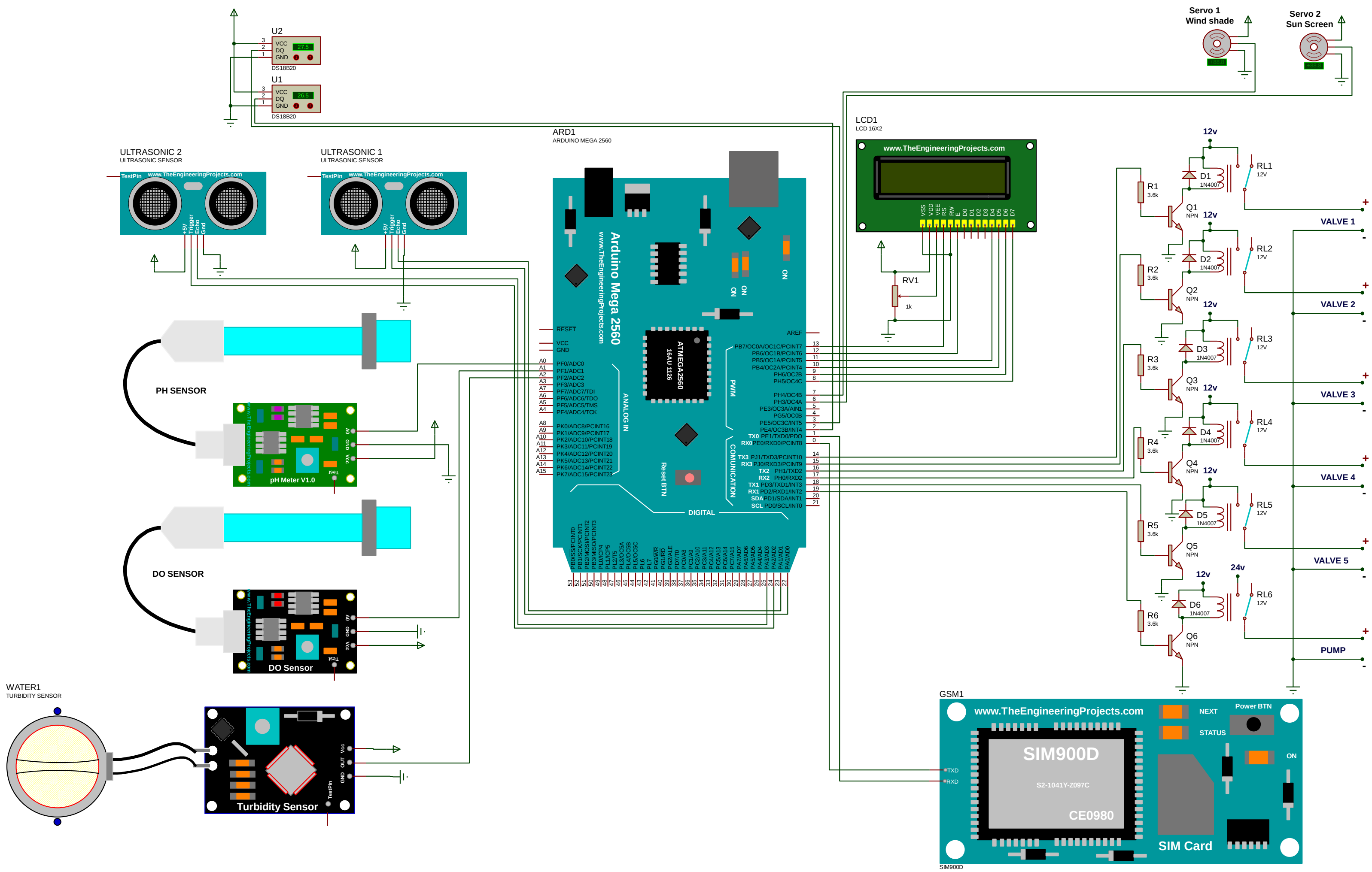


Figure 3.7: Circuit diagram of the smart electronic system for maintenance of optimum water quality in warmwater fish cul

The circuit consisted of input, processing and output components. The input components include temperature, DO, pH, turbidity and ultrasonic sensors for sensing levels of water quality parameters, water level and preventive maintenance parameters and power supply module. The processing component was an Arduino Mega 2560 (microcontroller board) and it was used for processing signals and controlling the operation of the entire system. The output components included solenoid valves, water pump, drivers (actuators), liquid crystal display (LCD) and GPRS gateway (GSM module).

The circuit components and their specification are depicted in Table 3.6.

Table 3.6: Specifications of circuit components

S/NO	COMPONENT	SPECIFICATION	QUANTITY
1	Microcontroller	Arduino Mega 2560	1
2	Temperature sensor	DS18B20	2
3	Dissolved oxygen sensor	Atlas Scientific Gen 2	1
4	pH sensor	SKU: SEN0169	1
5	Turbidity sensor	SKU: SEN0189	1
6	Ultrasonic sensor	HC-SR04	2
7	GSM module	SIM900D	1
8	Mobile phone	Android phone	1
9	Liquid crystal display	2 x16	1
10	Water pump	80m Head 24V DC	1
11	Solenoid valve	12V DC, 3/4 inch diameter	5
12	Servo motor	20kg-cm 5V DC	2
13	Solar panel	300W 24V (4183197)	1
14	Battery	24V, 200Ah	1
15	Charge controller	20A	1
16	Transformer	24V 15A	1
17	Diode rectifier	24V 20A	1
18	Capacitor	15000μf/63V	1
19	Circuit breaker	24V 100A	1
20	Regulator	LM2596	3
21	Relay	24V DC	2
22	Relay	12V DC	8
23	Transistor	BC337	6
24	Resistor	1KΩ	8
25	Light emitting diode	5V	1
26	Diode	IN4007	6

The circuit components were selected based on the guidelines for selecting electronic components and the justification for their selection was presented in design analysis of sections 3.2.4 to 3.2.6.

The configuration of Arduino Mega 2560 with the other components of the circuit is depicted in Table 3.7.

Table 3.7: Configuration of circuit components

COMPONENT DATA PIN	ARDUINO MEGA 2560 PIN
Valve 1	Pin 14
Valve 2	Pin 15
Valve 3	Pin 16
Valve 4	Pin 17
Valve 5	Pin 18
Water Pump	Pin 19
GSM Receive (RX)	Pin 0
GSM Transmit (TX)	Pin 1
Water Temperature Sensor	Pin 2
Air Temperature Sensor	Pin 3
Servo motor 1	Pin 6
Servo motor 2	Pin 7
pH Sensor	A0
Dissolve Oxygen Sensor	A1
Turbidity Sensor	A2
LCD	
RS	Pin 13
EN	Pin 12
D4	Pin 11
D5	Pin 10
D6	Pin 9
D7	Pin 8
Water Level Sensor 1(Ultrasonic Sensor)	
TRIG	Pin 22
ECHO	Pin 23
Water Level Sensor 2	
TRIG	Pin 24
ECHO	Pin 25

3.2.8 Operation of smart electronic system for optimum water quality maintenance in warmwater fish culture

The system automatically monitors the quad-essential water quality parameters regularly and adjusts when any of the parameters reaches optimum limit and take adequate preventive measures against pond water quality problems in warmwater fish culture. The value of optimum temperature, DO and pH used for this system was based on the general ranges recommended by Bhatnagar and Devi (2013) and the value for turbidity was based on that recommended by (Davis, 1993) and they are as shown in shown in Table 3.8.

Table 3.8: Optimum ranges of quad-essential water quality parameters

S/NO	PARAMETER	OPTIMUM RANGE
1	Temperature	20 – 28 (^oC)
2	pH	6.8 – 8.5
3	DO	5 – 7.5 (mg/L)
4	Turbidity	10 – 20 (mg/L)

The smart system performs its operation in four modes by applying top down design approach: optimum water temperature maintenance, optimum water DO maintenance, optimum water pH maintenance and preventive maintenance. When the system of figure 3.7 is switched ON, all the components receives electric power. The microprocessor of the microcontroller first sent command to water temperature sensor (temperature sensor 1) to sense pond water temperature. The sensed signal is sends to the microcontroller to process. The microcontroller compares the signal with values stored in its memory. If temperature signal is between 28^oC and 20^oC, the microcontroller sends command to DO sensor to sense DO because temperature level is within the optimum range. If signal is equal to 28^oC (upper optimum limit), the microcontroller sends command to LCD to display temperature level, send water temperature condition to smart phone via GSM module, discharge 20% of upper pond water via valve 3 and replenishes pond with cool oxygenated water via valve 1 and pump with the help of pond water level sensor (level sensor 1), delay for 1h and then sense pond water DO. The pond water level sensor monitors level of water during the water exchange and its sensed signal is used by microcontroller to determine when to switch ON or OFF the valves and pump. If signal is equal to 20^{o}C (lower optimum limit), the microcontroller sends command to LCD to display temperature level, send water temperature condition to smart phone via GSM module, discharge 20% of bottom pond water via valve 2 and replenishes it with warm water via valve 4. The microcontroller then sends command to refill the reservoir via valve 5 and pump with the help of reservoir water level sensor (level sensor 2) and then to sense DO.

When DO is sensed by DO sensor, the sensed signal is sent to the microcontroller to process. The microcontroller compares the signal with values stored in its memory. If DO signal is between 5mg/L and 7.5mg/L (within optimum range), the microcontroller sends command to pH sensor to sense water pH. If signal is equal to 7.5mg/L (upper optimum limit), the microcontroller sends command to LCD to display DO level, send water DO condition to smart phone via GSM module, discharge 20% of upper pond water via valve 3 and refill pond with warm water via valve 4 with the help of pond water level sensor (level sensor 1), refills reservoir via valve 5 and pump with the help of reservoir water level sensor (level sensor 2) and then to sense water pH. If signal is equal to 5mg/L, the microcontroller sends command to display temperature level on LCD, send water temperature condition to smart phone via GSM module, discharge 20% of bottom pond water via valve 2 and refill pond with cool oxygenated water via valve 1 and pump with the help of pond water level sensor (level sensor 1), delay for 1h and then sense pH.

When pH is sensed by pH sensor, the sensed signal is sent to the microcontroller to process. The microcontroller compares the signal with values stored in its memory. If pH signal is between 6.8 and 8.5 (within optimum range), the microcontroller sends command to turbidity sensor to sense turbidity. If signal is equal to 6.8 or 8.5 (lower and upper optimum limits), the microcontroller sends command to LCD to display pH level, send water pH condition to smart phone via GSM module, discharge 20% of bottom pond water via valve 2 and refill it with cool oxygenated water via valve 1 and pump with the help of pond water level sensor (level sensor 1), delay for 1h to enable the pH level to stabilized completely and then sense turbidity.

When turbidity is sensed by turbidity sensor, the sensed signal is sent to the microcontroller to process. The microcontroller compares the signal with values stored in its memory. If turbidity signal is between 10mg/L and 20mg/L (within optimum range), the microcontroller sends command to water level sensor to sense water level. If signal is equal to 20mg/L (upper optimum limit), the microcontroller sends command to LCD to display turbidity level, send water turbidity condition to smart phone via GSM module, discharge 20% of bottom pond water via valve 2 and refill pond with cool oxygenated water via valve 1 and pump with the help of pond water level sensor (level sensor 1), delay for 1h and then sense pond water level. If signal is equal to 10mg/L (lower optimum limit), the microcontroller sends command to LCD to display turbidity level, send water turbidity condition to smart phone via GSM module, and then sense pond water level.

When pond water level is sensed by water level sensor 1, the sensed signal is sent to the microcontroller to process. The microcontroller compares the signal with values stored in its memory. If signal is between 117cm to 120cm (normal range), the microcontroller sends command to sense pond water temperature through pond water temperature sensor. If signal is equal to 117cm (lower limit), the microcontroller sends command to LCD to display pond water level, send pond water level condition to smart phone via GSM module, replenishes pond via valve 1 and pump with the help of pond water level sensor (level sensor 1) and then sense pond water temperature through pond temperature sensor.

When temperature is sensed by air temperature sensor, the sensed signal is sent to the microcontroller to process. The microcontroller compares the signal with values stored in its memory. If temperature signal is between 28^oC and 20^oC, the microcontroller sends command to water level sensor 1 to sense pond water temperature. If signal is equal to 28^oC, the microcontroller sends command to LCD to display temperature level, send water temperature condition to smart phone via GSM module, set sun shade via servo motor 1 and then to sense pond water temperature when air temperature is less than 28^oC. If signal is equal to 20^oC, the microcontroller sends command to LCD to display air temperature level, send water temperature condition to smart phone via GSM module, set windbreak via servo motor 2 and then to sense pond water temperature when air temperature is greater than 20^oC**.**

The process of monitoring, maintenance of optimum water quality and prevention of water quality problems continues unless the system is switched OFF.

3.3 Software System Design of Smart Electronic System for Maintenance of Optimum Water Quality in Warmwater Fish Culture

The software system of the smart electronic system for optimum water quality maintenance in warmwater fish culture comprised of program and an Application.

3.3.1 Program design of the smart electronic system for optimum water quality maintenance

The program constitutes the major part of the system software. This program directs all the activities of the optimum water quality maintenance system. It directs sensing of quad-essential water quality parameters, analysis of sensed data, taking of action, displaying of values and communication of information and action taken at any time. The algorithm for the operation of the optimum water quality maintenance system is presented below.

(a) Algorithm 1: The system algorithm

First configure microcontroller pins 2, 3, 6, 7, 23, 25, A0, A1 and A2 input pins and pins 0, 1, 6 and 7, (8 to 13), 14 to 19, 23, and 25 as output pins.

Now initialize the LCD and GSM module.

Read pond water temperature into microcontroller through pin 2.

If pond water temperature is between 20^oC and 28^oC, read pond water DO into microcontroller through pin A1.

If pond water temperature is equal to 28^oC, display value on LCD, send information to smart phone via GSM module, ON valve 3, read pond water level into microcontroller through pin 23. OFF valve 3 when water level is 96cm, ON valve 1 and pump till water level is 120cm, delay for 1h, read pond water DO into microcontroller through pin A1.

If pond water temperature is equal to 20^oC, display value on LCD, send information to smart phone, ON valve 2, read pond water level into microcontroller through pin 23. OFF valve 2 when water level is 96cm, ON valve 4 till water level is 120cm, ON valve 5 *and pump, read reservoir water level into microcontroller through pin 25, OFF valve 5 and pump when level is 100cm, delay for 1h, read pond water DO into microcontroller through pin A1.*

If pond water DO is between 5mg/L and 7.5mg/L, read pond water pH into microcontroller through pin A0.

If pond water DO is equal to 5mg/L, display value on LCD, send information to smart phone, ON valve 2, read pond water level into microcontroller through pin 23, OFF valve 2 when water level is 96cm, ON valve 1 and pump till water level is 120cm, delay for 1h, read pond water pH into microcontroller through pin A0.

If pond water DO is equal to 7.5mg/L, display value on LCD, send information to smart phone, ON valve 3, read pond water level into microcontroller through pin 23. OFF valve 3 when water level is 96cm, ON valve 4 till water level is 120cm, ON valve 5 and pump, read reservoir water level into microcontroller through pin 25, OFF valve 5 and pump when level is 100cm, delay for 1h, read pond water pH into microcontroller through pin A0.

If pond water pH is between 6.8 and 8.5, read pond water turbidity into microcontroller through pin A2.

If pond water pH is equal to 6.8 or 8.5, display value on LCD, send information to smart phone, ON valve 2, read pond water level into microcontroller through pin 23, OFF valve 2 when water level is 96cm, ON valve 1 and pump till water level is 120cm, delay for 1h, read pond water turbidity into microcontroller through pin A2.

If pond water turbidity is between 10mg/L and 20mg/L, read pond water level into microcontroller through pin 23.

If pond water turbidity is equal to 20mg/L, display value on LCD, send information to smart phone, ON valve 2, read pond water level into microcontroller through pin 23, OFF valve 2 when water level is 96cm, ON valve 1 and pump till water level is 120cm, delay for 1h, read pond water level into microcontroller through pin 23.

If pond water turbidity is equal to10mg/L, display value on LCD, send information to smart phone and then read pond water level into microcontroller through pin 23.

If pond water level is between 117cm and 120cm or equal to 120cm, read air temperature into microcontroller through pin 3.

If pond water level is equal to 117cm, ON valve 1 and pump, read pond water level into microcontroller through pin 23, OFF valve 1 when water level is 120cm and then read air temperature into microcontroller through pin 3.

If pond air temperature is between 20^{o}C to 28^{o}C, read pond water temperature into microcontroller through pin 2.

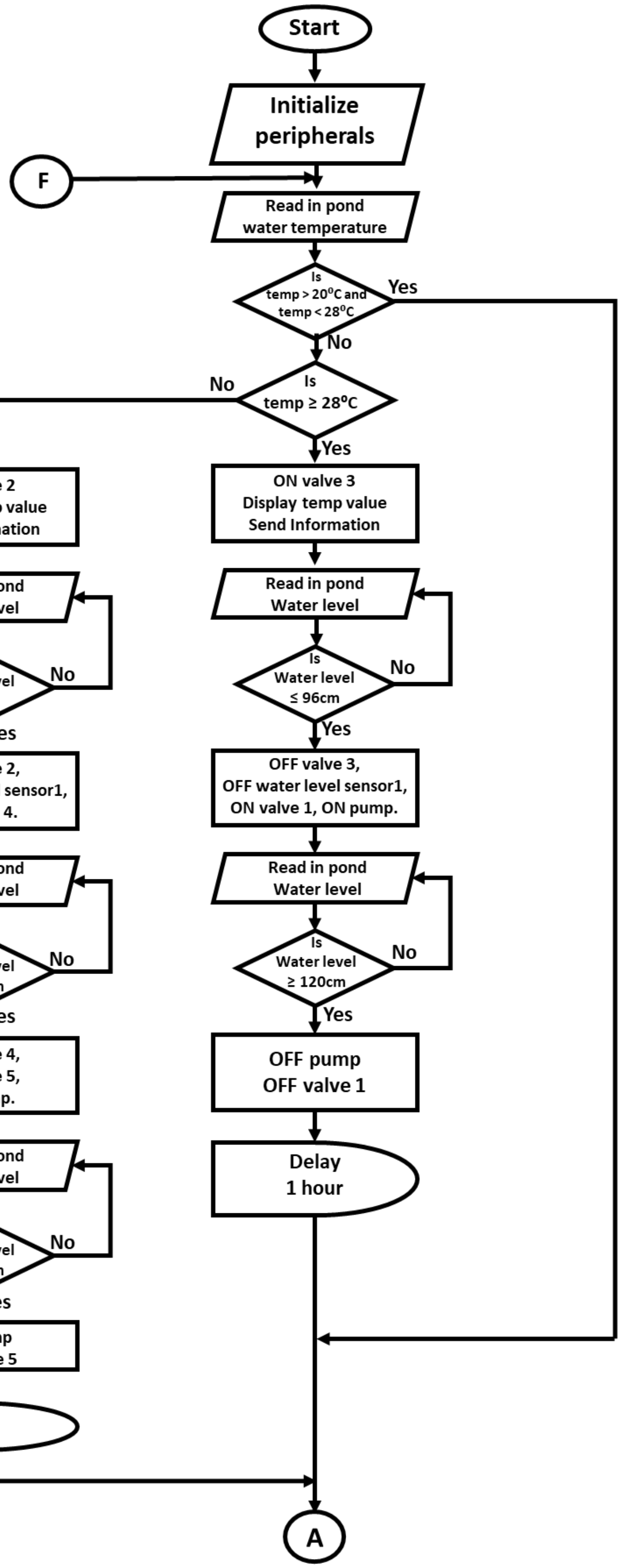
If air temperature is equal to 28^{o}C, display value on LCD, send information to smart phone via GSM module, ON servo motor 1, read air temperature into microcontroller through pin 2. If air temperature is equal to or less than 28^{o}C, OFF servo motor 1, OFF air temperature sensor and then read pond water temperature into microcontroller through pin 2.

If air temperature is equal to 20^{o}C, display value on LCD, send information to smart phone via GSM module, ON servo motor 2, read air temperature into microcontroller through pin 2. If air temperature is equal to or greater than 20^{o}C, OFF servo motor 2, OFF air temperature sensor and then read pond water temperature into microcontroller through pin 2.

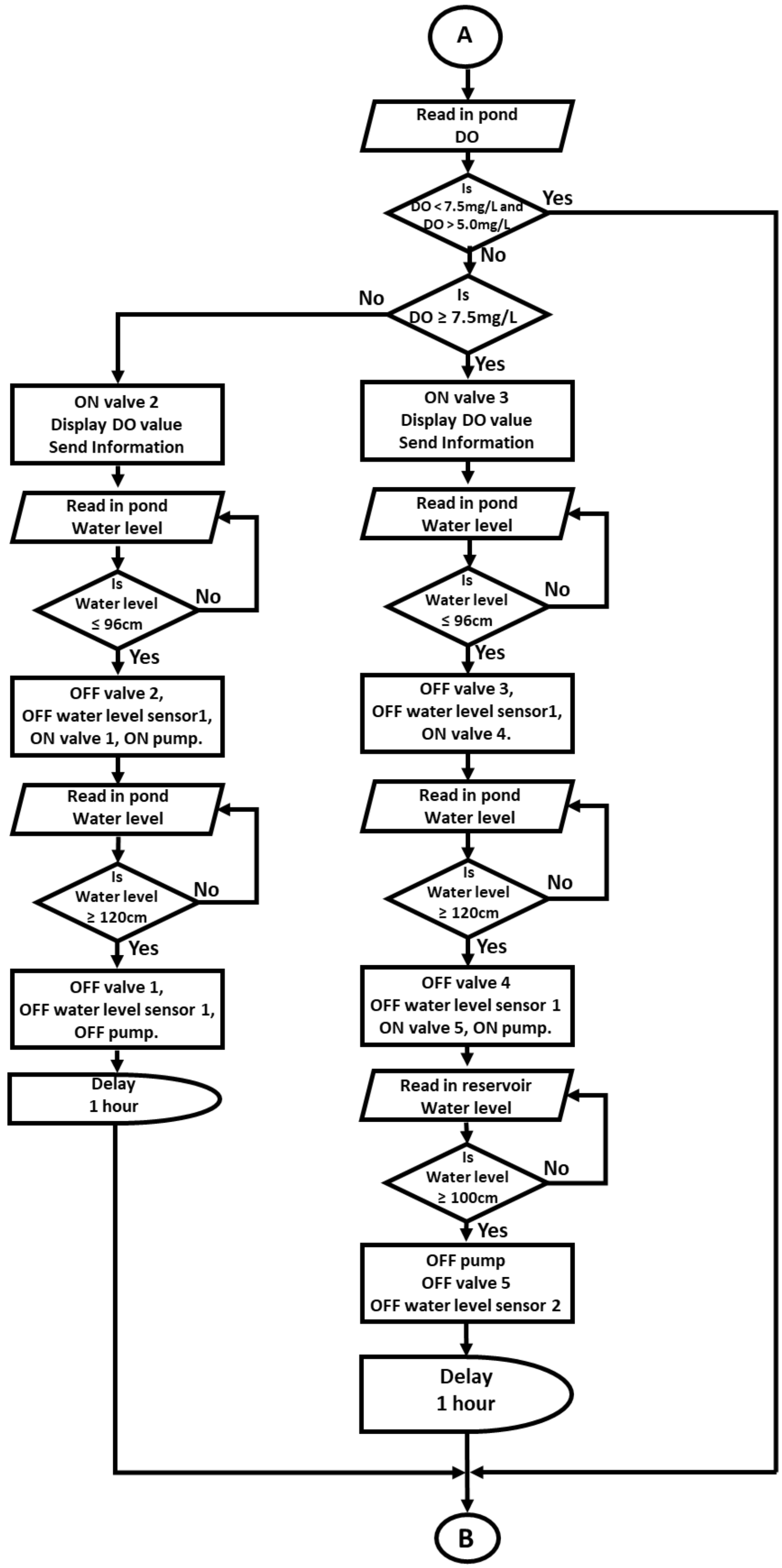
The operation continues unless the system is switched OFF.

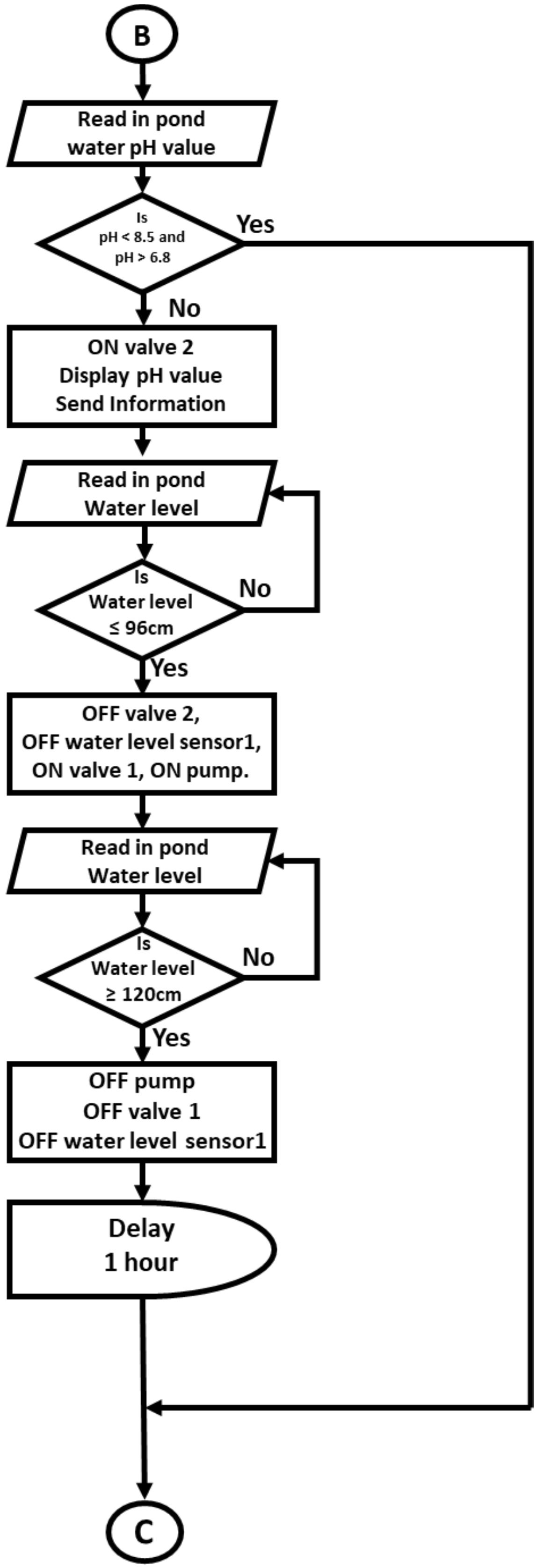
(b) Flowchart of the smart electronic system for optimum water quality maintenance

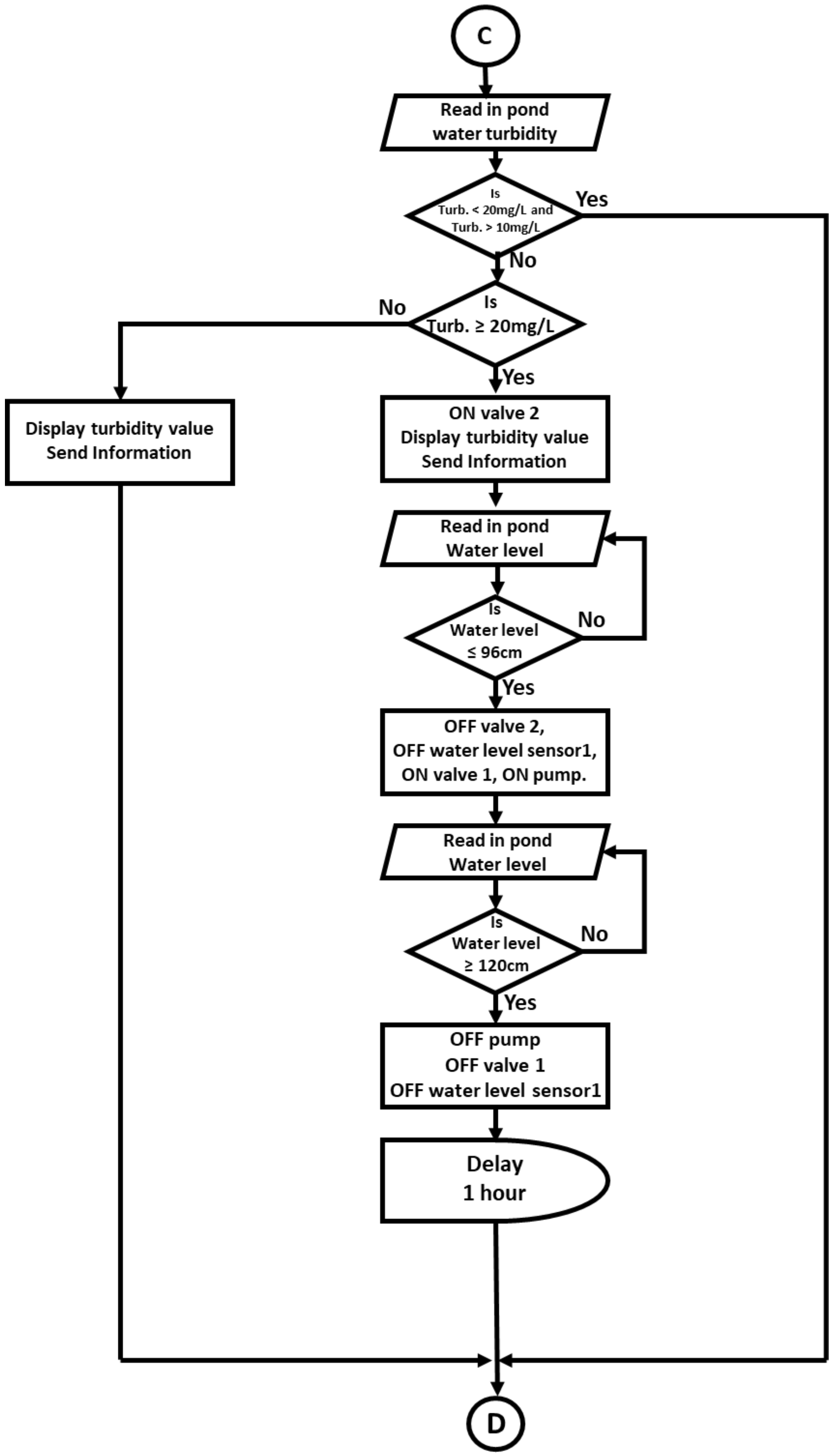
The flowchart that was used to implement the system algorithm is shown in figure 3.8.



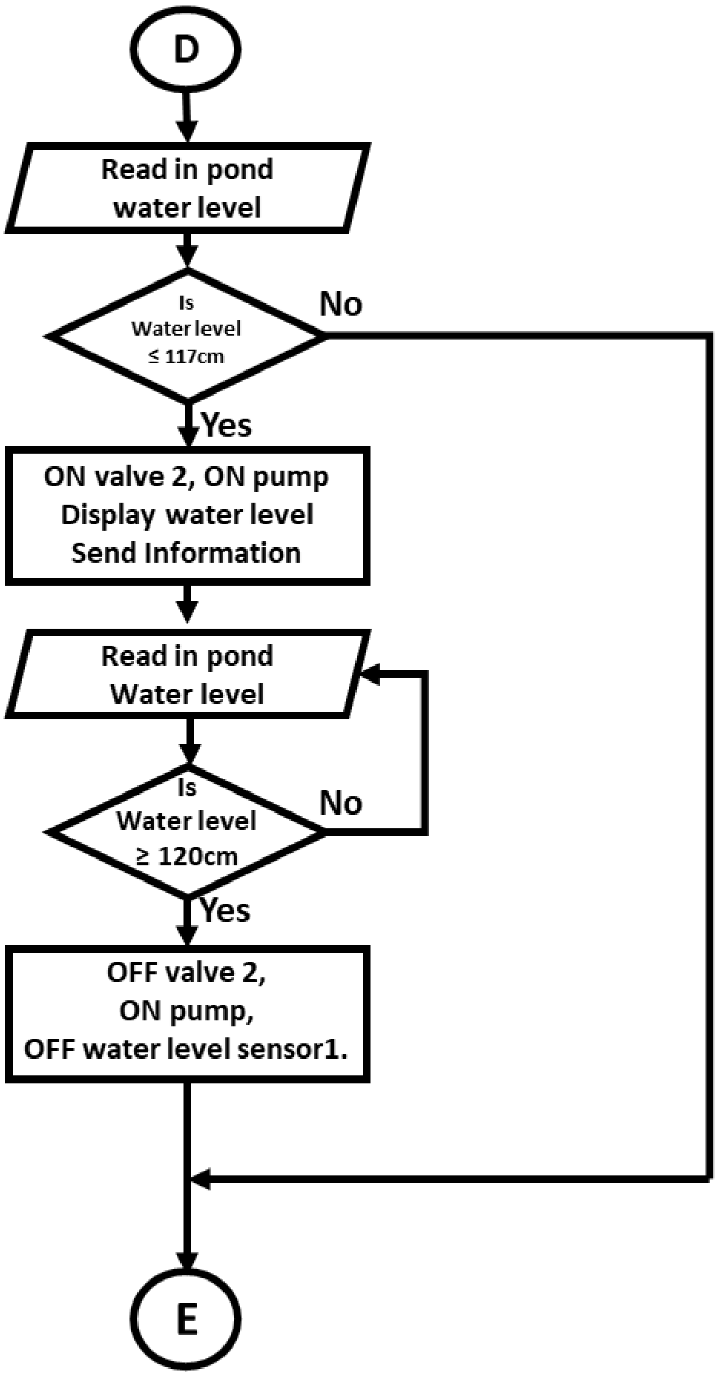
Start
Initialize peripherals
F
Read in pond water temperature
Is temp > 20°C and temp < 28°C
Yes
No
Is temp ≥ 28°C
No
Yes
ON valve 2
Display temp value
Send Information
ON valve 3
Display temp value
Send Information
Read in pond Water level
Is Water level ≤ 96cm
No
Yes
OFF valve 2,
OFF water level sensor1,
ON valve 4.
OFF valve 3,
OFF water level sensor1,
ON valve 1, ON pump.
Read in pond Water level
Is Water level ≥ 120cm
No
Yes
OFF valve 4,
OFF valve 5,
OFF pump.
OFF pump
OFF valve 1
Delay 1 hour
Read in pond Water level
Is Water level ≥ 100cm
No
Yes
OFF pump
OFF valve 5
Delay 1 hour
A


A
Read in pond DO
Is DO < 7.5mg/L and DO > 5.0mg/L
Yes
No
Is DO ≥ 7.5mg/L
No
Yes
ON valve 2
Display DO value
Send Information
Read in pond Water level
Is Water level ≤ 96cm
No
Yes
OFF valve 2,
OFF water level sensor1,
ON valve 1, ON pump.
Read in pond Water level
Is Water level ≥ 120cm
No
Yes
OFF valve 1,
OFF water level sensor 1,
OFF pump.
Delay 1 hour
ON valve 3
Display DO value
Send Information
Read in pond Water level
Is Water level ≤ 96cm
No
Yes
OFF valve 3,
OFF water level sensor1,
ON valve 4.
Read in pond Water level
Is Water level ≥ 120cm
No
Yes
OFF valve 4
OFF water level sensor 1
ON valve 5, ON pump.
Read in reservoir Water level
Is Water level ≥ 100cm
No
Yes
OFF pump
OFF valve 5
OFF water level sensor 2
Delay 1 hour
B


B
Read in pond water pH value
Is pH < 8.5 and pH > 6.8
Yes
No
ON valve 2
Display pH value
Send Information
Read in pond Water level
Is Water level ≤ 96cm
No
Yes
OFF valve 2,
OFF water level sensor1,
ON valve 1, ON pump.
Read in pond Water level
Is Water level ≥ 120cm
No
Yes
OFF pump
OFF valve 1
OFF water level sensor1
Delay 1 hour
C



C
Read in pond
water turbidity
Is
Turb. < 20mg/L and
Turb. > 10mg/L
Yes
No
Is
Turb. ≥ 20mg/L
No
Yes
Display turbidity value
Send Information
ON valve 2
Display turbidity value
Send Information
Read in pond
Water level
Is
Water level
≤ 96cm
No
Yes
OFF valve 2,
OFF water level sensor1,
ON valve 1, ON pump.
Read in pond
Water level
Is
Water level
≥ 120cm
No
Yes
OFF pump
OFF valve 1
OFF water level sensor1
Delay
1 hour
D


D
Read in pond
water level
Is
Water level
≤ 117cm
No
Yes
ON valve 2, ON pump
Display water level
Send Information
Read in pond
Water level
Is
Water level
≥ 120cm
No
Yes
OFF valve 2,
ON pump,
OFF water level sensor1.
E

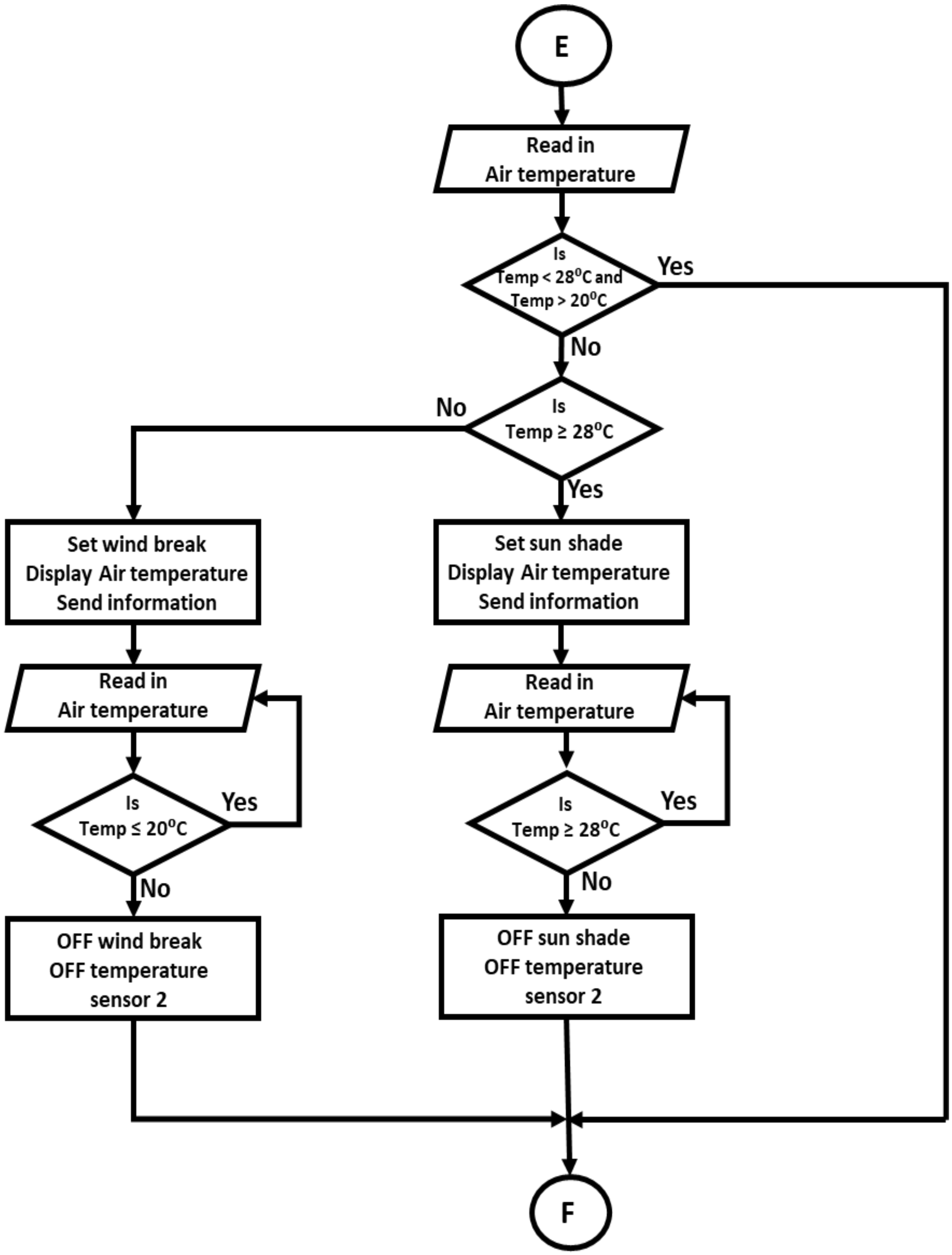


Fig. 3.8: Flowchart of the smart electronic system for optimum water quality maintenance

3.3.2 Application design of the smart electronic system for optimum water quality maintenance

Pond Water Quality Maintenance Record Application (PWQMR App) is a mobile application (part of the system software) designed for receiving feedback from the smart system for optimum water quality maintenance in warmwater fish culture. The PWQMR App offers timely updates on levels of water quality parameters and actions taken to maintain optimum water quality and prevent water quality problems. So, the PWQMR App enables fish farm operator or owner to record the pond water quality level, maintenance operation and preventive measures taken and monitoring of water quality parameters in warmwater fish culture. The app is made up of front-end and back-end.

(a) Front-end

The front-end referred to as "client-side" programming or "face" of the App is what the App users interact with. The front-end implements the required structure, design, animation and behaviour that are seen on the screen when the mobile App is opened up. Screenshot of the front-end is shown in Plate 3.1.

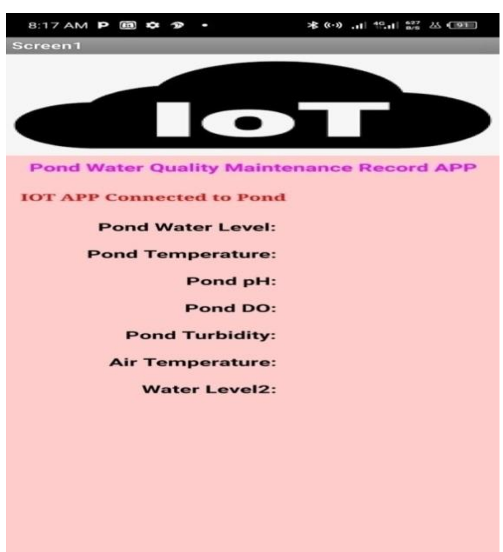


Plate 3.1: Front-end of PWQMR App

The front-end contains the name of the App, connection information, pond water level, temperature, DO, pH, turbidity and air temperature levels and reservoir water level (water level 2). So the App provides information about pond water, temperature, DO, pH and turbidity levels, air temperature level and reservoir water level when each reaches its optimum limit and maintenance operation. The App offers user interface with menus that is easy to navigate and presents data that is easy to interpret (values of parameters).

(b) Back-end

The back-end development or server technology is about the code, which dictates how the App functions. The screenshot of the Logic Blocks of the App is shown in screenshot of Plate 3.2.

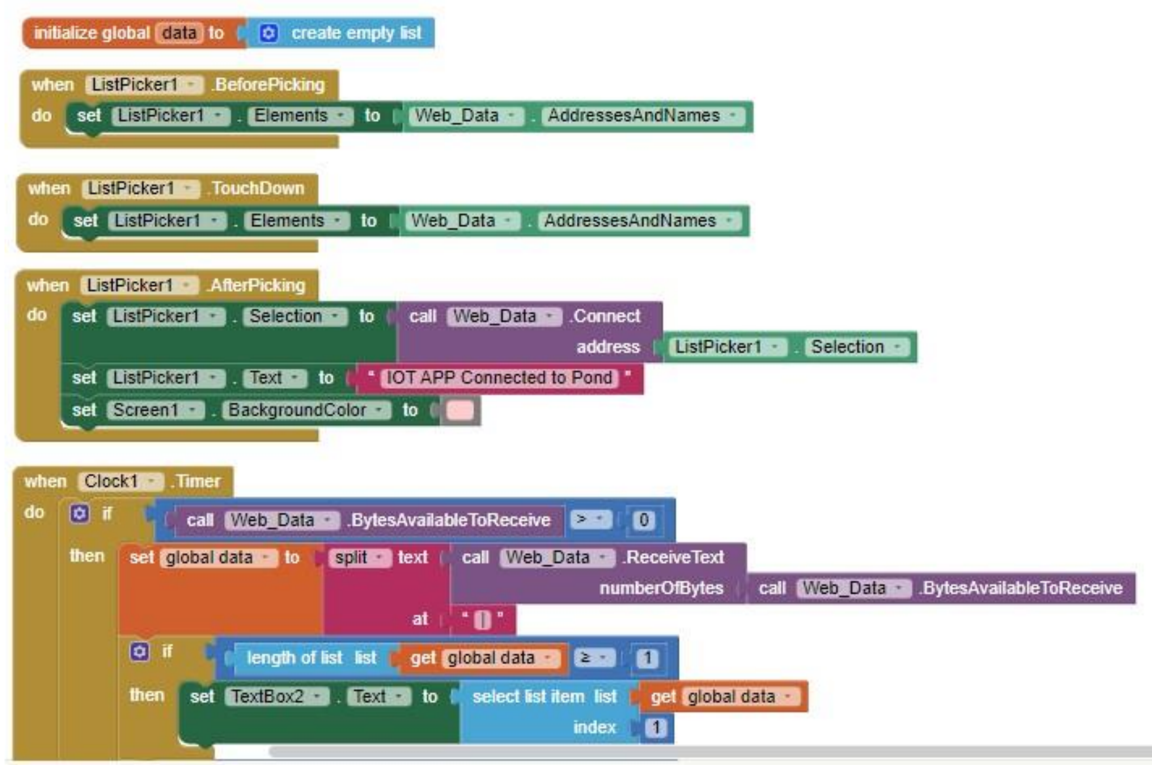


Plate 3.2: Screenshot of logic blocks of PWQMR App

A block is a logically connected group of program statements that is treated as a unit. In this design, the first block contains logic (code) for the first button (pond water level) and each of the remaining six blocks contains logic for a button (pond water temperature, DO, pH and turbidity levels, air temperature level and reservoir water level button).

3.4 Development of Optimum Water Temperature Maintenance System

The optimum water temperature maintenance system maintains optimum water temperature in fish pond or tank. The development of system involved designing and simulation of the system, calibration and validation of sensors, hardware implementation, program and application development and testing.

3.4.1 Design and simulation of optimum water temperature maintenance system

In this design, optimum temperature of pond or tank water is maintained by exchanging portion of the water with appropriate water (cooler or warm water) and aeration as the case may be. The system discharges 20% of upper portion of pond water and refills pond with groundwater of 18.5^oC to 22^oC via perforated screen when temperature of pond water rises to 28^oC and discharges 20% of bottom portion of pond water and refills pond with warm water when temperature of pond water falls to 20^oC.

The block diagram of the optimum water temperature maintenance system is as shown in figure 3.9.

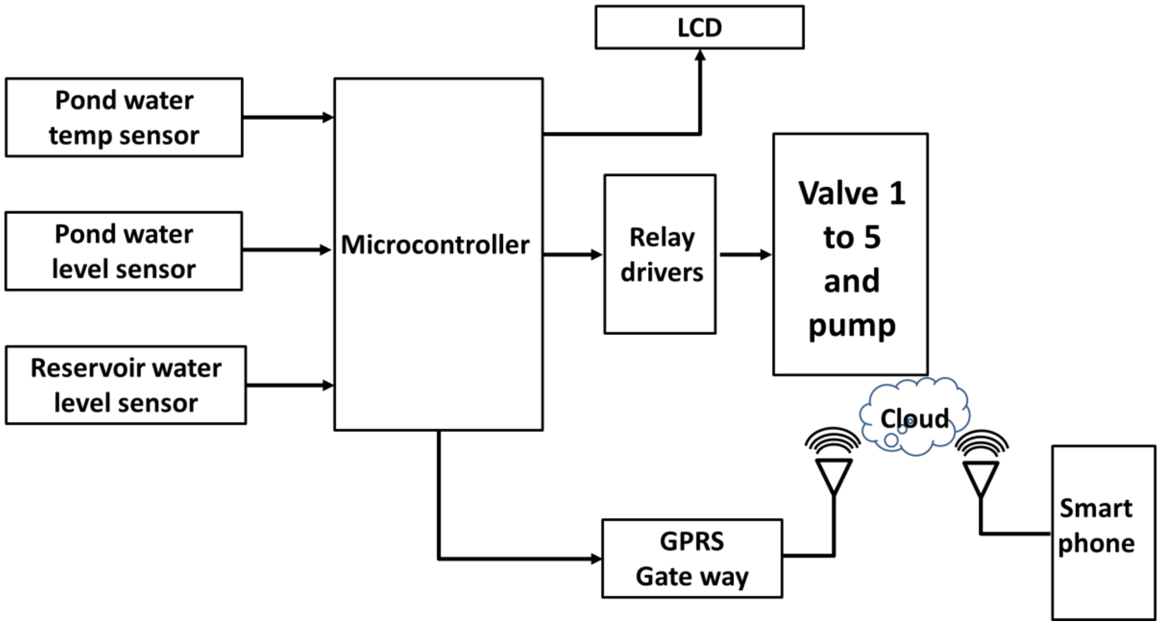


Figure 3.9: Block diagram of optimum water temperature maintenance system

The optimum water temperature maintenance system consists of a microcontroller, temperature sensor, water level sensors, water pump, solenoid valves, actuators, LCD, Relays, GSM module, Smartphone and DC voltage source and their interconnections.

The circuit diagram or simulation circuit of the optimum water temperature maintenance system for warmwater fish culture was drawn using Proteus 8.4 (circuit drawing and simulation software) after raw design or sketch was produced with hand based on the block diagram. Proteus 8.4 was first installed in the laptop computer before use and the simulation circuit drawn by picking and adding of components and connecting the components in the simulation window. The circuit diagram of the optimum water temperature maintenance system for warmwater fish culture is shown in figure 3.10.

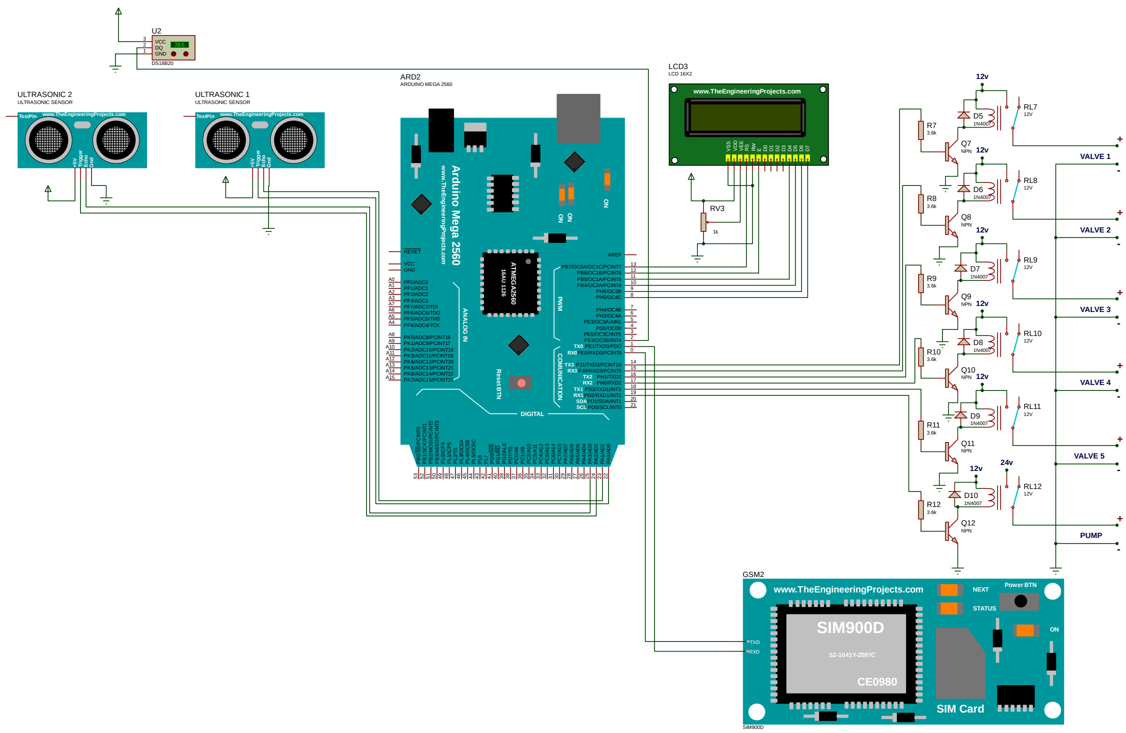


Figure 3.10: Circuit diagram of optimum water temperature maintenance system

The circuit components of optimum water temperature maintenance system include 1 Arduino Mega microcontroller, 1 temperature sensor (DS18B20), 1 water pump (3FLS1.8/80-D24/201C), 5 solenoid valves (12V), 6 actuators (relay circuits), 2 water level sensors (HC-SR04), 1 LCD (16X2), 1 GSM module (SIM900A), 1 Smartphone with PWQMR App installed in it, DC voltage source (24V, 12V, 5V) and their interconnections.

Simulation of the optimum temperature maintenance system was done after producing the simulation circuit**.** The simulation process involved writing a program, generating the hex file and running of the Proteus simulation. The program to control the operation of the optimum temperature maintenance system was written in Arduino programming language (embedded C) with 26.5°C and 120cm assigned to water temperature and water level respectively in the program**.** The result of the simulation is shown by LCD of the simulation diagram of Appendix B and indicates that the code and circuit connections are correct.

3.4.2 Calibration and validation of sensors of optimum temperature maintenance system

The sensors used by the optimum temperature maintenance system include water temperature sensor and 2 water level sensors. One of the water level sensors **(**ultrasonic sensor 1) is used for monitoring pond water level while the remaining sensor **(**ultrasonic sensor 2) is used for monitoring reservoir water level. The sensors were calibrated and validated to ensure that the values reported by the sensors are accurate and not affected by frequent usage, improper care of hardware, temperature, pressure, and other environmental variations and issues (Scott, 2019). In this work, calibration was done by verifying each sensor and adjusting its output parameter when value is not in line with a standard solution or substance. On the other hand, validation was done by verifying sensor and adjusting its output parameter when value is not in line with a standard meter. The temperature sensor and other sensors were validated in a controlled environment with the help of an expert.

(a) Calibration of water temperature sensor

The DS18B20 temperature sensor is a digital sensor and does not require adjustment as it produces accurate value of measured temperature. So, the sensor was tested to ensure that it was functioning. The digital thermometer constructed with the water temperature sensor was tested after preparing and verifying that the Arduino board was functioning.

The temperature sensor was first connected to the controller (Arduino Mega) based on instructions from the manufacturer (DFRobot, 2022b). Immediately after the connection, the red LED on the board went *on* indicating that the Arduino controller has received electric power. The temperature sensor sample code for testing the temperature meter or thermometer and getting the sensor feedback from the Arduino Serial Monitor was then downloaded from the manufacturer's website (DFRobot, 2022a) and uploaded to the Arduino controller. A water sample was collected in a glass cup and the probe of the sensor was dipped into the cup and the LCD in the Serial Monitor observed. The LCD in the Serial Monitor of the IDE showed the water temperature being measured by the water temperature meter after connecting it to the Arduino Mega.

(b) Validation of water temperature sensor

A simple Mercury-In-Glass thermometer calibrated in degrees centigrade was used in validation of water temperature sensor. A water sample was collected using method described by (Coche *et al*., 1996; Dubey and Maheshwari, 2004) using 500ml sterile sampling bottles dipped into the freshwater fish ponds with the aid of the rope tied round the bottle. A big stone was attached at the end of the rope to enable the bottle to sink. The sample was collected and tested by 06.30am (best time for the test) on 5th December 2022. The water temperature of each sample was determined by dipping the water temperature sensor probe and the mercury thermometer bulb into a glass cup containing the sample and taking records of temperature value when readings stabilized. The water temperatures were determined at points of sampling collection. The temperature values displayed by the temperature meter (system formed by the temperature sensor and Arduino Mega) via LCD in the Serial Monitor of the IDE and the standard thermometer were 23.34^{o}C and 23.42^{o}C respectively. The difference in temperature value was within the accuracy limit of the temperature sensor (±0.5cm). This showed that the sensor measured accurate value of temperature. The water temperature value displayed by the calibrated temperature meter is as shown in screenshot of Plates 3.3.

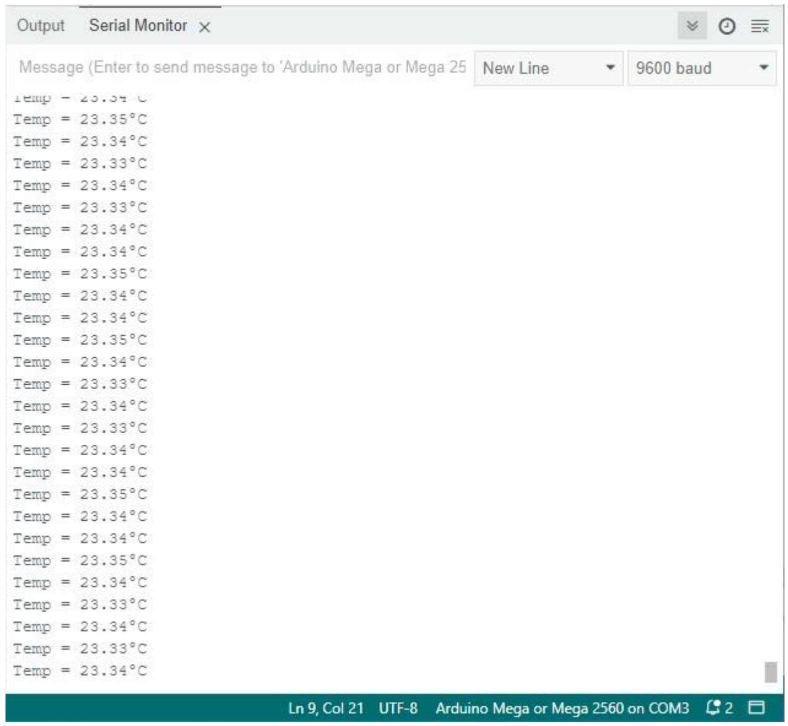


Plate 3.3: Screenshot of the pond water temperature meter reading

(c) Calibration of water level sensors

The individual ultrasonic sensor was calibrated after connecting it to the controller

The individual calibrated ultrasonic sensor was used to measure distances of 5, 10 and 25cm along the ruler to see if it matches the expected values. The pond water sensor's values for the three measurements seen on the Serial Monitor were 5.04, 10.05 and 25.06cm while the reservoir water sensor's values were 5.06, 10.06 and 25.08cm respectively. The sensors' values are within the accuracy limit of the ultrasonic sensor which is ±0.3cm (±0.1inches).

(d) Validation of water level sensors

A meter rule was used in validation of ultrasonic sensors. Each of the two ultrasonic sensors connected to Arduino Mega were suspended on top of a pond while a metallic plate was first placed horizontally at a depth of 16cm with the help of lever and record of measurement taken. The test was carried out on 9th December 2022.

The result of the pond water level sensor validation tests showed that the water level meter (system formed by the water level sensor and Arduino Mega) displayed 16.04cm in the Serial Monitor for depth of 16cm while reservoir water level meter displayed 15.91cm. The sensor values were within the accuracy limit of the ultrasonic sensor (±0.3cm), so no adjustments were made.

The pond water level sensor result verified is shown in screenshot of plate 3.4 while that of the reservoir water level sensor is shown in screenshot of plate 3.5.

Ultrasonic sensor.ino

```
void loop() {
  digitalWrite (trig_pin,LOW);
  delayMicroseconds (2000);
  digitalWrite (trig_pin,HIGH);
  delayMicroseconds (15);
  digitalWrite (trig_pin,LOW);

  travel_time = pulseIn(echo_pin,HIGH);
  travel_time = travel_time/1000000.;
  travel_time = travel_time/3600.;

  distance = speed_of_sound * travel_time;
  distance = distance/2.;
  distance = distance * 63360.;

  Serial.print ("Distance is: " );
  Serial.print(distance);
  Serial.println ("cm");
  delay(500);
  //while (distance < 35.)
}
```

Output   Serial Monitor ×

Message (Enter to send message to 'Arduino Mega or Mega 2560' on 'COM5')

```
Distance is: 16.04cm
Distance is: 16.11cm
Distance is: 16.11cm
Distance is: 16.04cm
```

Plate 3.4: Screenshot of pond water level meter reading

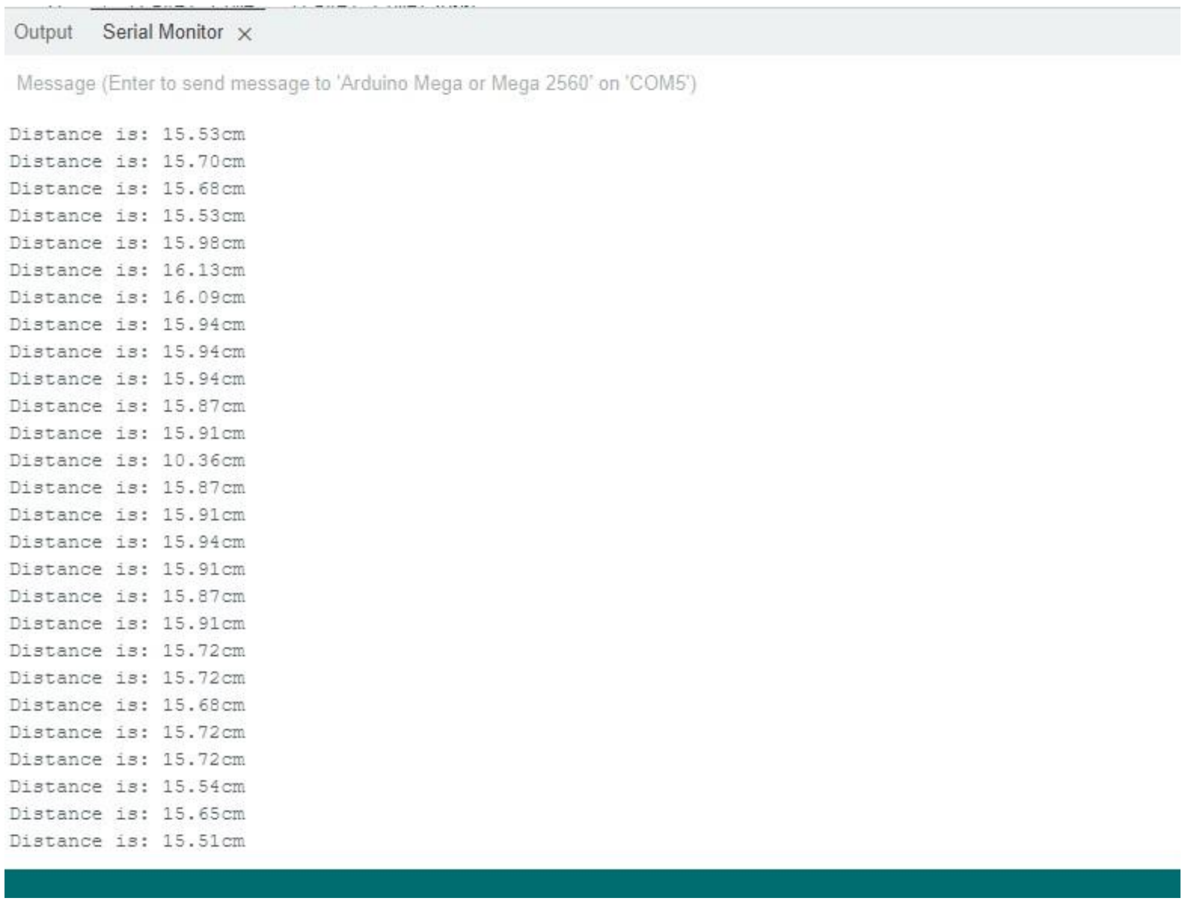


Plate 3.5: Screenshot of reservoir water level meter reading

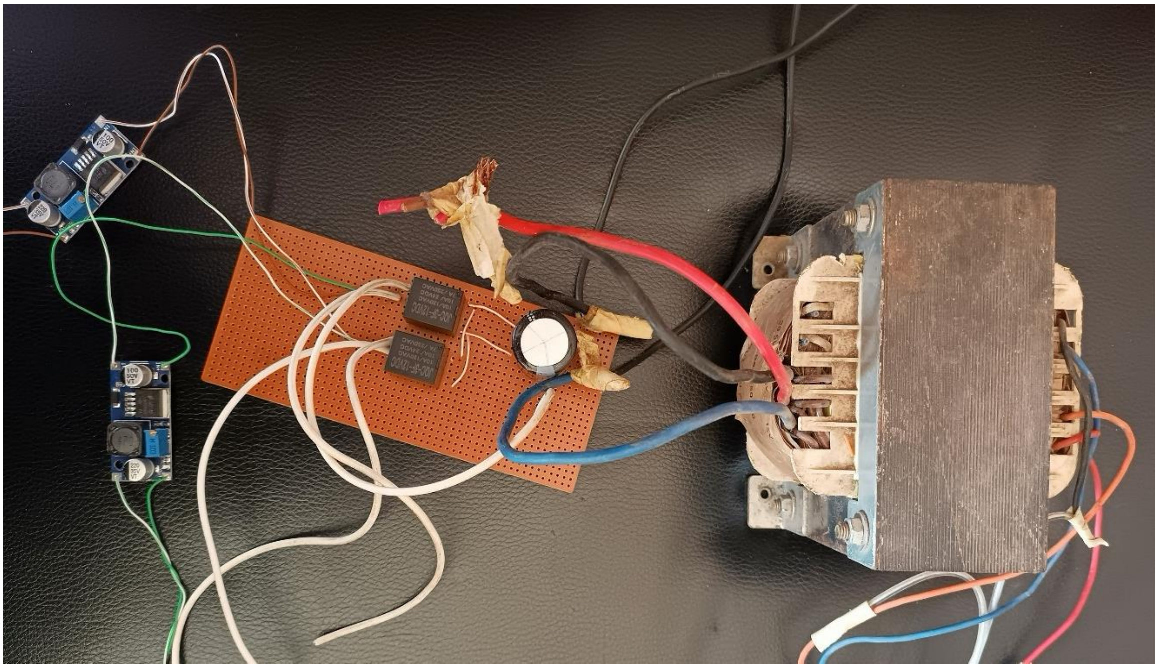
3.4.3 Hardware implementation of optimum temperature maintenance system

The hardware component of the optimum water temperature maintenance system was constructed after calibrating and validating temperature sensor. The first step taken was testing of hardware components of the system. Component tests were carried out on the components before they were soldered to the Vero board. This was to ensure that each component was in good working condition before they were finally soldered to the board. Discrete components such as resistors, light emitting diode, capacitors and transistors were tested with a multimeter by switching the meter to the required value and range corresponding to each component to check for continuity. Each of the valves was tested by connecting it to water container through plastic pipe and supplying 12V DC electric power to its terminals and observing its output. The pump was tested by dipping it into a bucket full of water and supplying 24V DC electric power to its terminals and observing its output (outlet). Integrated circuit component such as Arduino Mega was tested with Arduino IDE via computer as explained in temperature sensor calibration section. During this phase of testing, all the faulty components like transistor, diode and transformer were replaced. Continuity tests were also carried out on the subunits during construction of the system.

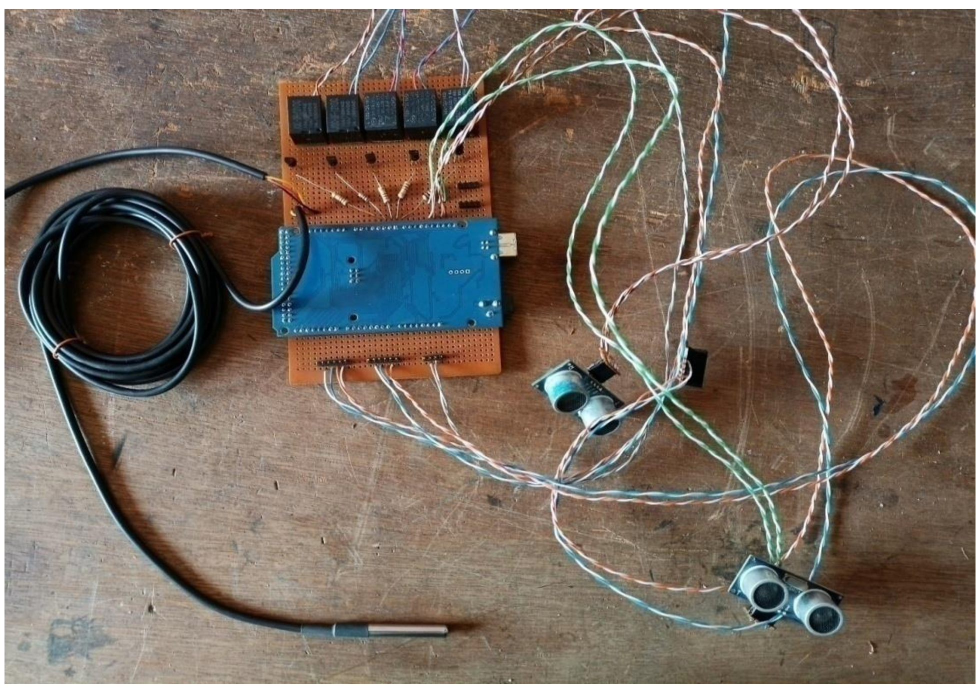
Trial version of the system was constructed on a Bread board after components and unit tests in order to test its functionality. The construction of the system was based on the circuit design of figure 3.10 and was done in three phases: construction of power supply unit, construction of system's circuit and installation of pump, sensors and valves.

The trial version of the optimum water temperature maintenance system was tested and its performance accepted before the components were transferred to Vero Board used for permanent construction of the system.

The snapshot of implemented circuit of optimum water temperature maintenance system (power supply circuit and circuit containing other components) is as shown in Plate 3.6.



(a) Power supply circuit component diagram



(b) Circuit containing other components

Plate 3.6: Circuit component diagram of optimum water temperature maintenance system

The 24V DC water pump was installed underground by an expert. One inch diameter pipes were used in connecting the pump's outlet to ground level. The valves were installed using ¾ inch diameter pipes and sitting. The snapshot of the installed temperature and water level sensors and valves is shown in plate 3.7.

Plate 3.7: Snapshot of installed temperature and water level sensors and valves

The water temperature sensor was installed inside a plastic basket at the middle of the pond (60cm depth) via a plastic lever. The plastic basket prevents fish from having contact with the sensor. The pond water level sensor was fixed at the surface of pond water near one edge of the pond with an opaque movable flat plastic material (plate) held underneath it. The plastic material was fixed to a system that allows it to float on the water. The distance between the pond water level sensor and the plate is a measure of the level of water in the pond. The reservoir water level sensor was also installed in the same manner.

3.4.4 Development of optimum water temperature maintenance system program

The program directs sensing of water temperature, analysis of sensed data, taking of action, displaying of values and communication of temperature level and action taken at any time. Arduino IDE was used in developing the program. The methods involved in the development of the program include planning/analysis, designing, development, testing and implementation of program (programming of microcontroller and performing the fish pond optimum water temperature maintenance task using the system). The algorithm for the operation of the optimum water temperature maintenance system is presented below.

(a) Algorithm 2: Optimum water temperature maintenance system

First configure microcontroller pins 2, 23 and 25 input pins and pins 0, 1, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 23 and 25 as output pins.

Now initialize the LCD and GSM module.

Read pond water temperature into microcontroller through pin 2.

If pond water temperature is between 20^oC and 28^oC, read pond water temperature into microcontroller through pin 2.

If pond water temperature is equal to 28^oC, display value on LCD, send information to smart phone via GSM module, ON valve 3, read pond water level into microcontroller through pin 23. OFF valve 3 when water level is 96cm, ON valve 1 and pump till water level is 120cm, delay for 1h, read pond water temperature into microcontroller through pin 2.

If pond water temperature is equal to 20^oC, display value on LCD, send information to smart phone, ON valve 2, read pond water level into microcontroller through pin 23. OFF valve 2 when water level is 96cm, ON valve 4 till water level is 120cm, ON valve 5 and pump, read reservoir water level into microcontroller through pin 25, OFF valve 5 and pump when level is 100cm, delay for 1h, read pond water temperature into microcontroller through pin 2.

(b) Flow chart of the optimum water temperature maintenance system

The flow chat that implements the system algorithm is shown in figure 3.11.

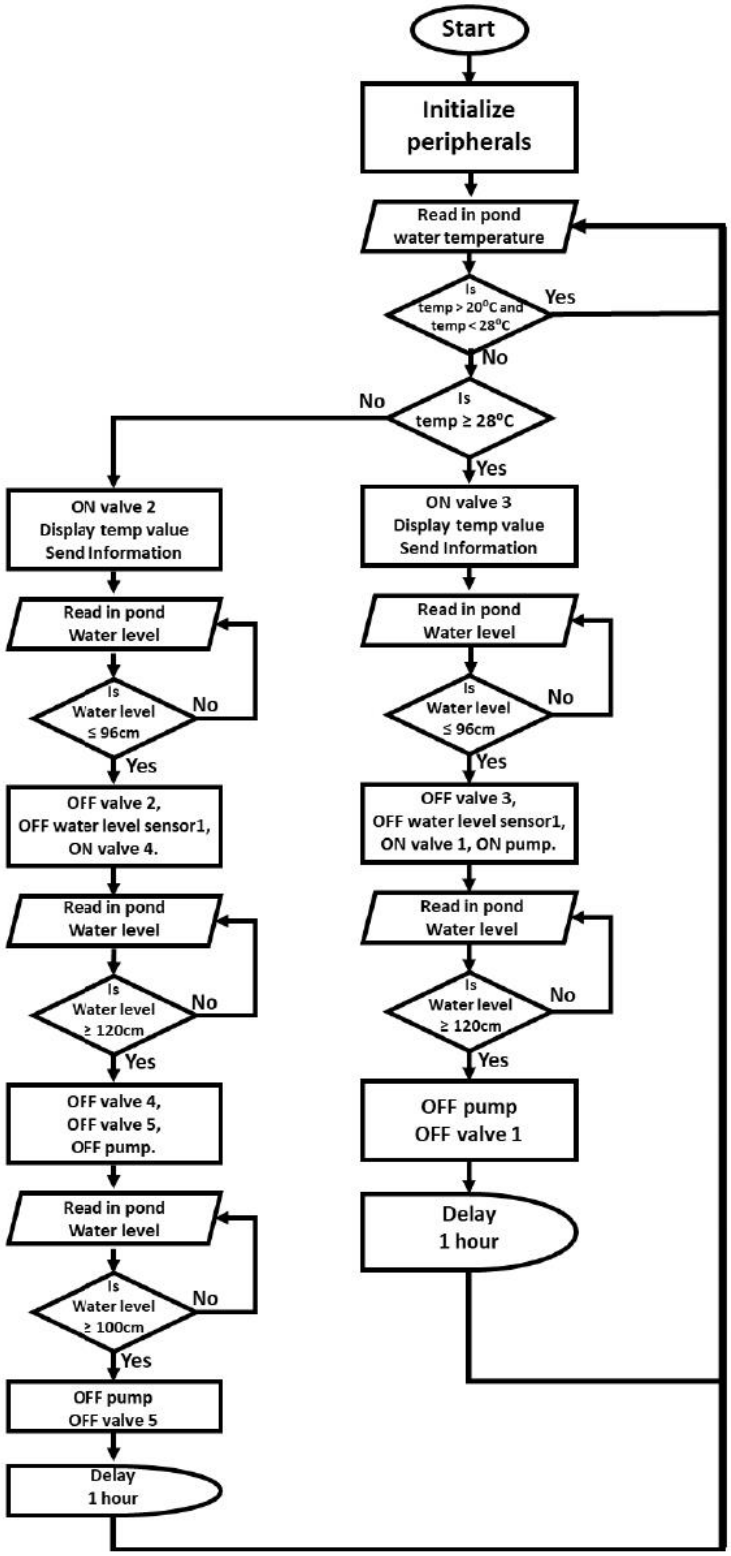


Figure 3.11: Flowchart of the optimum water temperature maintenance system

3.4.5 Development of optimum water temperature maintenance system application

The Pond Water Quality Maintenance Record Application (PWQMR App) for receiving feedback from the smart system for optimum water quality maintenance in warmwater fish culture was developed for the operation of its subsystems. The App was developed with the help of an expert (mobile app developer) using MIT App Inventor (web application integrated development environment). The MIT App Inventor was selected for this design because it is free and open-source software and allows people with no previous programming experience to create application software (Apps) for Android and iOS operating systems-based mobile phones. MIT App Inventor uses a graphical user interface (GUI) very similar to the programming languages Scratch (programming language) and StarLogo (Hardesty**,** 2010). The GUI allows users to drag and drop visual objects to create an application that can be tested on Android devices and built to run as an Android App. The App uses a companion mobile App that allows for instant live testing and debugging. MIT App Inventor also supports the use of cloud data via its CloudDB component (App Inventor, 2020). This App does not require launching or submitting it in the Google Play Store or Apple store because the App only provides information about levels of water quality and maintenance parameters, pond water quality maintenance operation and preventive measures taken to operator or pond owner.

The methods involved in the development of the program include planning/analysis, designing, development, testing and implementation of App (downloading and installing app on Smartphone and performing the fish pond optimum water temperature maintenance communication task using the App).

During development phase, appropriate development environment was established, different parts of the code developed, preliminary test carried out, and the mobile application that can be installed and tested was created**.** The App front-end (“face” of the App) was first developed before the back-end (code). The front-end of the developed PWQMR App after installation is as shown in screenshot of plate 3.1**.**

3.5 Development of Optimum Water DO Maintenance System

The development of optimum water DO maintenance system involved designing and simulation of the system, calibration and validation of sensors, hardware implementation, program and application development and testing. The PWQMR App developed for optimum water temperature maintenance system was also used in this subsystem for communicating information about pond water condition. .

3.5.1 Design and simulation of optimum water DO maintenance system

In this design, the optimum DO of fish pond or tank water was maintained by discharging portion of the water and replacing it with appropriate water (cooler or warm water) and aeration. The system discharged 20% of upper portion of pond water and refilled it with warm water when DO of pond water reached 7.5mg/L and discharged 20% of bottom portion of pond water and refilled it with refills it with groundwater via perforated screen when DO of pond water decreased to 5.0mg/L.

The block diagram of the optimum water DO maintenance system is as shown in figure 3.12.

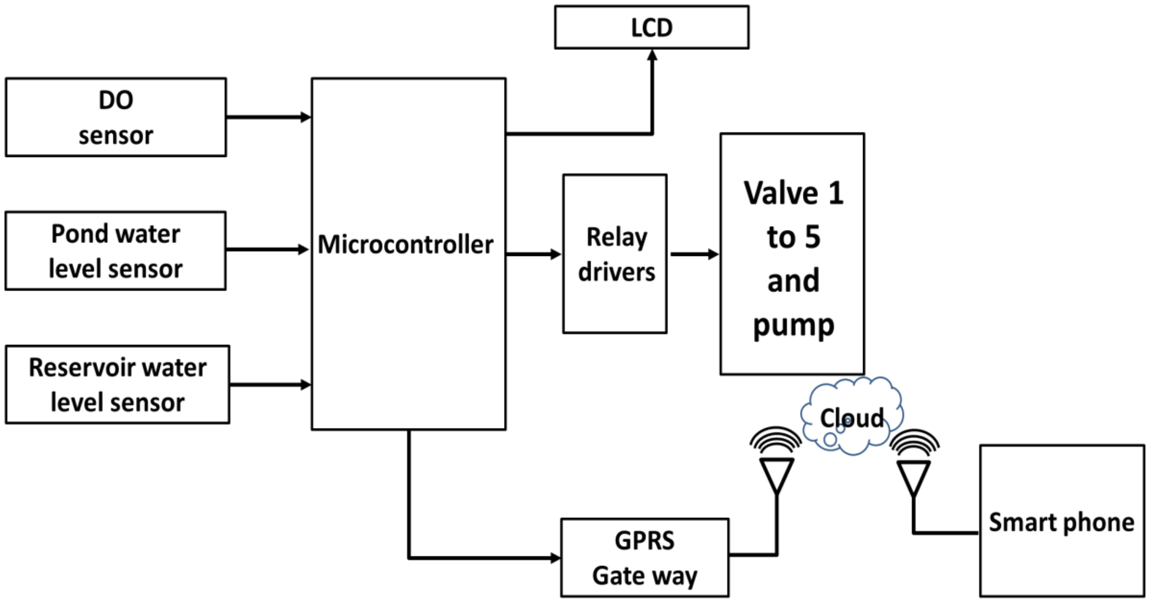


Figure 3.12: Block diagram of optimum water DO maintenance system

The optimum water DO maintenance system consists of a microcontroller, DO sensor, water level sensors, water pump, solenoid valves, actuators, LCD, Relays, GSM module, Smartphone and DC power source and their interconnections.

The circuit diagram or simulation circuit of the optimum water DO maintenance system for warmwater fish culture was drawn using Proteus 8.4 (circuit drawing and simulation software) after drawing circuit with hand (raw design) based on its block diagram. The circuit diagram of the optimum water DO maintenance system for warmwater fish culture is shown in figure 3.13.

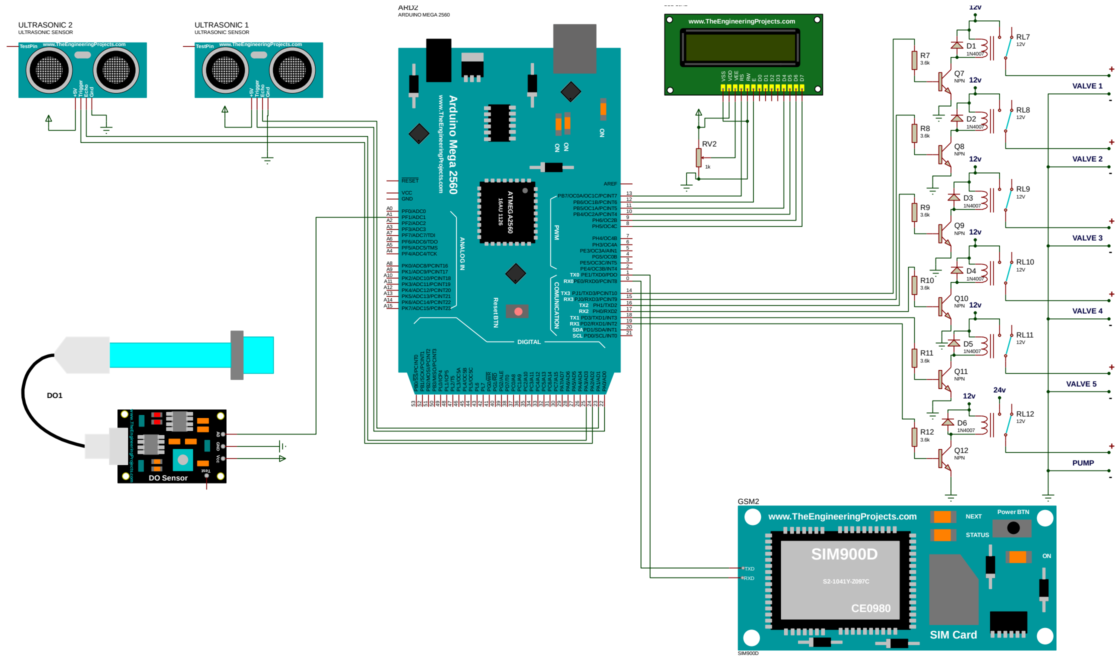


Figure 3.13: Circuit diagram of optimum water DO maintenance system

The components of optimum water DO maintenance system include 1 Arduino Mega microcontroller, 1 DO sensor (Atlas Scientific Gen 2 Dissolved Oxygen Probe), 1 water pump (3FLS1.8/80-D24/201C), 5 solenoid valves (12V), 6 actuators (relay circuits), 2 water level sensors (HC-SR04), 1 LCD (16X2), 1 GSM module (SIM900A), 1 Smartphone with PWQMR app installed in it, DC voltage source (24V, 12V, 5V) and their interconnections.

Simulation of the optimum DO maintenance system was done after the simulation circuit was drawn. The simulation process involved writing a program, generating the hex file and running of the Proteus simulation. The program to control the operation of the optimum DO maintenance system was written in Arduino programming language (embedded C language) with 6.95mg/L and assigned to water DO and water level in the program respectively. The result of the simulation was shown by LCD of the simulation diagram of Appendix C and indicated that the code and circuit connections ere correct.

3.5.2 Calibration and validation of sensors of optimum water DO maintenance system

The sensors used in the optimum water DO maintenance system included one DO sensor and two water level sensors. The two water level sensors calibrated and validated during the development of optimum water temperature maintenance system were used in this system. So, only the DO sensor was calibrated and validated.

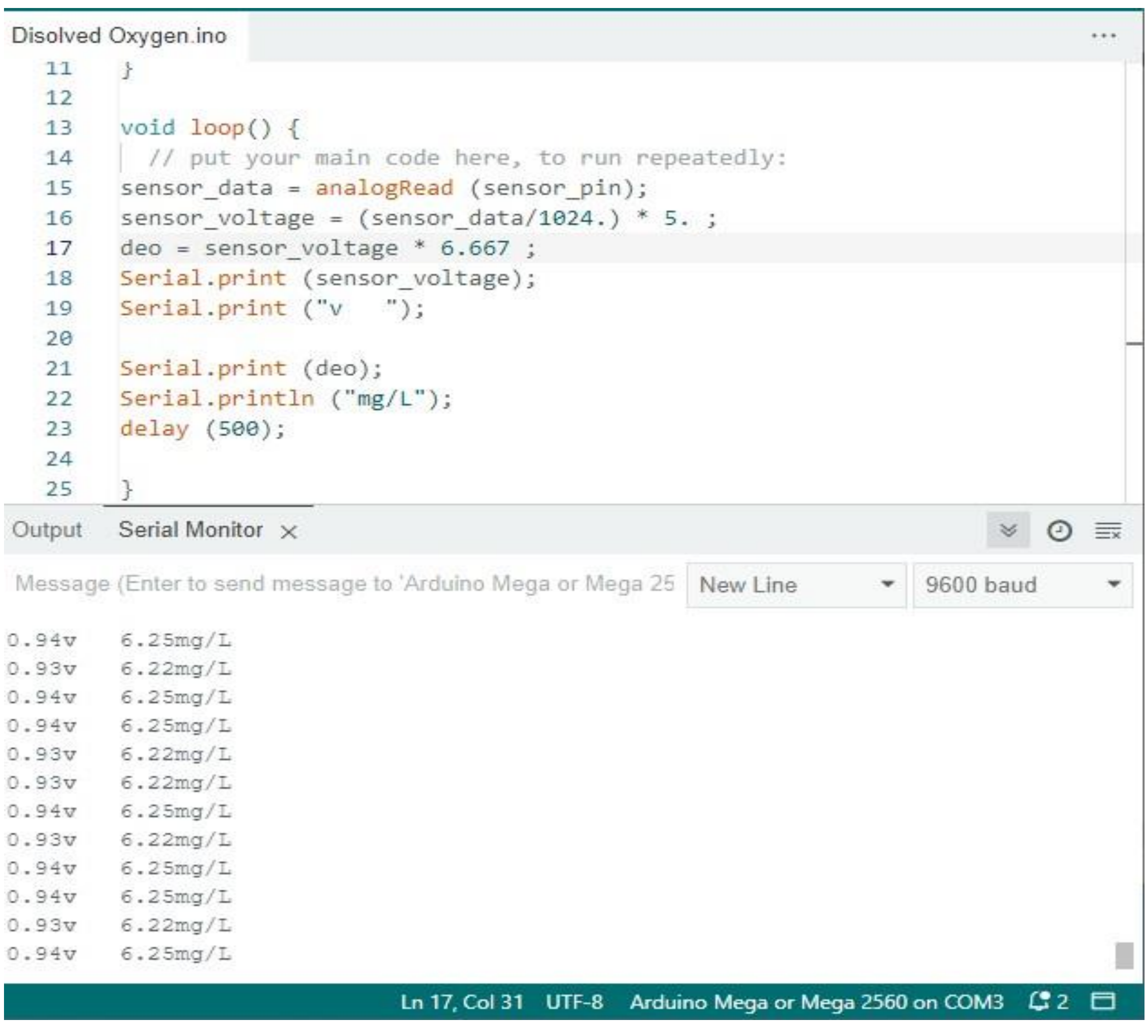
(a) Calibration of DO sensor

Single-point calibration method was used in the calibration of the DO sensor which allowed only calibration using saturated dissolved oxygen at a fixed temperature, and suitable for use when the temperature was stable. The calibration procedure did not use any chemical buffer solution; instead the open air was used to calibrate the sensor to 100% saturation. The sensor was calibrated in its default state (UART mode, with continuous readings enabled). The calibration of DO sensor was done based on the manufacturer's instructions accessed from its website **(**DFRobot, 2022a).

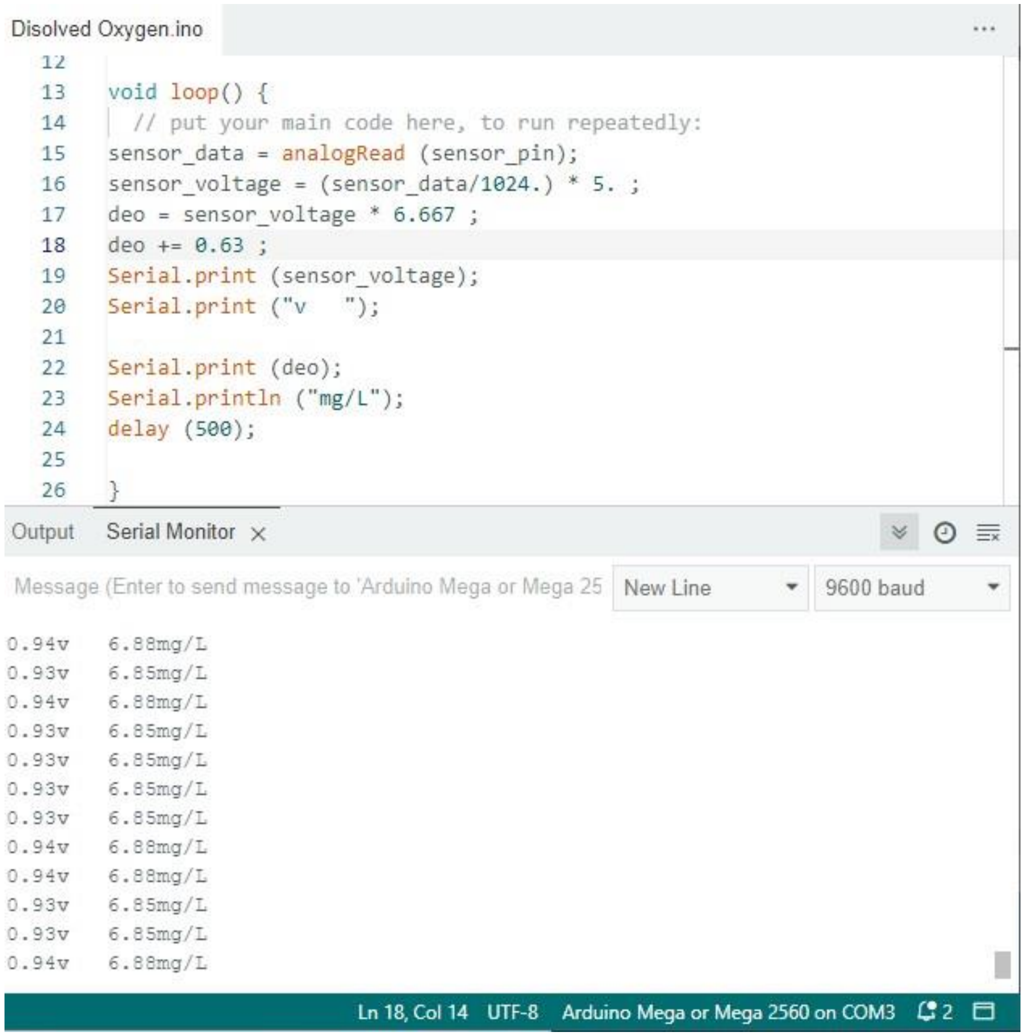
(b) Validation of DO sensor

A dissolved oxygen meter (Model OXi315i), WTW82362 was used as a standardized DO meter for the validation of calibrated meter (meter formed by the DO sensor and Arduino Mega). The method described by APHA (2005) was used for collection of water sample and determination of DO. The probe of the DO meter and probe of calibrated DO meter were inserted into a 100cm^3 beaker containing water sample and readings were taken. Record was taken when readings on the DO meters stabilized. The tests were conducted by 6.30am on the 6th of December 2022.

The DO readings were compared to ensure agreement within a tolerance of ±0.5 mg/L. The DO values for the calibrated DO meter (meter formed by the DO sensor and Arduino Mega) and standard DO meter were 6.87 mg/L and 6.25 mg/L respectively. The test result of the calibrated DO meter did not agree within accuracy limit. So, the temperature and saturation voltage of the calibrated DO meter for the test was adjusted until its output was within the accuracy limit (6.88 mg/L). The reading of the calibrated DO meter before adjustment is shown in Plate 3.8a while the reading after adjustment is shown in of Plate 3.8b.



(a) DO value before adjustment



(b) DO value after adjustment

Plate 3.8: Screenshot of DO meter reading

3.5.3 Hardware implementation of optimum water DO maintenance system

The hardware component of the optimum water DO maintenance system was constructed after calibrating and validating DO sensor. The system was implemented following the steps used in constructing the optimum water temperature maintenance system; from testing of hardware components, implementation of circuit to installation of sensors and valves. The snapshot of implemented circuit component diagram of optimum water DO maintenance system is shown in plate 3.9.

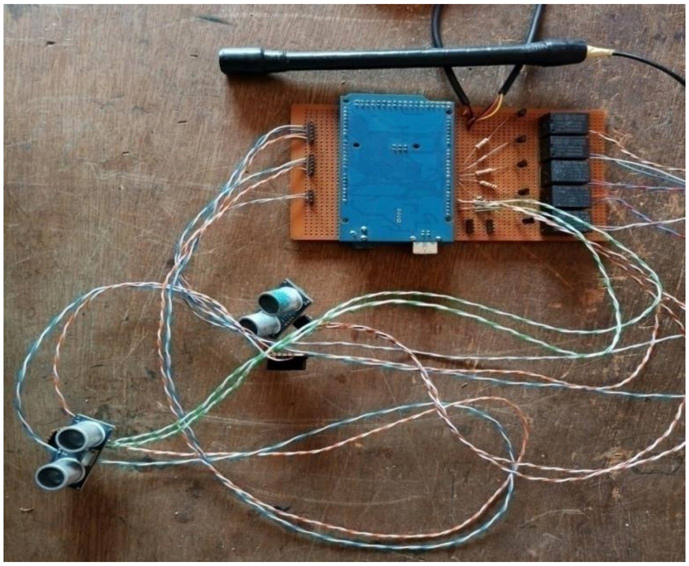


Plate 3.9: Circuit component diagram of optimum water DO maintenance system

The snapshot of the installed DO and water level sensors and valves is shown in plate 3.10.

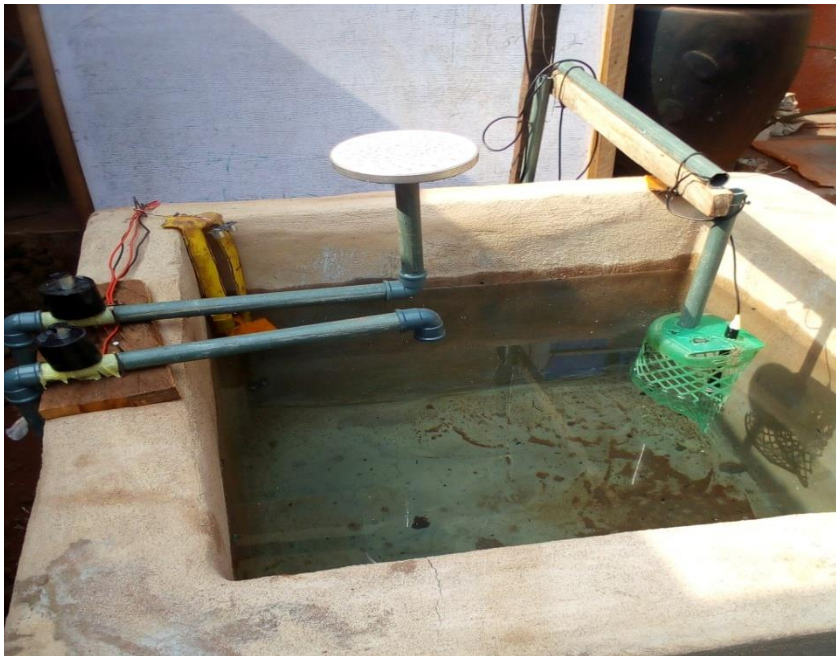


Plate 3.10: Snapshot of installed DO and water level sensors and valves

3.5.4 Development of optimum water DO maintenance system program

The program was developed following the steps used in developing the program for optimum water temperature maintenance system (planning and analysis, designing, development, testing and implementation of program). The program consisted of instructions that direct the operation of the optimum fish pond water DO maintenance system. The algorithm for the operation of the optimum water DO maintenance system is presented below.

(a) Algorithm 3: Optimum water DO maintenance system

First configure microcontroller pins A1, 23 and 25 input pins and pins 0, 1, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 23 and 25 as output pins.

Now initialize the LCD and GSM module.

Read pond water DO into microcontroller through pin A1.

If pond water DO is between 5mg/L and 7.5mg/L, read pond water DO into microcontroller through pin A1.

If pond water DO is equal to 5mg/L, display value on LCD, send information to smart phone, ON valve 2, read pond water level into microcontroller through pin 23, OFF valve 2 when water level is 96cm, ON valve 1 and pump till water level is 120cm, delay for 1h, read pond water DO into microcontroller through pin A1.

If pond water temperature is equal to 7.5mg/L, display value on LCD, send information to smart phone, ON valve 3, read pond water level into microcontroller through pin 23. OFF valve 3 when water level is 96cm, ON valve 4 till water level is 120cm, ON valve 5 and pump, read reservoir water level into microcontroller through pin 25, OFF valve 5 and pump when level is 100cm, delay for 1h, read pond water DO into microcontroller through pin A1.

(b) Flowchart of optimum water DO maintenance system

Figure 3.14 shows the flowchart of the optimum water DO maintenance system.

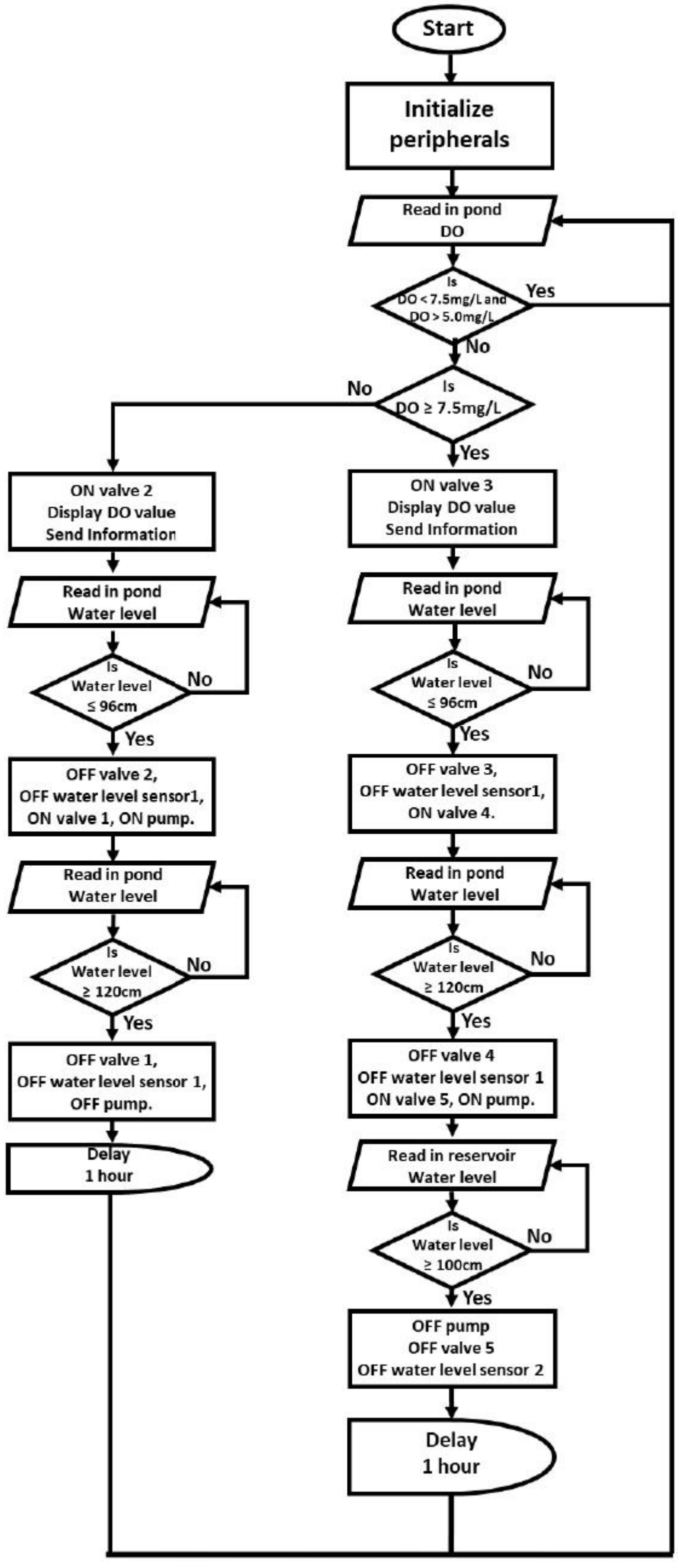


Figure 3.14: Flowchart of the optimum water DO maintenance system

3.6 Development of Optimum Water pH Maintenance System

The development of optimum water pH maintenance system involved designing and simulation of the system, calibration and validation of sensors, hardware implementation, program and application development and testing. The PWQMR App developed for optimum water temperature maintenance system was also used in this subsystem for communicating information about pond water condition. .

7.6.1 Design and simulation of optimum water pH maintenance system

In this design, optimum pH of pond or tank water was maintained by discharging portion of the water and replacing it with appropriate water (underground or warm water) and aeration. The system discharged 20% of bottom portion of pond water and refilled it with groundwater via perforated screen when pH of pond water reached 8.5 or when it decreased to 6.8. Adding water from borehole to pond through perforated screen as inlet with the help of wind helped in aerating the pond.

The block diagram of the optimum water pH maintenance system is as shown in figure 3.15.

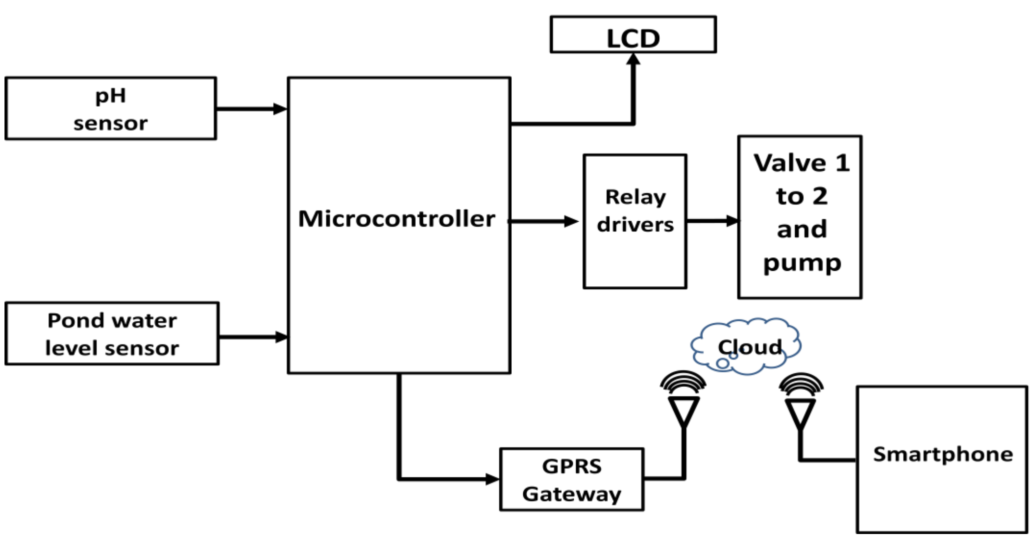


Figure 3.15: Block diagram of optimum water pH maintenance system

The optimum water pH maintenance system consisted of a microcontroller, pH sensor, water level sensors, water pump, solenoid valves, actuators, LCD, Relays, GSM module, Smartphone and DC power source and their interconnections.

The circuit diagram or simulation circuit of the optimum water pH maintenance system for warmwater fish culture was drawn using Proteus 8.4 after raw design was produced with hand based on its block diagram. The circuit diagram of the optimum water pH maintenance system for warmwater fish culture is as shown in figure 3.16.

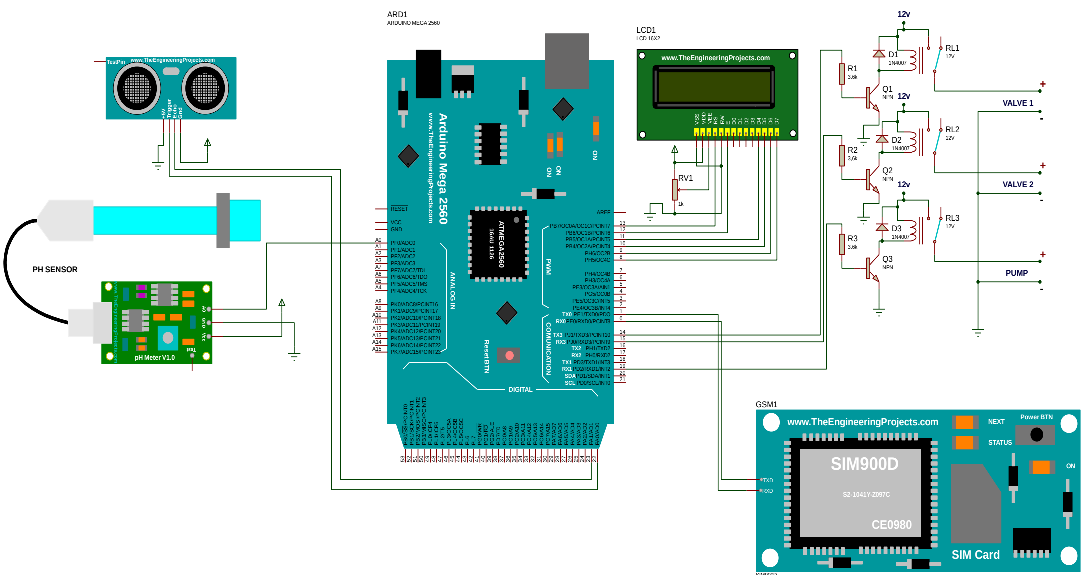


Fig. 3.16: Circuit diagram of optimum water pH maintenance system

The circuit components of optimum water pH maintenance system included 1 Arduino Mega microcontroller, 1 pH sensor (SKU: SEN0169), 1 ultrasonic sensors (HC SR-04), 1 water pump (3FLS1.8/80-D24/201C), 2 solenoid valves (12V), 3 actuators (12V relay circuits), 1 Water level sensors (HC-SR04), 1 LCD (16X2), 1 GSM module (SIM900D), 1 Smartphone with PWQMR app installed in it, DC voltage source (24V, 12V, 5V) and their interconnections.

Simulation of the optimum pH maintenance system was done after the simulation circuit was drawn. The simulation process involved writing a program, generating the hex file and running of the Proteus simulation. The program to control the operation of the optimum pH maintenance system was written in Arduino programming language (embedded C language) with 7.5 and assigned to water pH and water level in the program respectively. The result of the simulation was shown by the simulation diagram of Appendix D and indicated that the code and circuit connections were correct.

3.6.2 Calibration and validation of sensors of optimum water pH maintenance system

The sensors used in the optimum water pH maintenance system include one pH sensor and one water level sensor. The pond water level sensor calibrated and validated during the development of optimum water temperature maintenance system was used in this system. So, only the pH meter was calibrated and validated.

(a) Calibration of pH sensor

The pH meter was calibrated after connecting it to Arduino controller based on the manufacturer’s guideline accessed from its website (Dfrobot, 2021). The pH meter was calibrated by putting the pH electrode into the standard solutions whose pH value were 7.00, 4.00 and 9.18 at a temperature of 25^{o}C, and adjusting the "Offset" variable in the sample code seen in the LCD of the Serial Monitor of the Arduino IDE.

(b) Validation of pH sensor

A multipurpose pH meter (Model HANNA pH 209, U.S.A), was used as a standardized pH meter for the validation of the calibrated pH meter. The method described by APHA (2005) which involved tying test tube on long stick and dipping it inside pond, was used for collection of water sample and determination of pH. The test was conducted by 6.30am on the 7th of December 2022. The calibrated pH meter and the standard pH meter were switched *on* and their probes were inserted into a 100 cm^3 beaker containing water sample collected from the fish pond at about 6.30am and record of their readings were taken.

The readings of the calibrated pH meter (meter formed by the pH sensor and Arduino Mega) and the standard pH meter for the test were 6.38 and 6.42 respectively. The difference in the values presented by the calibrated pH meter and the standard pH meter was within the accuracy limit (± 0.1pH at 25^{o}C), so, the gain potential device of the sensor was not adjusted. The pH value displayed by the pH meter is as shown in screenshot of Plate 3.11.

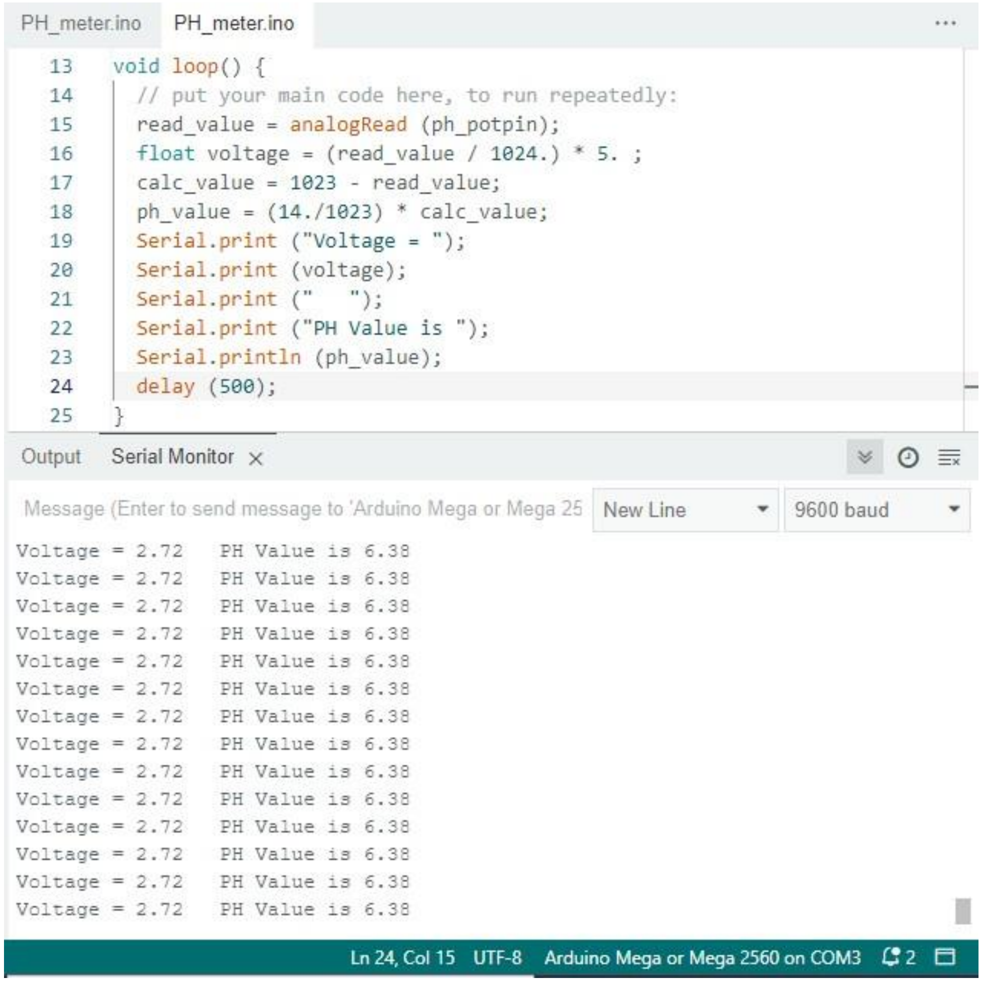


Plate 3.11: Screenshot of the pH Meter Reading

3.6.3 Hardware implementation of optimum water pH maintenance system

The hardware component of the optimum water pH maintenance system was constructed after calibrating and validating pH sensor. The subsystem was implemented following the steps used in constructing the optimum water temperature maintenance system; from testing of hardware components implementation of circuit to installation of sensors and valves. The snapshot of the circuit component diagram of optimum water pH maintenance system is as shown in Plate 3.12.

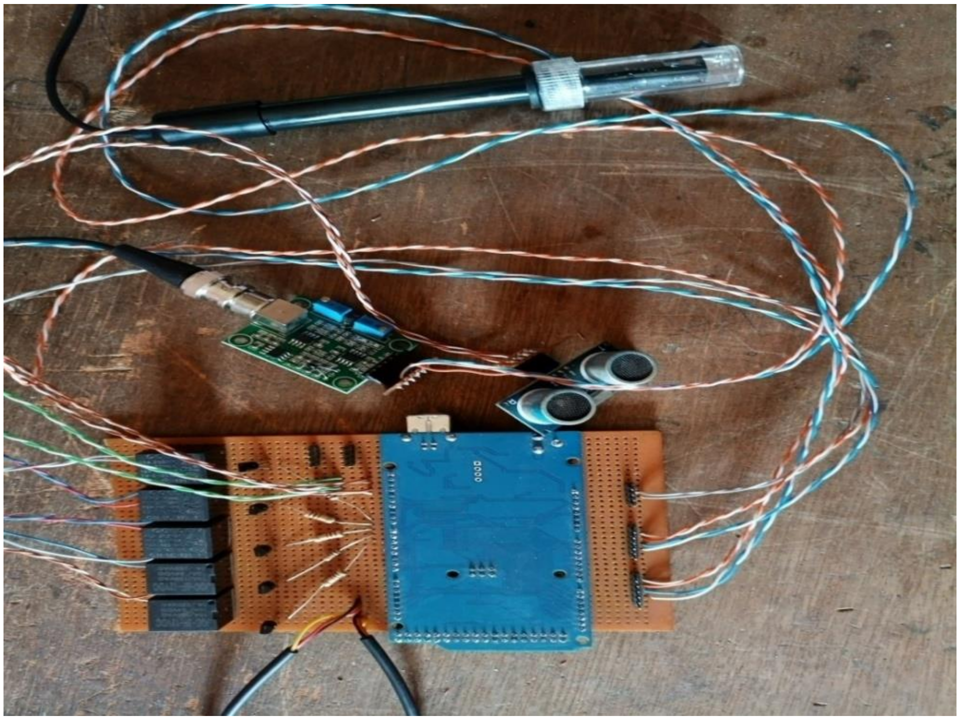


Plate 3.12: Circuit component diagram of optimum water pH maintenance system

The snapshot of the installed pH and water level sensors and valves is as shown in Plate 3.13.

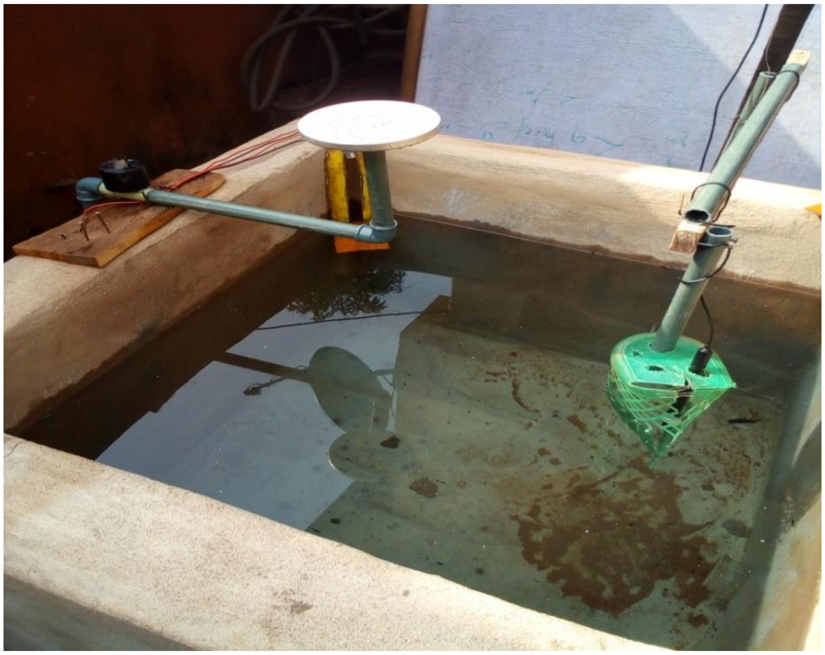


Plate 3.13: Snapshot of installed pH and water level sensors and valves

3.3.4 Development of program for optimum water pH maintenance system

The program for controlling the operation of optimum water pH maintenance system was developed following the steps used in developing the program for optimum water temperature maintenance system (planning and analysis, designing, development, testing and implementation of program). The program comprised of instructions that directed the operations of optimum water pH maintenance system. The algorithm for the operation of the optimum water pH maintenance system is presented below.

(a) Algorithm 4: Optimum water pH maintenance system

First configure microcontroller pins A0 and 23 input pins and pins 0, 1, 8, 9, 10, 11, 12, 13, 14, 15 and 19 as output pins.

Now initialize the LCD and GSM module.

Read pond water pH into microcontroller through pin A0.

If pond water pH is between 6.8 and 8.5, read pond water pH into microcontroller through pin A0.

If pond water pH is equal to 6.8 or 8.5, display value on LCD, send information to smart phone, ON valve 2, read pond water level into microcontroller through pin 23, OFF valve 2 when water level is 96cm, ON valve 1 and pump till water level is 120cm, delay for 1h, read pond water pH into microcontroller through pin A0.

(b) Flowchart of the optimum water pH maintenance system

The flowchart of the optimum water pH maintenance system is as shown in figure 3.17.

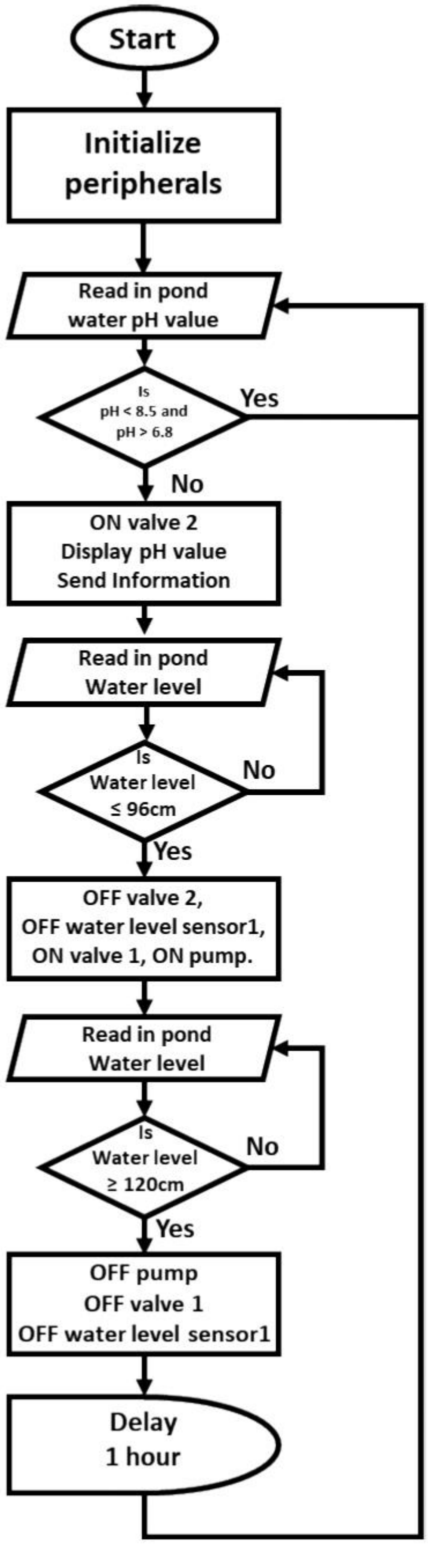


Fig. 3.17: Flowchart of the optimum water pH maintenance system

3.7 Development of Preventive Maintenance System

The development of preventive maintenance system involved designing and simulation of the system, calibration and validation of sensors, hardware implementation, program and application development and system testing. The PWQMR App developed for optimum water temperature maintenance system was also used in this subsystem for communicating information about pond water condition.

3.7.1 Design and simulation of preventive maintenance system

In this design, water quality problems were prevented by taking adequate preventive measures such as exchange of bottom dirty water (more turbid water), replenishment of pond with water and erection of sun shade/screen or windbreak/shade and providing information about pond water quality to operator or owner of pond. The system discharged 20% of bottom portion of pond water and refilled it with groundwater via perforated screen when turbidity of pond water reached 20mg/L or 20NTU, erects sun shade/screen and windbreak/shade when temperature of air reached 28^{o}C and decreased to 20^{o}C respectively and refilled pond when water level decreased by 3cm. Replacement of lost water and exchange of bottom dirty water helped in preventing water quality problems (turbidity, temperature, DO and pH problem) and maintaining optimum turbidity while erection of sun screen or wind shade helped in preventing water quality problems (temperature, DO and pH problem) and maintaining optimum temperature.

The block diagram of the preventive maintenance system is as shown in figure 3.18.

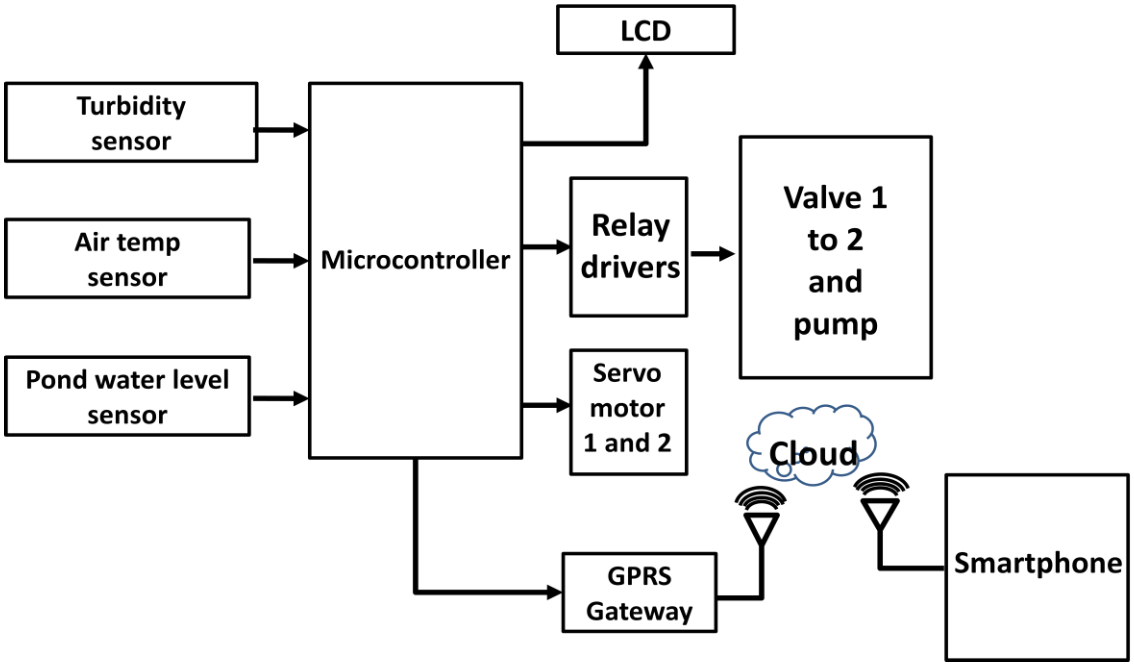


Figure 3.18: Block diagram of preventive maintenance system

The preventive maintenance system consisted of a microcontroller, turbidity sensor, water level sensor, air temperature sensor, water pump, solenoid valves, actuators, LCD, Relays, GSM module, Smartphone and DC power source and their interconnections.

The circuit diagram or simulation circuit of the preventive maintenance system for warmwater fish culture was drawn using Proteus 8.4 after raw design was produced with hand based on its block diagram. The circuit diagram of the preventive maintenance system is as shown in figure 3.19.

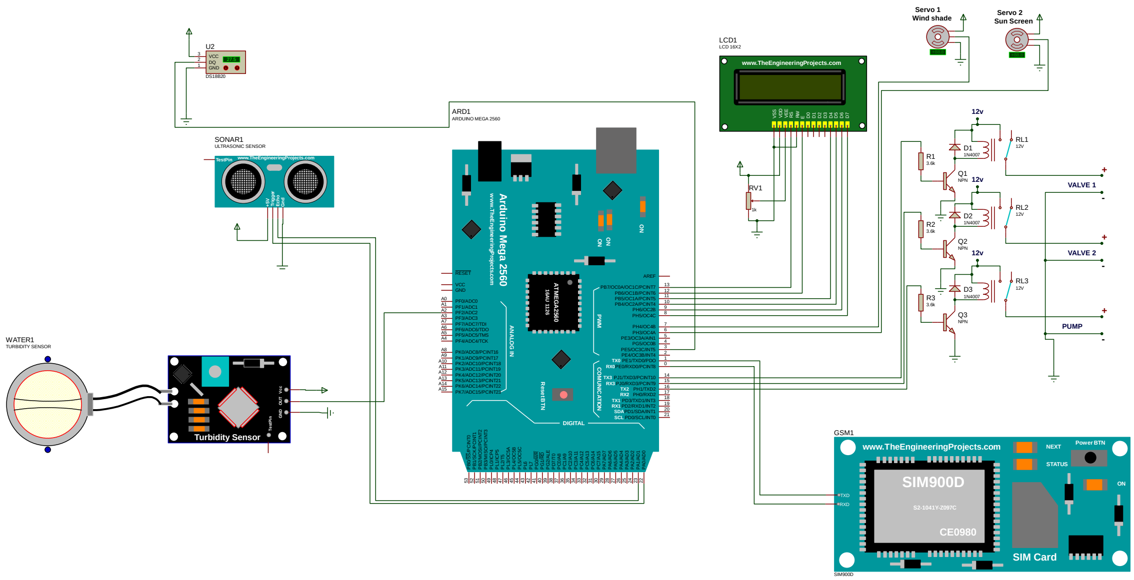


Fig. 3.19: Circuit diagram of preventive maintenance system

The components of preventive maintenance system included: 1 Arduino Mega microcontroller, 1 turbidity sensor (SKU: SEN0189 gravidity arduino turbidity sensor), 1 water level sensor (HC SR-04), 1 temperature sensor (DS18B20), 1 water pump (3FLS1.8/80-D24/201C), 2 solenoid valves (12V), 3 actuators (relay circuits), 1 LCD (16X2), 1 GSM module (SIM900D), 1 Smartphone with PWQMR app installed in it, DC voltage source (24V, 12V, 5V) and their interconnections.

Simulation of the preventive maintenance system was done after the simulation circuit was drawn. The simulation process involved writing a program, generating the hex file and running of the Proteus simulation. The program to control the operation of the preventive maintenance system was written in embedded C with 17.5mg/L and 120cm assigned to water turbidity and water level respectively in the program. The pond water turbidity and water level displayed on the LCD were 17.5mg/L and 120cm respectively**.** The result of the simulation was shown by LCD of the simulation diagram of Appendix E and indicated that the code and circuit connections were correct.

3.7.2 Calibration and validation of sensors of preventive maintenance system

The sensors used in the preventive maintenance system include one turbidity sensor, one air temperature sensor and one water level sensor. The pond water level sensor calibrated and validated during the development of optimum water temperature maintenance system was used in this system. So, only the turbidity sensor and air temperature sensor were calibrated and validated.

(a) Calibration of turbidity sensor

The turbidity meter was calibrated after connecting it to Arduino controller based on the manufacturer's guideline accessed from its website (DFRobot, 2022a). The turbidity sensor was calibrated by taking measurement of clean/pure water which had turbidity of 0 NTU or 0mg/L at water temperature 10 to 50^{o}C.

(b) Validation of turbidity sensor

The calibrated turbidity monitoring system was validated by taking some measurements of sample of water and comparing the result with standard turbidity meter. Turbidimeter (HACH 2100P, U.S.A) was used as a standardized turbidity meter for the validation of the calibrated turbidity sensor system. The method described by APHA (2005) was used for collection of water sample and determination of turbidity. Two samples were used for the validation and were collected 10cm from the surface of the pond used for the test. In order to validate the calibrated turbidity sensor system, the probe of the standard turbidity meter was inserted into a bowl containing water sample and the probe of calibrated turbidity sensor system placed on the surface of water on the bowl and record was taken when readings on the turbidity meters stabilized. The Turbidimeter presented its measured value in Nephelometric Turbidity Units (NTU) which is equivalent to milligram per liter (mg/L). The tests were conducted by 10.30am on the 8th of December 2022.

The turbidity value displayed by the standard turbidity meter and calibrated turbidity meter (meter formed by turbidity sensor and Arduino Mega) were 15.02 mg/L and 14.91 mg/L respectively. The turbidity value displayed by the calibrated turbidity meter is as shown in screenshot of Plate 3.14.

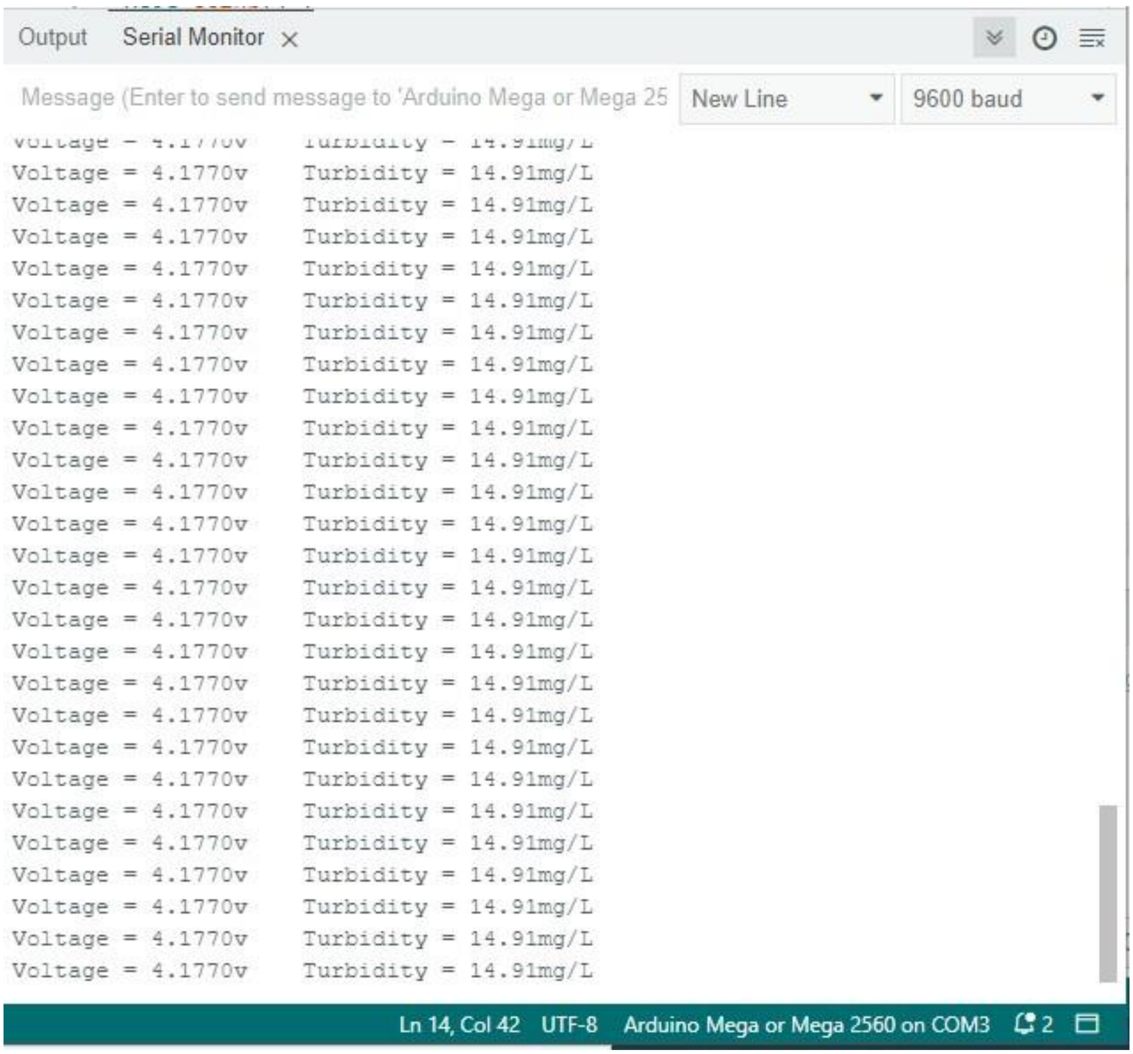


Plate 3.14: Screenshot of the turbidity meter reading

The turbidity value of the calibrated turbidity sensor system for the test was within the accuracy limit of the calibrated turbidity sensor system (±0.3 mg/L) when compared to the value shown by the standard turbidity meter. So, the values shown on the Serial Monitor for the calibrated turbidity sensor was not adjusted by rotating the potentiometer in the sensor.

(c) Calibration of air temperature sensor

The air temperature sensor was calibrated following the steps used in calibrating the water temperature sensor. A water sample was collected in a glass cup and the probe of the sensor was dipped into the cup and the LCD in the Serial Monitor observed after connecting the sensor to Arduino Mega. The LCD in the Serial Monitor of the IDE showed the water temperature being measured by the water temperature meter after connecting it to the Arduino Mega. The water temperature value shown by the Serial Monitor for air temperature was 25.31^{o}C and this showed that the temperature sensor was functioning.

(d) Validation of air temperature sensor

The same Mercury-In-Glass thermometer used for validating water temperature sensor was also used in validation of air temperature sensor. The air temperature around the fish pond used for the study was tested by 06.40am on 5th December 2022. The air temperature was determined by suspending the air temperature sensor and the standard thermometer in air and taking records of temperature value when readings stabilized.

The air temperature value displayed by the temperature meter via LCD in the Serial Monitor of the IDE and the standard thermometer were 23.91^{o}C and 23.97^{o}C respectively. The difference in temperature values from the standard thermometer and the calibrated temperature sensor system was within the accuracy limit of the temperature sensor (±0.5cm), so no adjustments were made on their codes. The air temperature value displayed by the temperature meter is shown in screenshot of Plate 3.15.

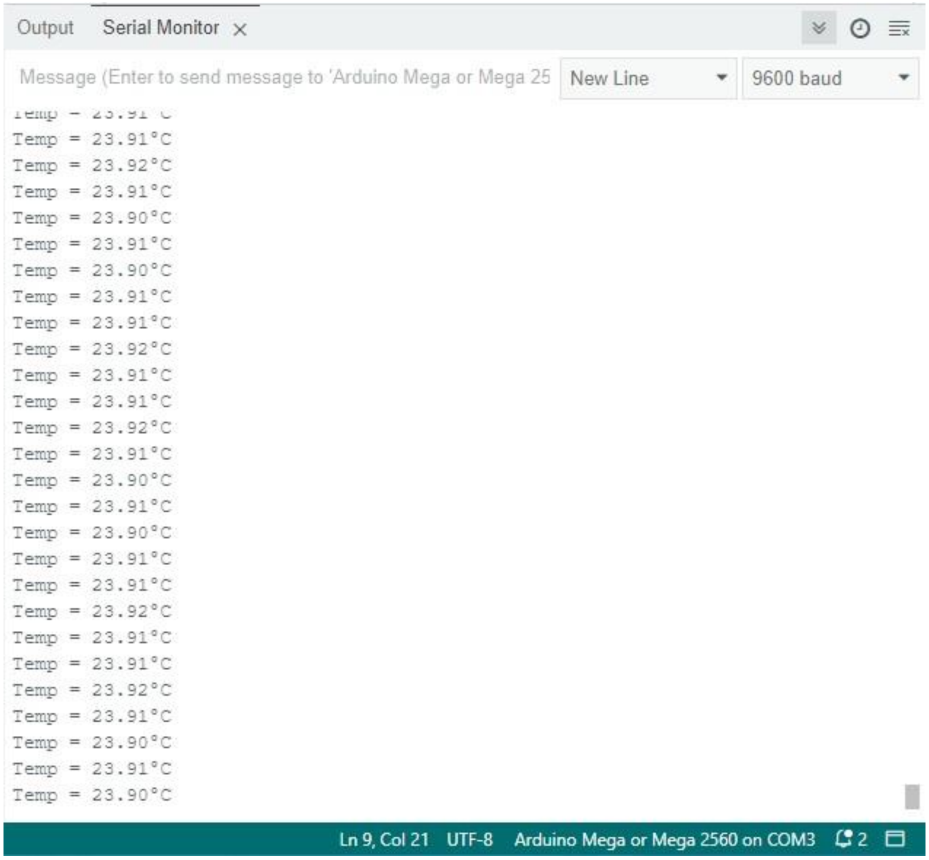


Plate 3.15: Screenshot of the air temperature meter reading

3.7.3 Hardware implementation of preventive maintenance system

The hardware of the preventive maintenance system was constructed after calibrating and validating turbidity and air temperature sensors. The preventive maintenance system was implemented following the steps used in constructing the optimum water temperature maintenance system; from testing of hardware components implementation of circuit to installation of sensors and valves. The snapshot of circuit component diagram of preventive maintenance system is shown in Plate 3.16.

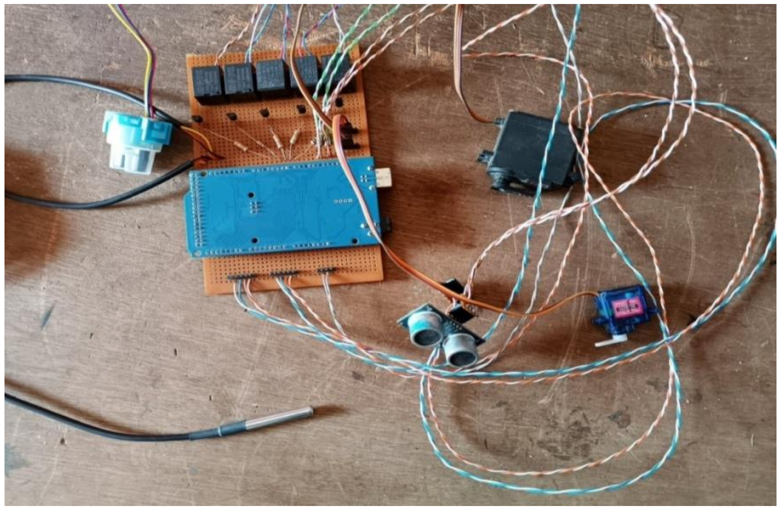


Plate 3.16: Circuit component diagram of preventive maintenance system

(a) Installation of pump, sensors, valves and servo motors

The turbidity sensor was fixed at the surface of pond water via plastic sitting fixed on the pond dike while the air temperature sensor was installed above the pond via a metallic pipe. The water level sensor was installed as in Plate 3.7. The snapshot of the installed turbidity, air temperature and water level sensors and valves is shown in Plate 3.17.

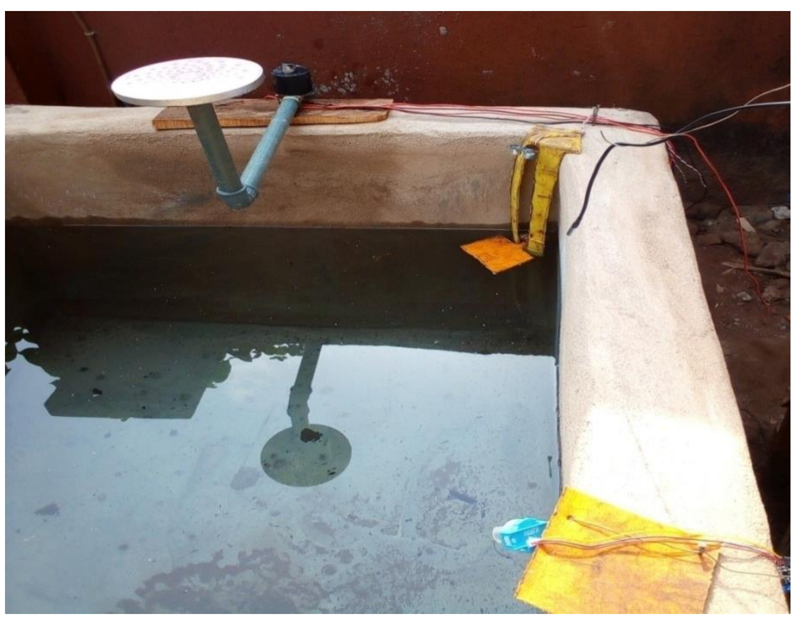


Plate 3.17: Snapshot of installed turbidity, temperature and water level sensors and valve

The arm of each of the servo motors was fixed to one side of a 1m x 1m frame covered with tarpaulin and guided by metallic rails to ensure that they did not tilt**.** The servo motor for sun shade was fixed at the horizontal bottom side of the frame kept in vertical position with screws while the servo motor for windbreak was fixed at the horizontal side of the frame kept in horizontal position and close to the pond dike. The snapshot of installed of servo motor-based wind break is shown in Plate 3.18.

Plate 3.18: Snapshot of installed servo motor-based windbreak

3.7.4 Development of preventive maintenance system program

The program for controlling the operation of the preventive maintenance system was developed following the steps used in developing the program for optimum water temperature maintenance system (planning and analysis, designing, development, testing and implementation of program). The program comprised of instructions that directed the operation of the optimum fish pond water preventive maintenance system. The algorithm for the operation of the preventive maintenance system is presented below.

(a) Algorithm 5: Preventive maintenance system

The algorithm for the operation of the preventive maintenance system is as follows:

First configure microcontroller pins A2, 3 and 23 input pins and pins 0, 1, 8, 9, 10, 11, 12, 13, 14, and 19 as output pins.

Now initialize the LCD and GSM module.

Read pond water turbidity into microcontroller through pin A2.

If pond water turbidity is between 10mg/L and 20mg/L, read pond water level into microcontroller through pin 23.

If pond water turbidity is equal to 20mg/L, display value on LCD, send information to smart phone, ON valve 2, read pond water level into microcontroller through pin 23, OFF valve 2 when water level is 96cm, ON valve 1 and pump till water level is 120cm, delay for 1h, read pond water level into microcontroller through pin 23.

If pond water turbidity is equal to10mg/L, display value on LCD, send information to smart phone and then read pond water level into microcontroller through pin 23.

If pond water level is between 117cm and 120cm or equal to 120cm, read air temperature into microcontroller through pin 3.

If pond water level is equal to 117cm, ON valve 1 and pump, read pond water level into microcontroller through pin 23, OFF valve 1 when water level is 120cm and then read air temperature into microcontroller through pin 3.

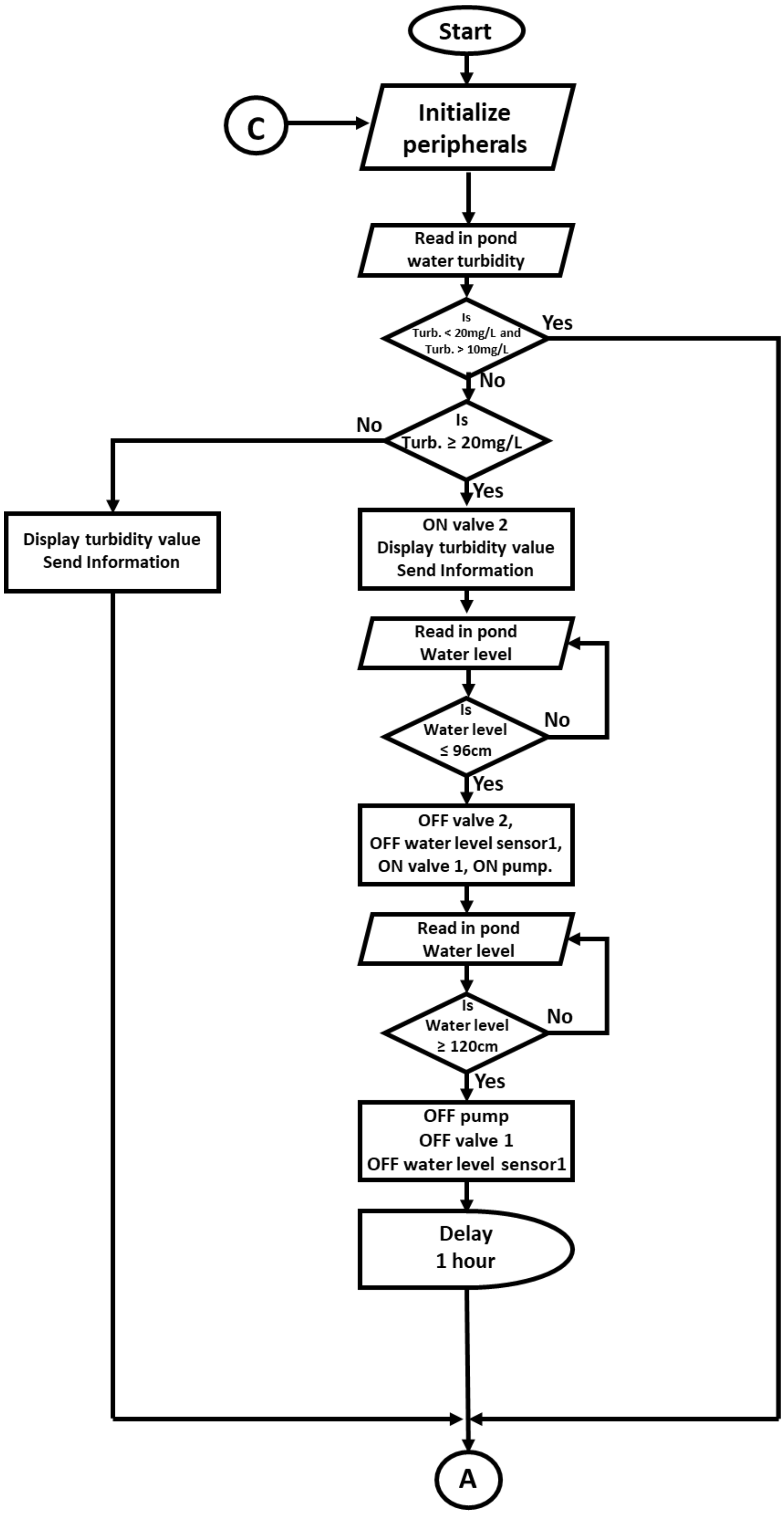
If pond air temperature is between 20^{o}C to 28^{o}C, read pond water turbidity into microcontroller through pin A2.

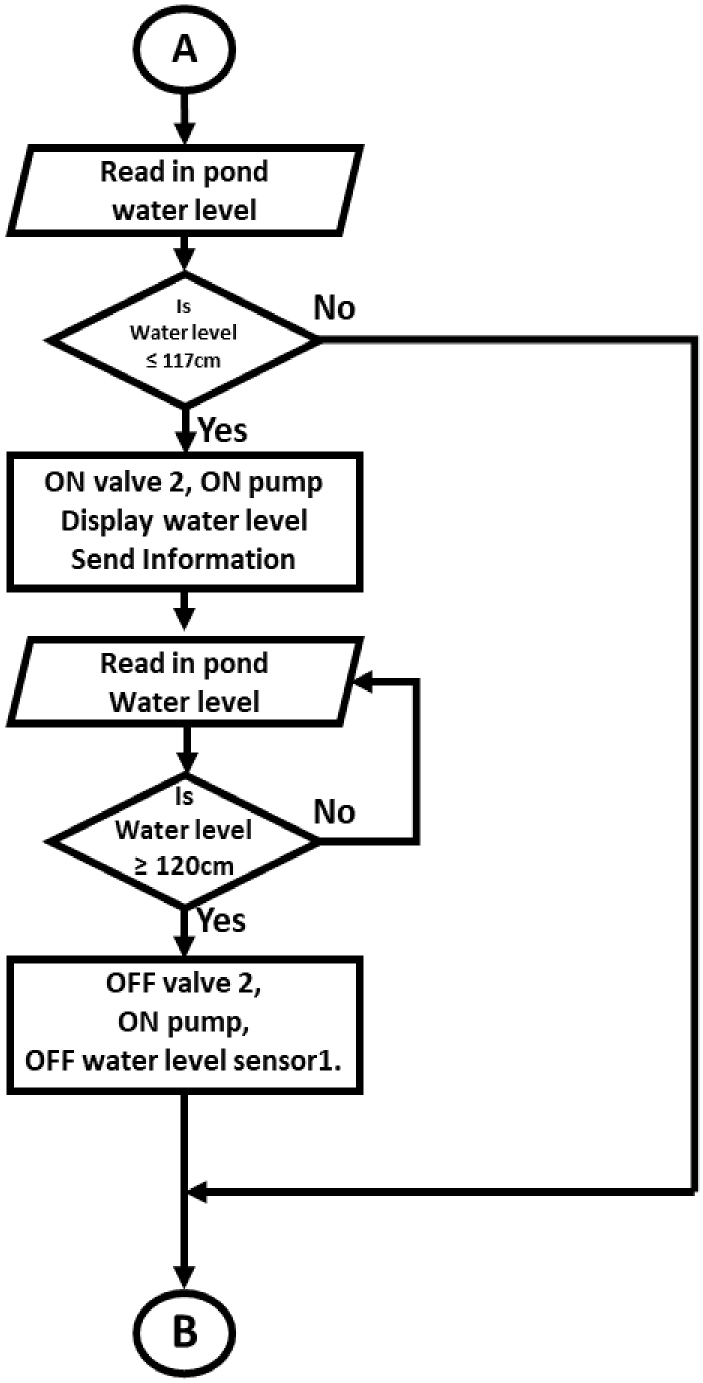
If air temperature is equal to 28^{o}C, display value on LCD, send information to smart phone via GSM module, ON servo motor 1, read air temperature into microcontroller through pin 2. If air temperature is equal to or less than 28^{o}C, OFF servo motor 1, OFF air temperature sensor and then read pond water turbidity into microcontroller through pin A2.

If air temperature is equal to 20^{o}C, display value on LCD, send information to smart phone via GSM module, ON servo motor 2, read air temperature into microcontroller through pin 2. If air temperature is equal to or greater than 20^{o}C, OFF servo motor 2, OFF air temperature sensor and then read pond water turbidity into microcontroller through pin A2.

(b) Flowchart of the preventive maintenance system

The flowchart of the preventive maintenance system is as shown in figure 3.20


Start
C
Initialize peripherals
Read in pond water turbidity
Is Turb. < 20mg/L and Turb. > 10mg/L
Yes
No
Is Turb. ≥ 20mg/L
No
Yes
Display turbidity value
Send Information
ON valve 2
Display turbidity value
Send Information
Read in pond Water level
Is Water level ≤ 96cm
No
Yes
OFF valve 2,
OFF water level sensor1,
ON valve 1, ON pump.
Read in pond Water level
Is Water level ≥ 120cm
No
Yes
OFF pump
OFF valve 1
OFF water level sensor1
Delay 1 hour
A


A
Read in pond water level
Is Water level ≤ 117cm
No
Yes
ON valve 2, ON pump
Display water level
Send Information
Read in pond Water level
Is Water level ≥ 120cm
No
Yes
OFF valve 2,
ON pump,
OFF water level sensor1.
B

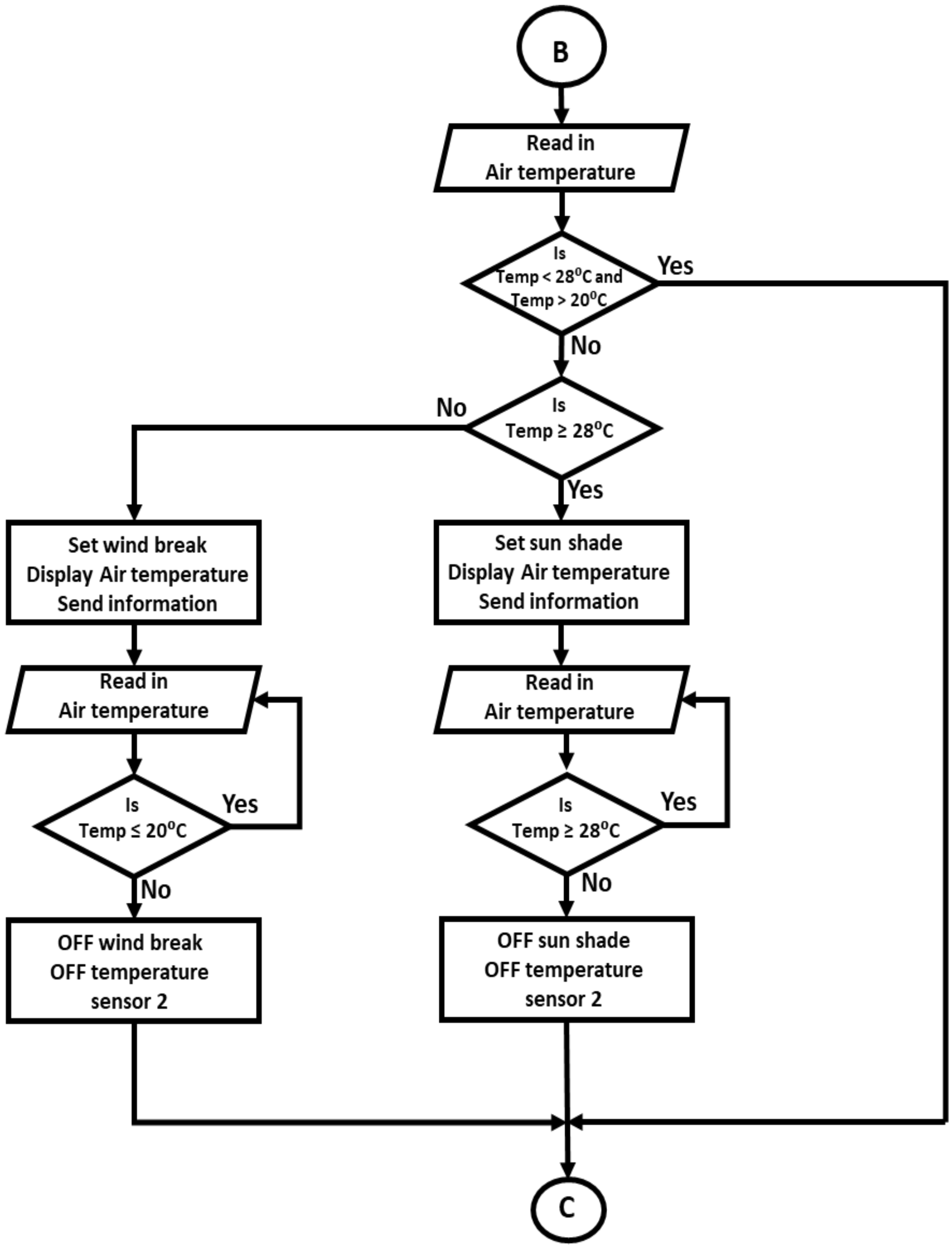


Figure 3.20: Flowchart of preventive maintenance system

3.8 Integration of Subsystems

In this phase of the development, the complete system (smart electronic system for optimum water quality maintenance in warmwaater fish culture) that comprised of the four subsystems (optimum water temperature maintenance system, optimum water DO maintenance system, optimum water pH maintenance system and preventive maintenance system) was constructed based on circuit diagram of figure 3.7. The preventive maintenance system circuit of Plate 3.16 which was the last subsystem circuit constructed was used as base for integration of other circuit components. The remaining components such as pond water temperature sensor, DO sensor, pH sensor and level sensor, and valves 4 and 5 and their interconnection system were integrated as in Plate 3.19.

Plate 3.19: Snapshot of components and casing containing circuit of implemented smart electronic system for optimum water quality maintenance in warmwater fish culture

The components of the complete system such as pond water temperature sensors, DO sensor, pH sensor, turbidity sensor and level sensors, and valves and their interconnection system were installed as in Plate 3.20.

Plate 3.20: Snapshot of installed sensors, valves and perforated screen of smart electronic system for optimum water quality maintenance

The processor (Arduino Mega 2560) used in constructing the individual subsystem systems, was also used for the complete system construction. The Arduino Mega 2560 was reprogrammed with the program for the smart electronic system for optimum water quality maintenance in warmwaater fish culture as presented in Appendix A and used to control the entire operation of complete system.

3.9 System Tests

The tests were conducted to verify the performance of the optimum pond water temperature maintenance system, optimum pond water DO maintenance system, optimum pond water pH maintenance system, preventive maintenance system and complete system. The system tests were performed in a shallow and small concrete fish pond (2m x 1.6m x 1.2m) constructed for this work. This small pond was constructed because the smart electronic system for optimum water quality maintenance in warmwater fish culture was designed to be used in fish ponds and tanks with maximum area of $45m^2$ and maximum depth of 2m (shallow and small ponds and tanks) that have overflow pipe.

3.9.1 Optimum pond water temperature maintenance system test

The optimum pond water temperature maintenance system installed in the filled fish pond was switched ON, the LCD, smart phone and pond water outlets and inlets observed and warm water was gradually poured into the fish pond and stirred. In order to have a detailed record of the result of the test, the laptop computer used for calibration and validation of sensors was connected to Arduino Mega 2560 and the Serial Monitor of the IDE observed for about one and half hours and the result screenshot. This test was conducted in the afternoon of February 15, 2023 when the water temperature was 26.8^{o}C initially.

A second test was conducted in the morning of February 16, 2023 when the water temperature was 25.5^{o}C initially. In this test, cool water produced using water and ice was gradually poured into the fish pond and stirred immediately the optimum pond water temperature maintenance system was switched ON. The LCD, smart phone and pond water outlets and inlets were observed. The Serial Monitor of the IDE was also observed for about one and half hours and the result screenshot.

3.9.2 Optimum water DO maintenance system test

The optimum pond water DO maintenance system installed in the farm was switched ON, the LCD, smart phone and pond water outlets and inlets were observed and cool, more oxygenated water was gradually poured into the fish pond and stirred. In order to have a detailed record of the result of the test, the laptop computer used for calibration and validation of sensors was connected to Arduino Mega 2560 and the Serial Monitor of the IDE observed for about one and half hours and the result screenshot. This test was conducted in the morning of February 17, 2023 when the water DO 7.3mg/L initially.

A second test was conducted in the afternoon of February 18, 2023 when the water DO was 6.5mg/L initially. In this test, warm, less oxygenated water was gradually poured into the fish pond and stirred immediately the optimum pond water DO maintenance system was switched ON. The LCD, smart phone and pond water outlets and inlets were observed. The Serial Monitor of the IDE was also observed for about one and half hours and the result screenshot

3.9.3 Optimum water pH maintenance system test

The optimum pond water pH maintenance system installed in the farm was switched ON, the LCD, smart phone and pond water outlets and inlets observed and standard alkaline solution was poured into the pond gradually and stirred. In order to have a detailed record of the result of the test, the laptop computer used for calibration and validation of sensors was connected to Arduino Mega 2560 and the Serial Monitor of the IDE observed for about one and half hours and the result screenshot. This test was conducted in the afternoon of February 19, 2023 when the water pH was 8.2.

A second test was conducted in the morning of February 20, 2023 when the water pH was 8.1. In this test, standard acidic solution was gradually poured into the fish pond and stirred immediately the optimum pond water pH system was switched ON. The LCD, smart phone and pond water outlets and inlets were observed. The Serial Monitor of the IDE was also observed for about one and half hours and the result screenshot

3.9.4 Preventive maintenance system test

The preventive maintenance system test comprised of:

i. Optimum pond water turbidity maintenance system test.
ii. Optimum pond water level maintenance system test.
iii. Sun radiation and wind control system test.

(a) Optimum pond water turbidity maintenance system test

The preventive maintenance system installed in the farm was switched ON, the LCD, smart phone and pond water outlets and inlets observed and highly turbid water (mud water and water containing plankton) was gradually poured into the fish pond and stirred. In order to have a detailed record of the result of the test, the laptop computer used for calibration and validation of sensors was connected to Arduino Mega 2560 and the Serial Monitor of the IDE observed for about one and half hours and the result screenshot. This test was conducted in the morning of February 21, 2023 when the water turbidity was 18.2mg/L.

A second test was conducted in the morning of February 22, 2023 when the water turbidity was 11.5mg/L initially. In this test, pure water was gradually poured into the fish pond and stirred immediately the preventive maintenance system was switched ON. The LCD, smart phone and pond water outlets and inlets were observed. The Serial Monitor of the IDE was also observed for about one and half hours and the result screenshot.

(b) Optimum pond water level maintenance system test

In this test, the pond water was discharged via a manually operated tap until its level was 117cm. The LCD, smart phone and pond water outlets and inlets were then observed after the system was switched ON. In order to have a detailed record of the result of the test, the laptop computer used for calibration and validation of sensors was connected to Arduino Mega 2560 and the Serial Monitor of the IDE observed for about one and half hours and the result screenshot. A mark was made at the 117cm level of the pond during construction to enable conduct this test and to ensure that the pond water level sensor produced an accurate result. This test was conducted in the morning of February 23, 2023 when the water level was 119.4cm.

(c) Sun radiation and wind control system test

The sun radiation and wind control system test comprises of sun radiation control test and wind control test.

(i) Sun radiation control test

The preventive maintenance system installed in the farm was switched ON, the LCD, smart phone and sun shade and windbreak systems observed and warm water was gradually poured into the fish pond and stirred. In order to have a detailed record of the result of the test, the laptop computer used for calibration and validation of sensors was connected to Arduino Mega 2560 and the Serial Monitor of the IDE observed for about one and half hours and the result screenshot. This test was conducted in the afternoon of February 24, 2023 when the water temperature was 26.3^{o}C initially.

(ii) Wind control test

A second test was conducted in the morning of February 24, 2023 when the water temperature was 23.5^{o}C initially. In this test, cool water produced using water and ice was gradually poured into the fish pond and stirred immediately the optimum pond water temperature maintenance system was switched ON. The LCD, smart phone and sun shade and windbreak systems observed. The Serial Monitor of the IDE was also observed for about one and half hours and the result screenshot.

Pond water was used in the two tests instead of air because of the difficulty in increasing and decreasing air temperature.

3.9.5 Optimum water quality maintenance system test

The fish pond was prepared before the tests were carried out on the constructed smart electronic system for optimum water quality maintenance in warmwater fish culture. The pond was filled with underground water and fertilized with poultry droppings prior to the test. The pond was then stocked with 60 tilapia fishes with average weight of 0.46kg each. Sixty fishes were stocked based on Food and Agricultural Organization (FAO, 2005) standard on pond carrying capacity (10 litres to 1 fish of 1kg size). The smart system was then switched ON and the LCD, smart phone, pond water outlets, sun shade and windbreak systems was observed for two month (January 1, to March 1 2023) in order to ascertain its general performance.

3.10 Summary of the Materials and Methods

The developed optimum water quality maintenance system was made up of four subsystems; optimum water temperature maintenance system, optimum water dissolved oxygen maintenance system, optimum water pH maintenance system and preventive maintenance system. The four subsystems where developed separately and then integrated to form the desired optimum water quality maintenance system for warmwater fish culture. Each of subsystems was developed via designing and simulation, calibration and validation of sensors, hardware implementation and software development. Top down design approach was adopted in designing the system hardware and program while bottom up design approach was adopted in designing application for the system.

The hardware design was tested by simulation of the circuit diagrams of the subsystems while the program was tested by compilation and the app was tested by simulation using companion software.

The subsystems' sensors were calibrated and validated before being used for implementing the hardware system to ensure that the values reported by them are accurate. The hardware of each of the four subsystems of the smart system for optimum water quality maintenance was constructed based on their designs. The software was implemented by loading the developed program for each of the subsystems into the memory of the microcontroller and installing the developed PWQMR App on the Smartphone.

System tests were conducted after implementation of each of the subsystems and the complete system. Components and unit tests were also conducted during the implementation of the subsystems.

CHAPTER FOUR

RESULTS AND DISCUSSION

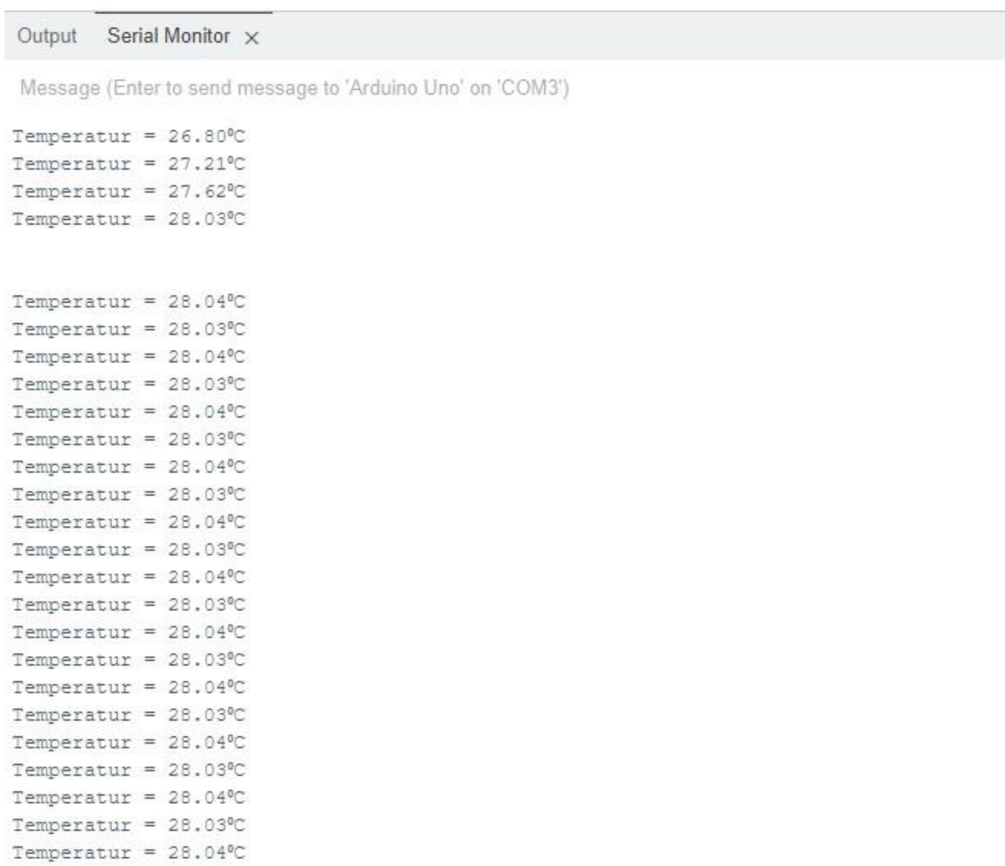
4.1 Results

The results of all the tests conducted in section 3.9 are presented in this section. They include optimum pond water temperature maintenance results, optimum pond water DO maintenance results, optimum pond water pH maintenance results, preventive maintenance result and optimum pond water quality maintenance result.

4.1.1 Optimum pond water temperature maintenance test result

First result

The pond water temperature levels during first optimum pond water temperature maintenance test are as shown in plate 4.1.



```
Output    Serial Monitor ×
Message (Enter to send message to 'Arduino Uno' on 'COM3')
Temperatur = 26.80ºC
Temperatur = 27.21ºC
Temperatur = 27.62ºC
Temperatur = 28.03ºC


Temperatur = 28.04ºC
Temperatur = 28.03ºC
Temperatur = 28.04ºC
Temperatur = 28.03ºC
Temperatur = 28.04ºC
Temperatur = 28.03ºC
Temperatur = 28.04ºC
Temperatur = 28.03ºC
Temperatur = 28.04ºC
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Temperatur = 28.03ºC
Temperatur = 28.04ºC
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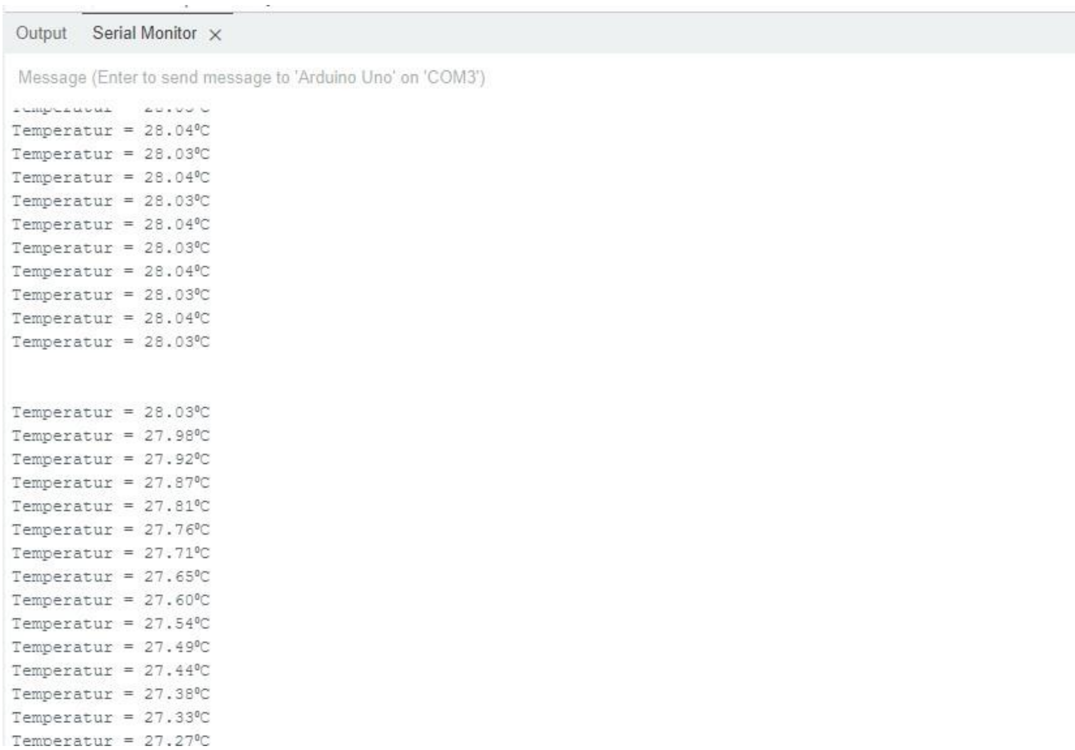


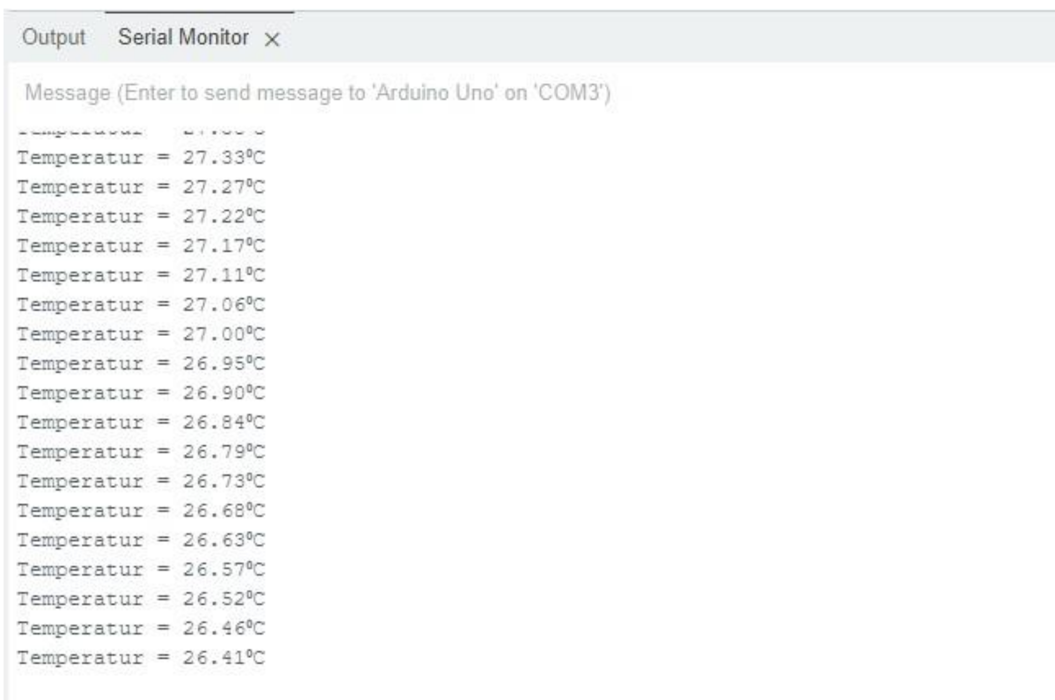


Plate 4.1: Temperature levels during first test

The screenshots of pond water temperature values/levels displayed on the LCD of the Serial Monitor of the IDE every 1minute during first optimum pond water temperature maintenance test showed that the initial temperature level was 26.80^{o}C, the highest level was 28.00^{o}C and the final level was 26.41^{o}C. The graph of pond water temperature variation during first optimum pond water temperature maintenance test was draw using Microsoft Excel and is as shown in Plate 4.2.

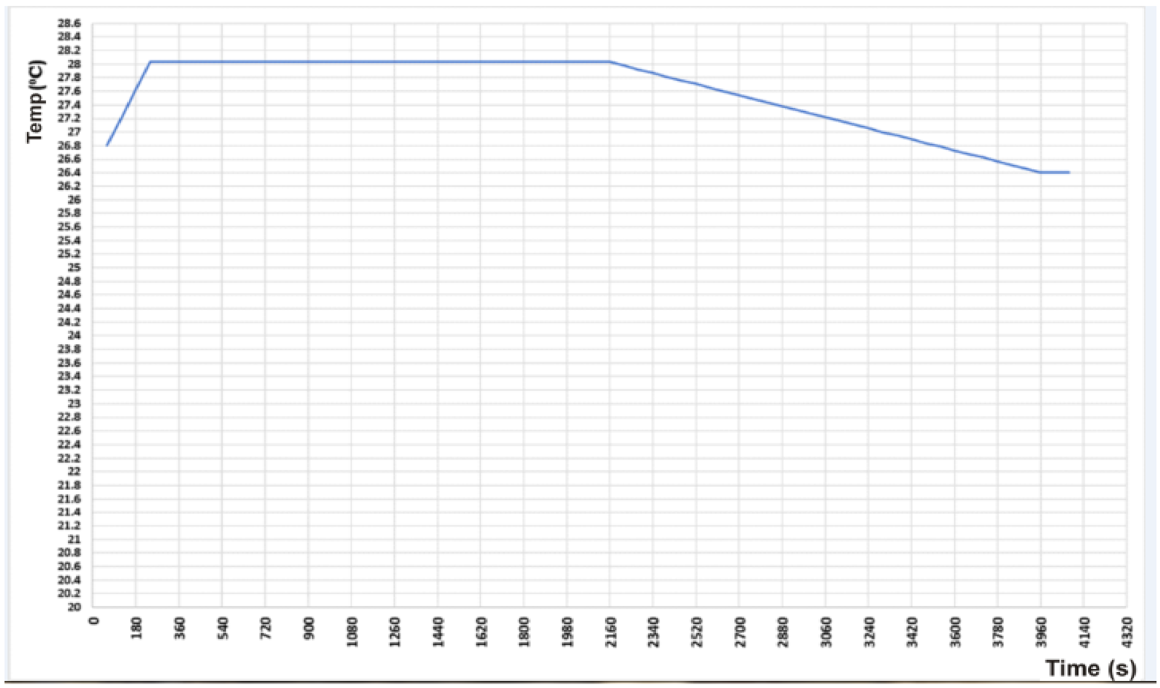


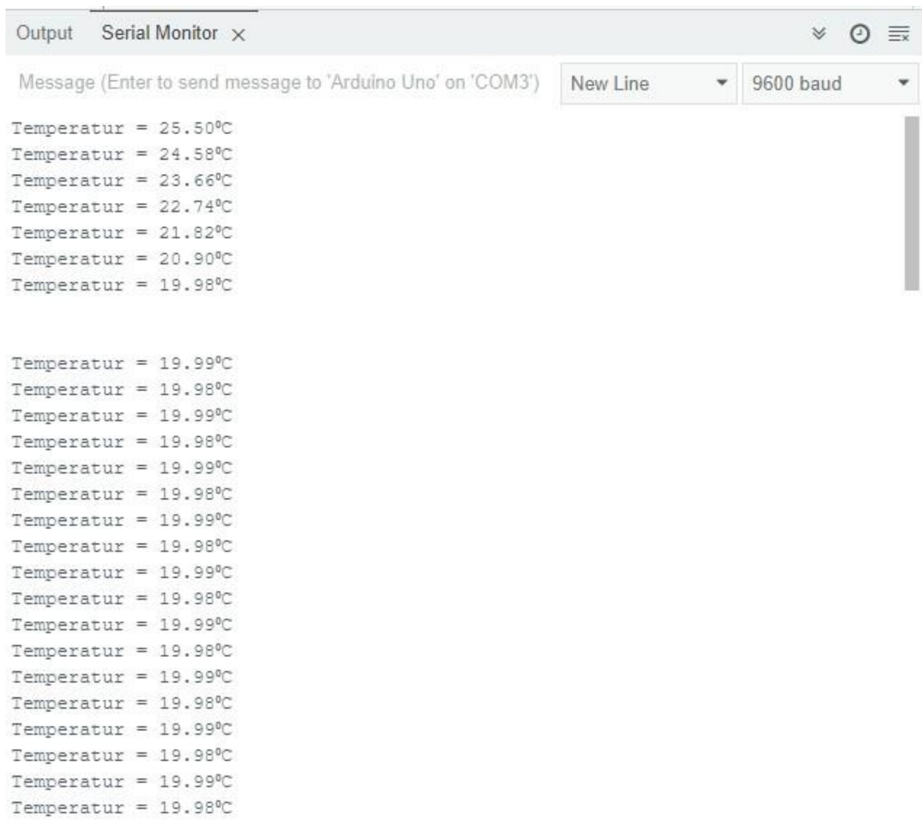
Plate 4.2: Temperature variation during first test

The pond water temperature was 26.80^{o}C initially, rose to 28.00^{o}C after about 3 minutes and remained at this level for about 32 minutes before falling. The pond water temperature fell to its lowest level of 26.41^{o}C (normalized level) after about 30minutes.

In addition to the result of the LCD of the Serial Monitor, the physical LCD displayed the temperature value, smart phone provided notification on pond water temperature condition and the upper water outlet discharged 20% of pond water through valve 3 of figure 3.10 when temperature rose to 28.00^{o}C. The system then refilled the pond with cool water through cool water inlet via valve 1 of figure 3.10.

Second result

The pond water temperature levels during second optimum pond water temperature maintenance test are shown in Plate 4.3.



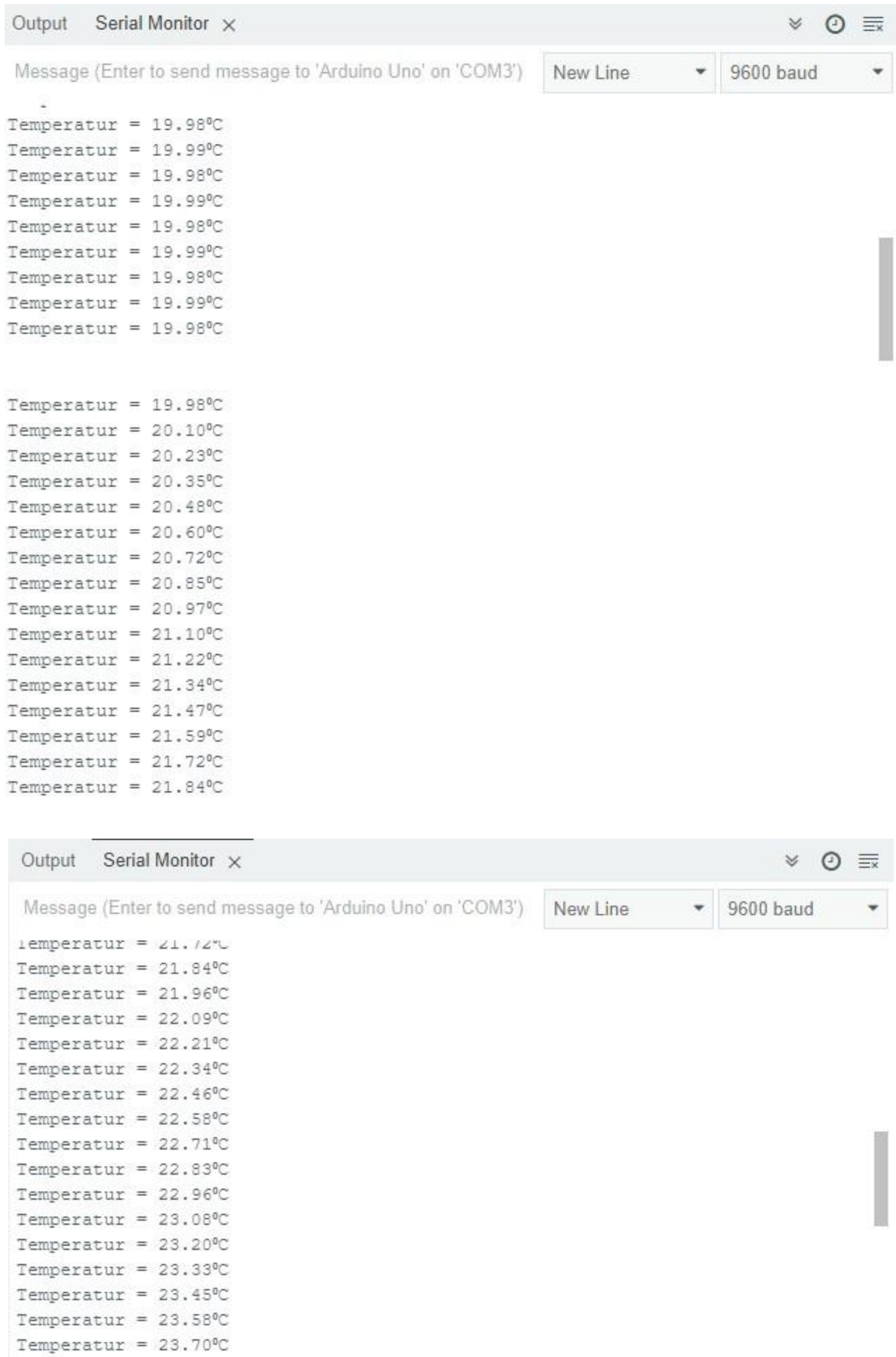


Plate 4.3: Temperature levels during second test

The screenshots of pond water temperature values/levels displayed on the LCD of the Serial Monitor of the IDE every 1minute during second optimum pond water temperature maintenance test showed that the initial temperature level was 25.50°C, the lowest level was 19.98°C and the final level was 23.70°C. The graph of pond water temperature variation during second optimum pond water temperature maintenance test is as shown in Plate 4.4.

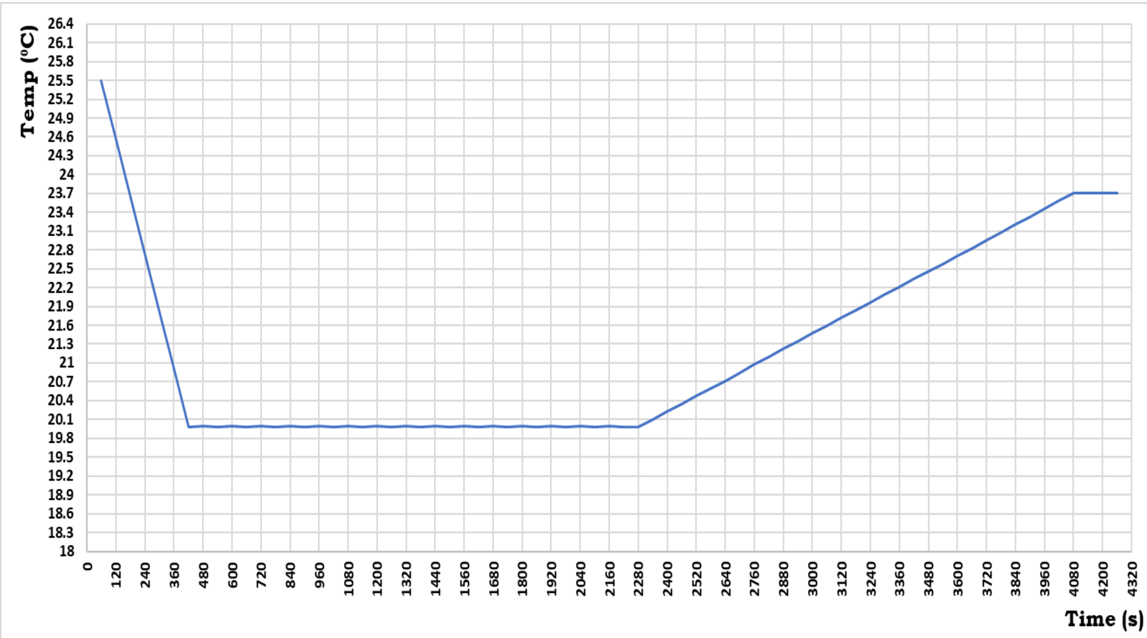


Figure 4.4: Temperature variation during second test

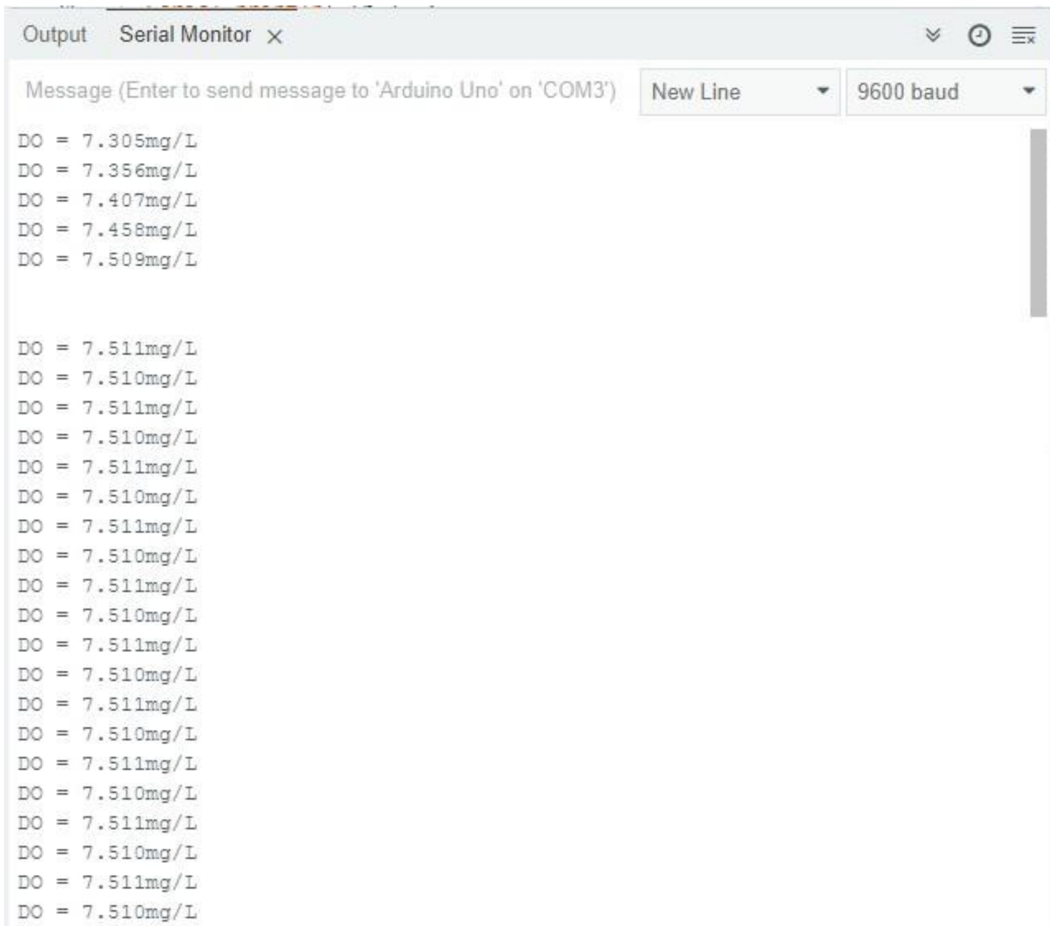
The pond water temperature was 25.50°C initially, fell to 19.98°C after about 6 minutes and remained at this level for about 31 minutes before rising. The pond water temperature started rising and reached 23.70°C (normalized level) after about 30 minutes.

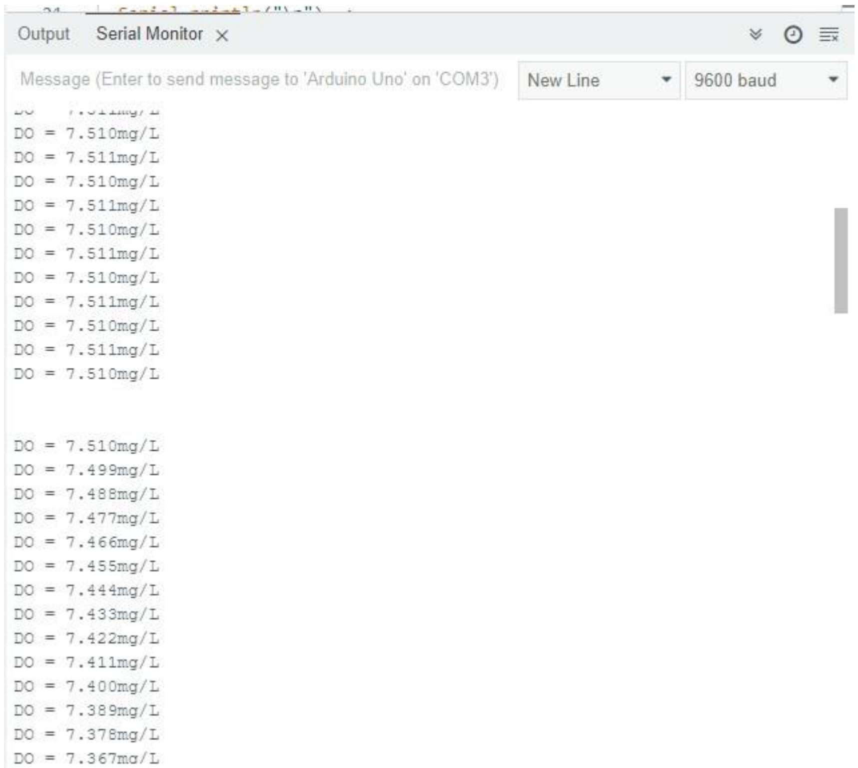
In addition to the result of the LCD of the Serial Monitor, the physical LCD displayed the temperature value, smart phone provided notification on pond water temperature condition and the lower water outlet discharged 20% of pond water through valve 2 of figure 3.10 when temperature rose to 28.00°C. The system then refilled the pond with cool water through cool water inlet via valve 1 of figure 3.13.

4.1.2 Optimum pond water DO maintenance test result

First result

The pond water DO levels during first optimum pond water DO maintenance test are shown in Plate 4.5.





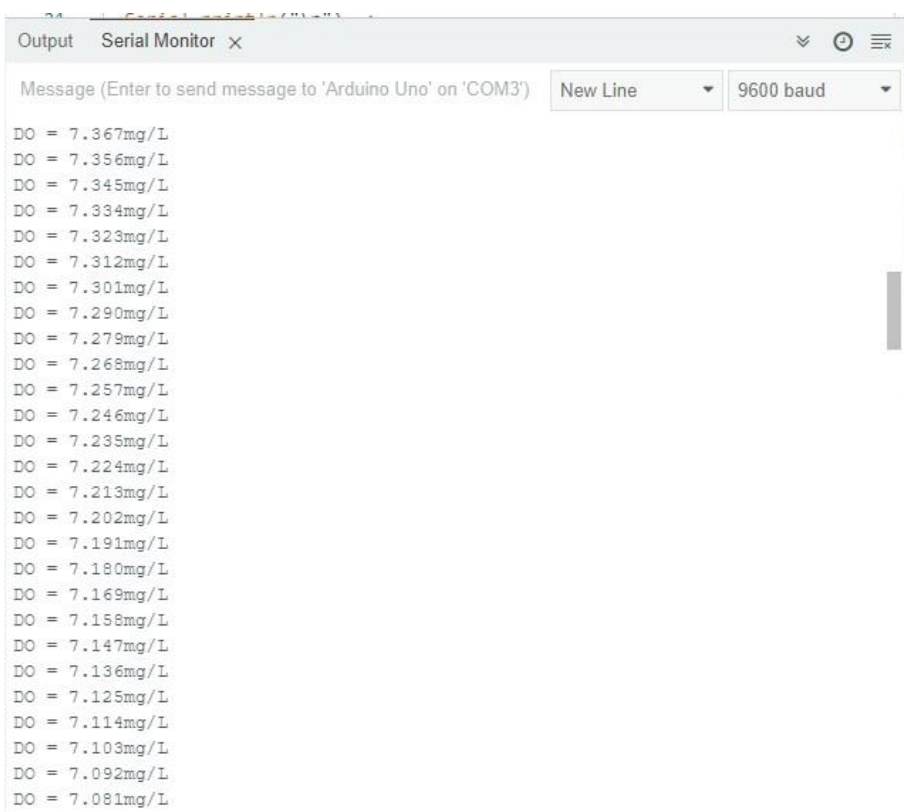


Plate 4.5: DO Levels during first test

The screenshots of pond water DO values/levels displayed on the LCD of the Serial Monitor of the IDE every 1minute during first optimum pond water DO maintenance test showed that the initial DO level was 7.3mg/L, the highest level was 7.5mg/L and the final level was 7.1mg/L. The graph of pond water DO variation during first optimum pond water DO maintenance test is shown in figure 4.3.

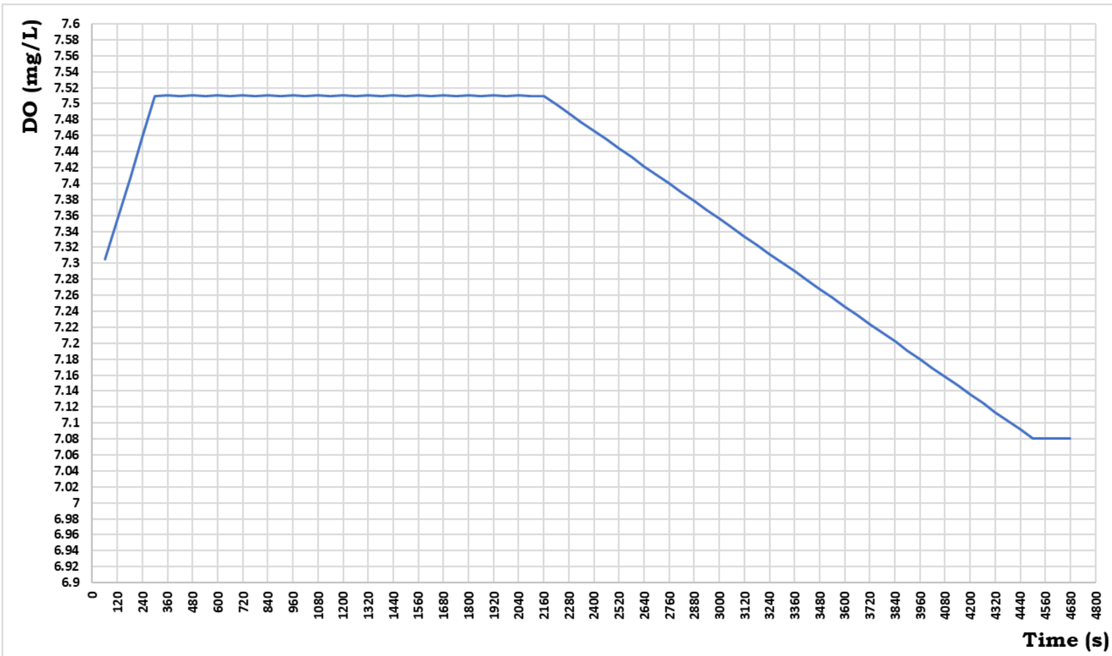


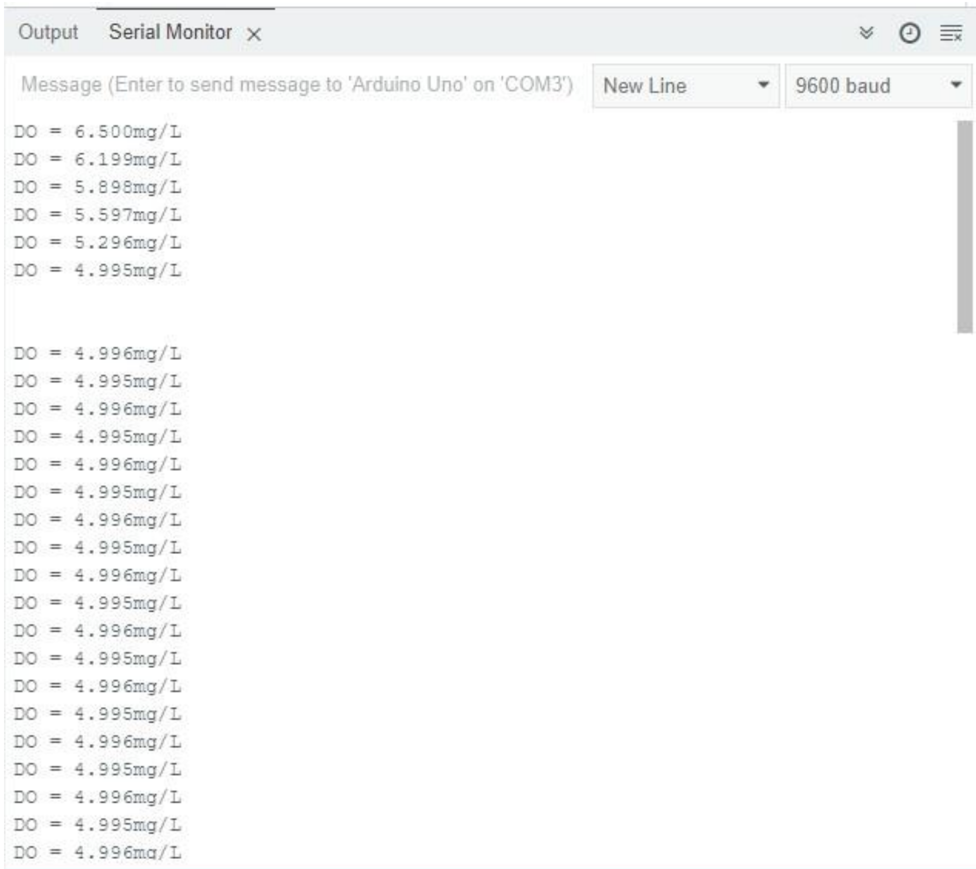
Plate 4.6: DO Variation during first test

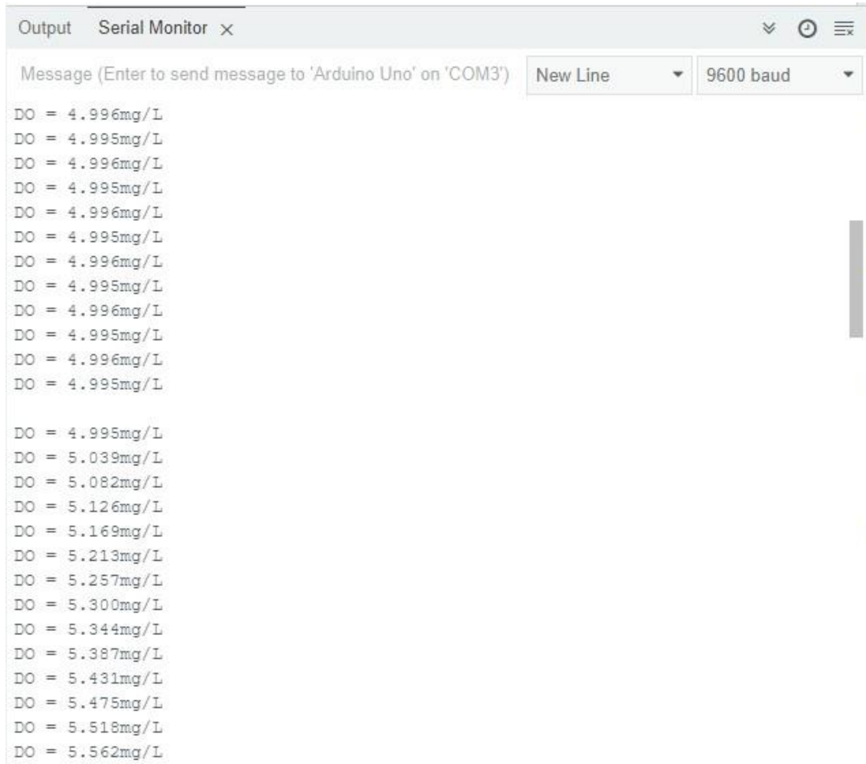
The pond water DO was 7.3mg/L initially, rose to 7.5mg/L after about 4 minutes and remained at this level for about 31 minutes before falling. The pond water DO fell to its lowest level of 7.1mg/L (normalized level) after about 39 minutes.

In addition to the result of the LCD of the Serial Monitor, the physical LCD displayed the DO level, smart phone provided notification on pond water DO condition and the upper water outlet discharged 20% of pond water through valve 3 of figure 3.13 when DO rose to 7.5mg/L. The system then refilled the pond with warm water through warm water inlet via valve 4 of figure 3.13.

Second result

The pond water DO levels during second optimum pond water DO maintenance test are shown in Plate 4.7.





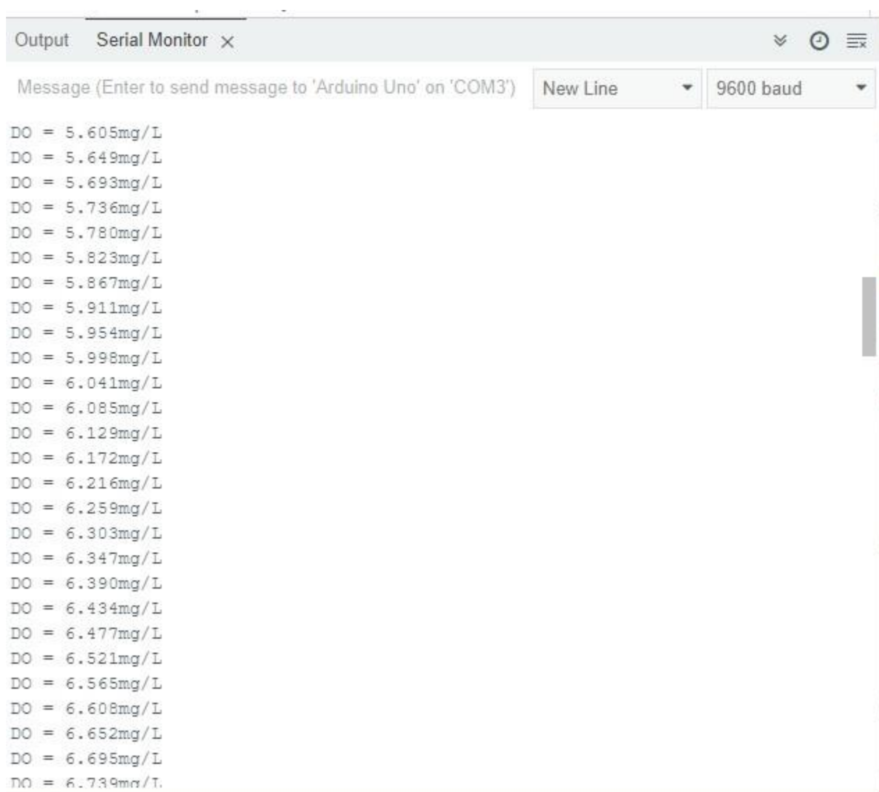


Plate 4.7: DO levels during second test

The screenshots of pond water DO values/levels displayed on the LCD of the Serial Monitor of the IDE every 1minute during second optimum pond water DO maintenance test showed that the initial DO level was 6.5mg/L, the lowest level was 5mg/L and the final level was 6.7mg/L**.** The graph of pond water DO variation during second optimum pond water DO maintenance test is shown in Plate 4.8.

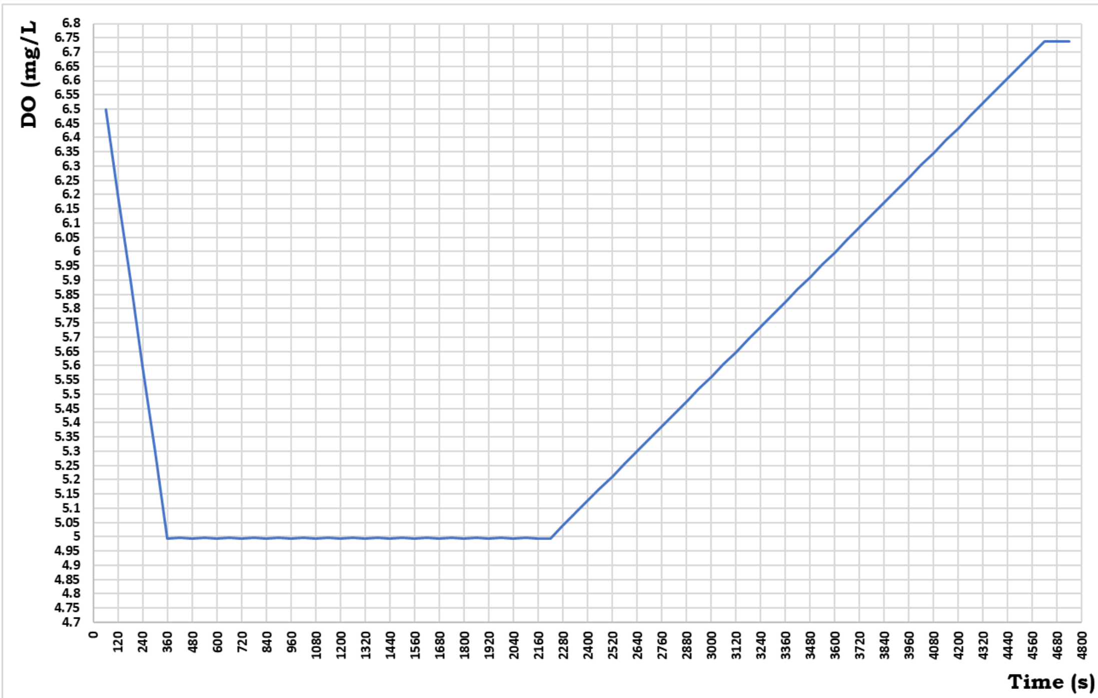


Figure 4.8: DO variation during second test

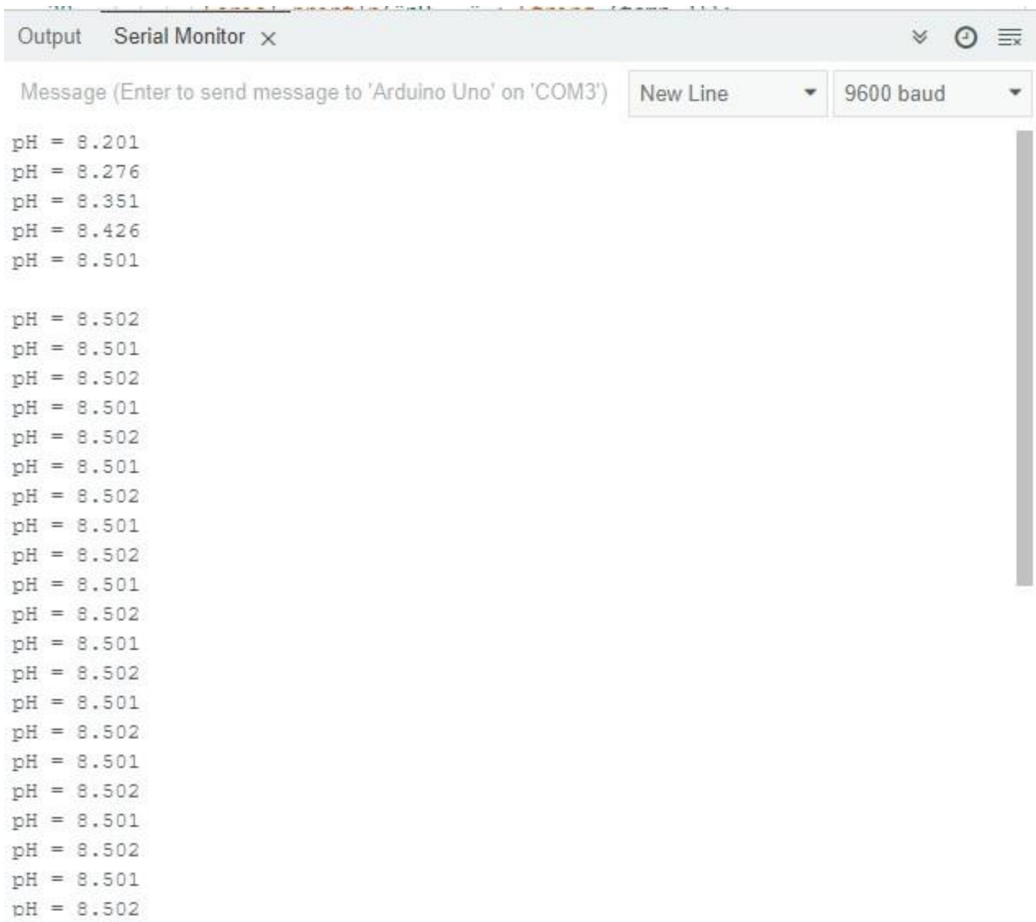
The pond water DO was 6.5mg/L initially, fell to 5mg/L after about 5 minutes and remained at this level for about 31 minutes before rising. The pond water DO started rising and reached 6.7mg/L (normalized level) after about 40 minutes.

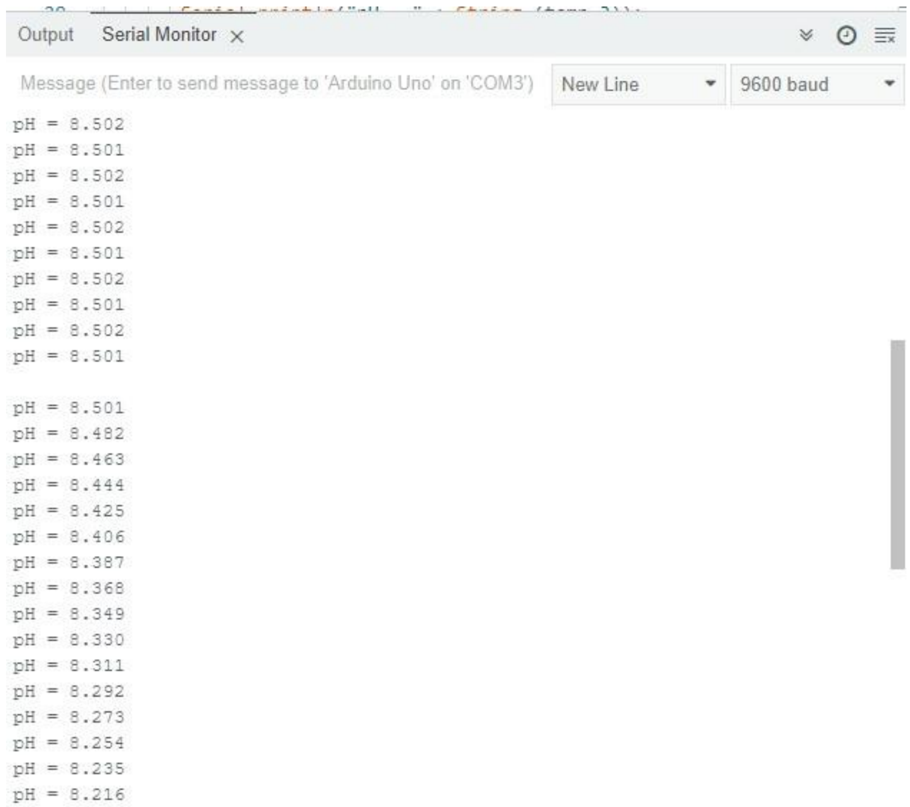
In addition to the result of the LCD of the Serial Monitor, the physical LCD displayed the DO level, smart phone provided notification on pond water DO condition and the lower water outlet discharged 20% of pond water through valve 2 of figure 3.13 when DO fell to 5mg/L. The system then refilled the pond with cool water through cool water inlet via valve 1 of figure 3.16.

4.1.3 Optimum pond water pH maintenance test result

First result

The pond water pH levels during the first optimum pond water pH test are shown in screenshots of Plate 4.9.





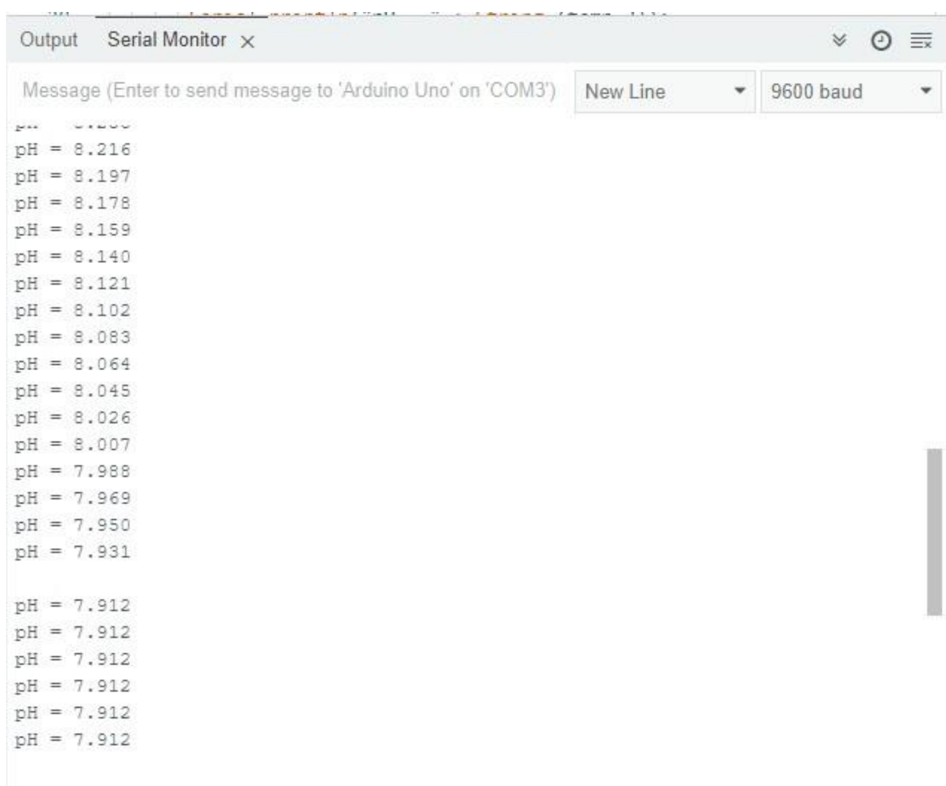


Plate 4.9: pH levels during first test

The screenshots of pond water pH values/levels displayed on the LCD of the Serial Monitor of the IDE every 1minute during first optimum pond water pH maintenance test showed that the initial pH level was 8.2, the highest level was 8.5 and the final level was 7.9 (constant level). The graph of pond water pH variation during first optimum pond water pH maintenance test is shown in Plate 4.10.

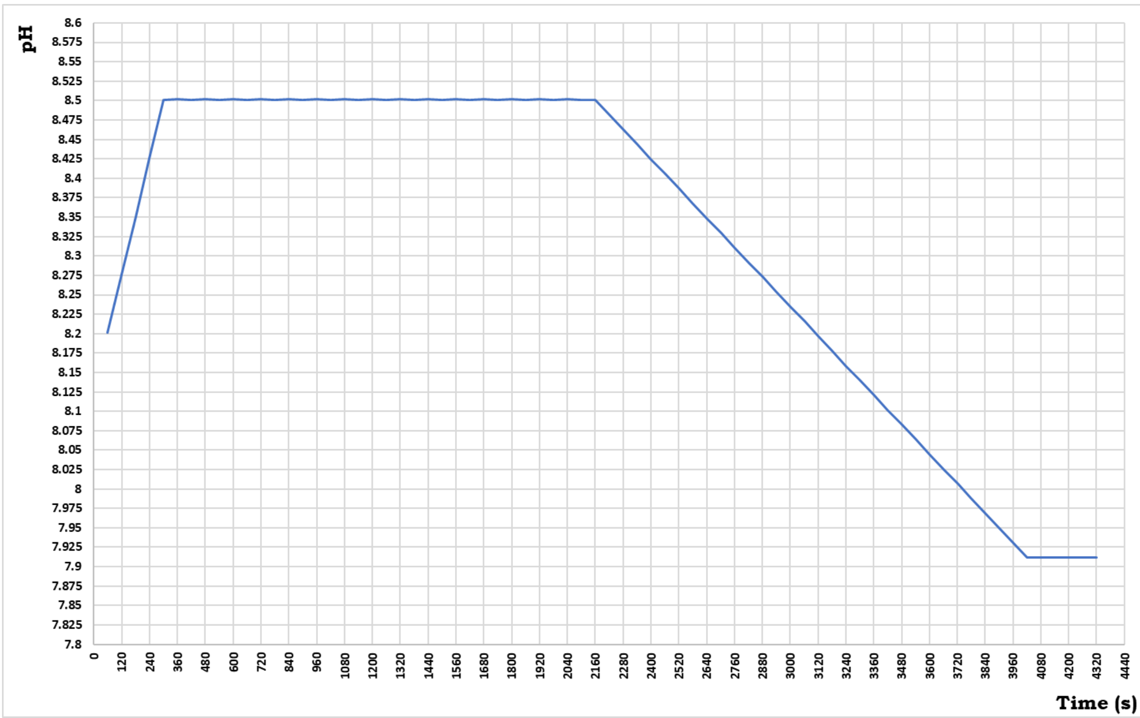


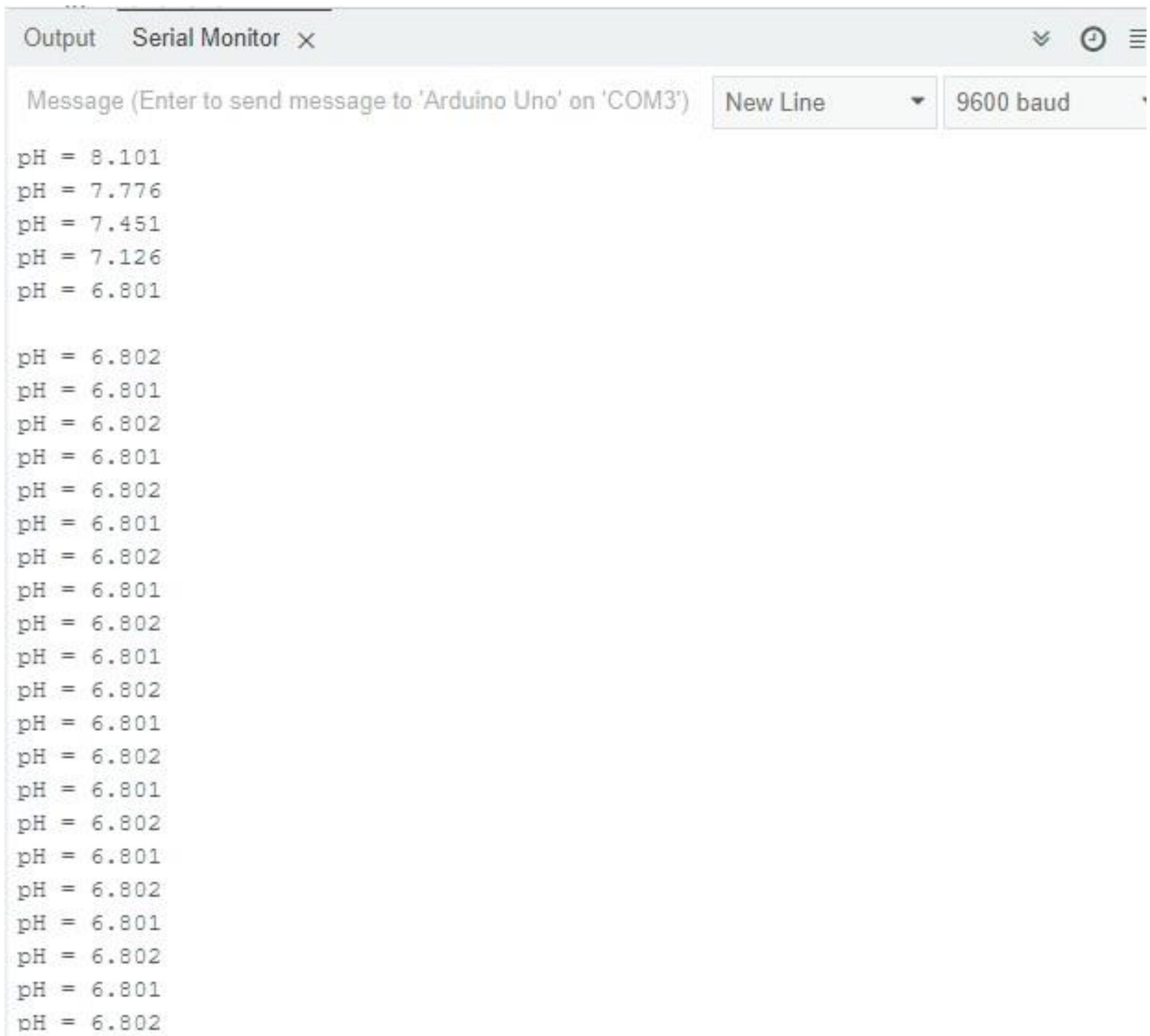
Plate 4.10: pH variation during first test

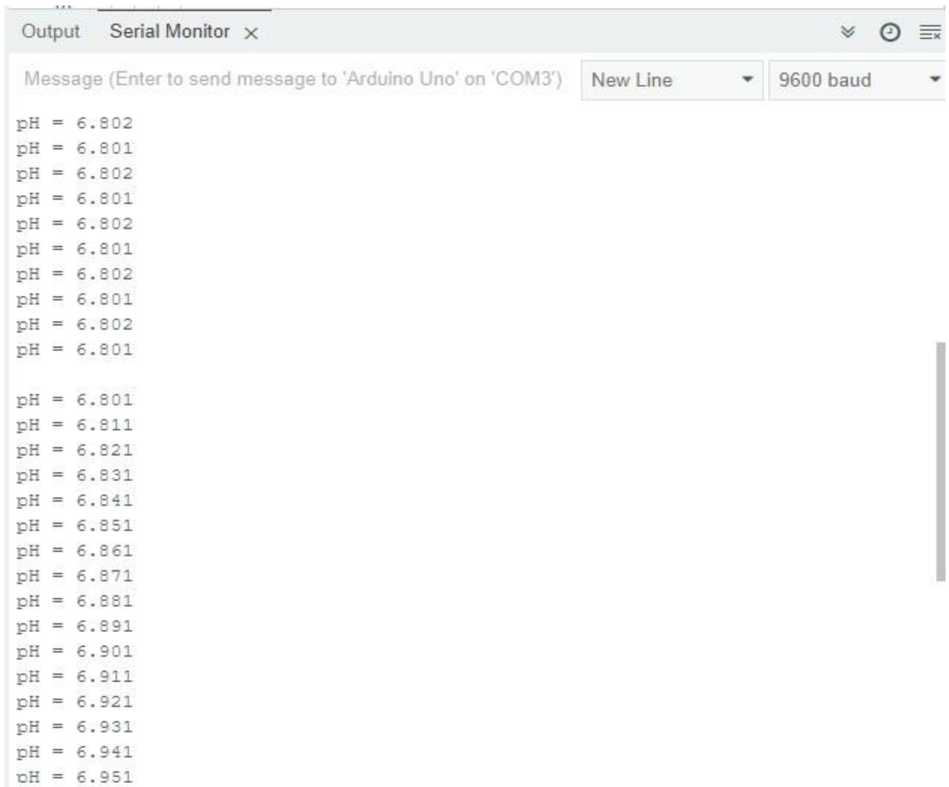
The pond water pH was 8.2 initially, rose to 8.5 after about 4 minutes and remained at this level for about 31 minutes before falling. The pond water pH fell to 7.9 (normalized level) after about 32minutes.

In addition to the result of the LCD of the Serial Monitor, the physical LCD displayed the pH level, smart phone provided notification on pond water pH condition and the lower water outlet discharged 20% of pond water through valve 2 of figure 3.16 when pH rose to 8.5. The system then refilled the pond with cool, oxygenated water through cool water inlet via valve 1 of figure 3.16.

Second result

The pond water pH levels during the second optimum pond water pH maintenance test are shown in Plate 4.11.





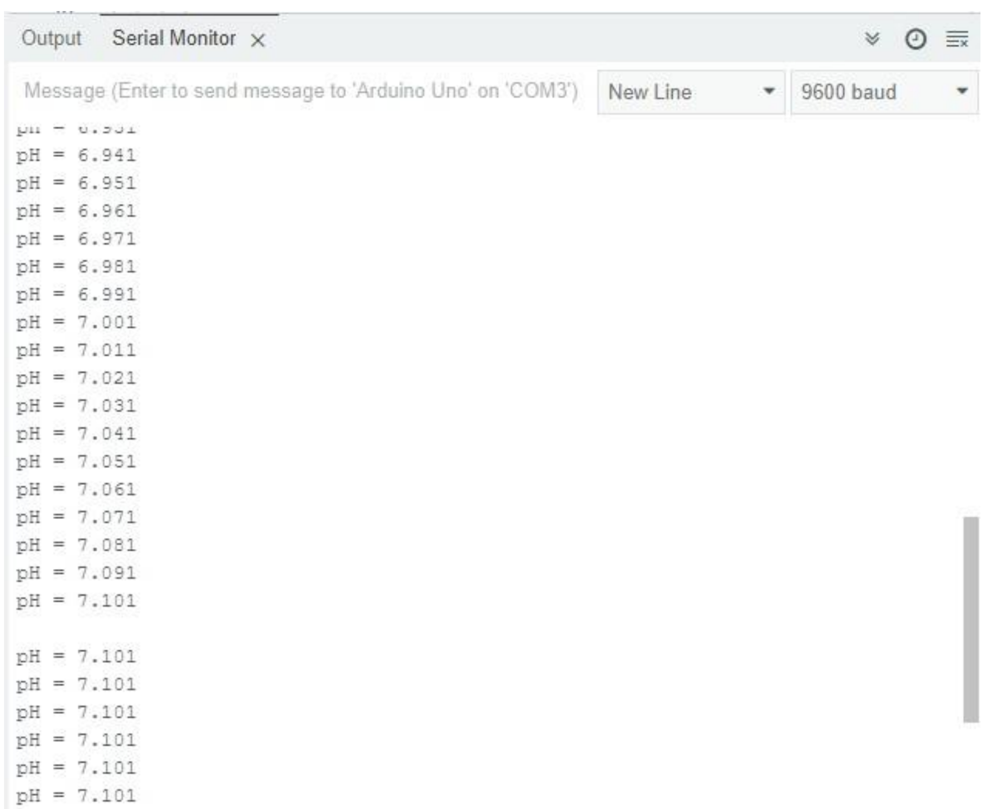


Plate 4.11: pH levels during second test

The screenshots of pond water pH values/levels displayed on the LCD of the Serial Monitor of the IDE every 1minute during second optimum pond water pH maintenance test showed that the initial pH level was 8**.**1, the lowest level was 6.8 and the final level was **7**.1. The graph of pond water pH variation during second optimum pond water pH maintenance test is shown in Plate 4.12.

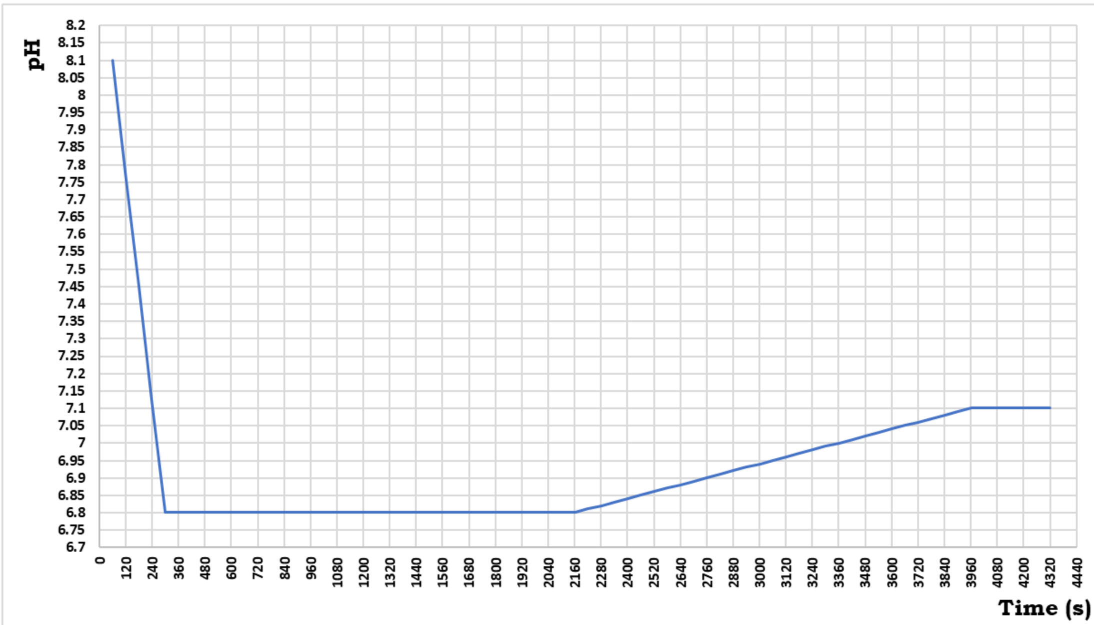


Plate 4.12: pH variation during second test

The pond water pH was 8.1 initially, fell to 6.8 after about 4 minutes and remained at this level for about 31 minutes before rising. The pond water pH rose to 7.1 (normalized level) after about 30minutes.

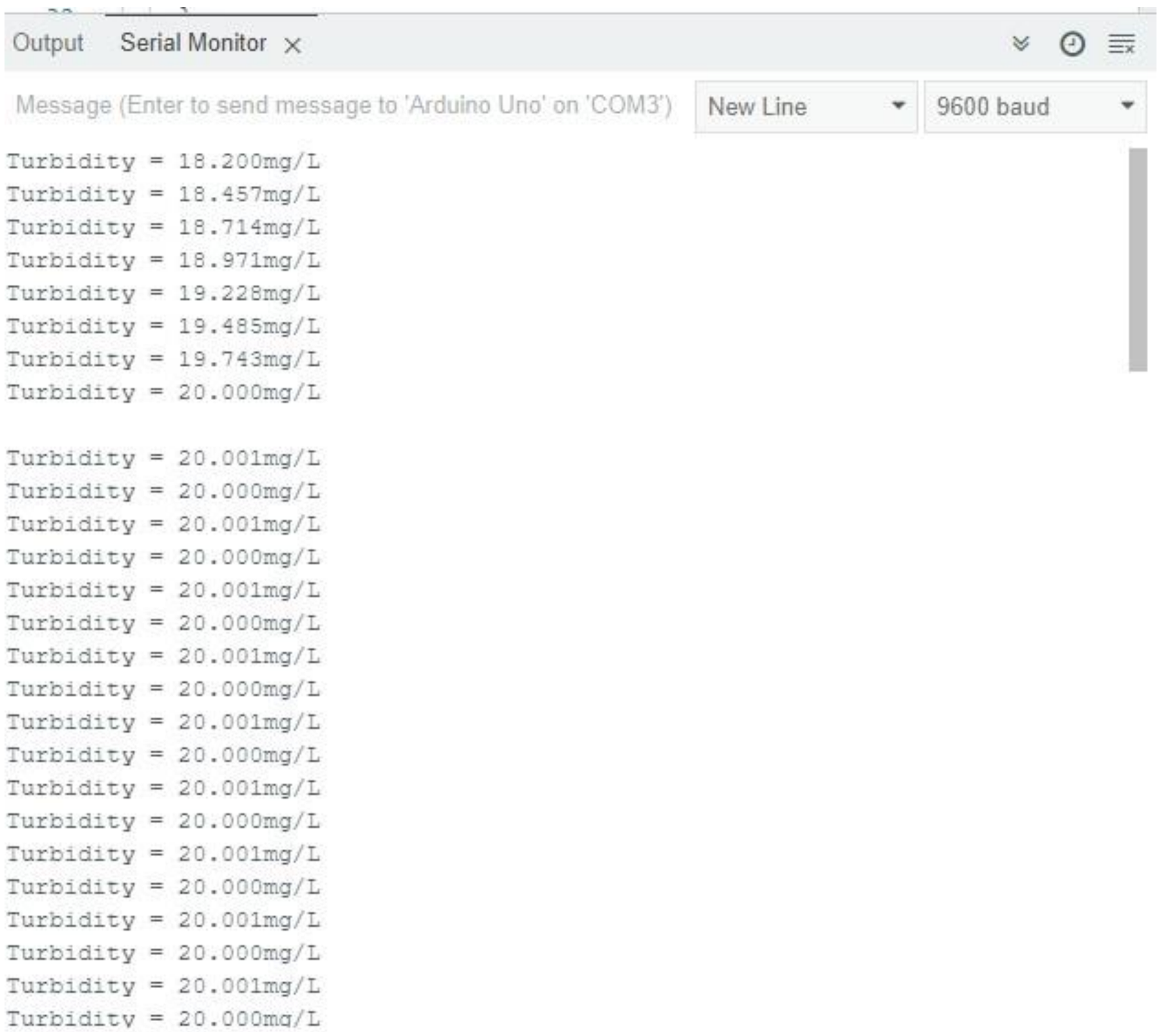
In addition to the result of the LCD of the Serial Monitor, the physical LCD displayed by the pH level, smart phone provided notification on pond water pH condition and the lower water outlet discharged 20% of pond water through valve 2 of figure 3.16 when pH fell to 6.8. The system then refilled the pond with cool, oxygenated water through cool water inlet via valve 1 of figure 3.19.

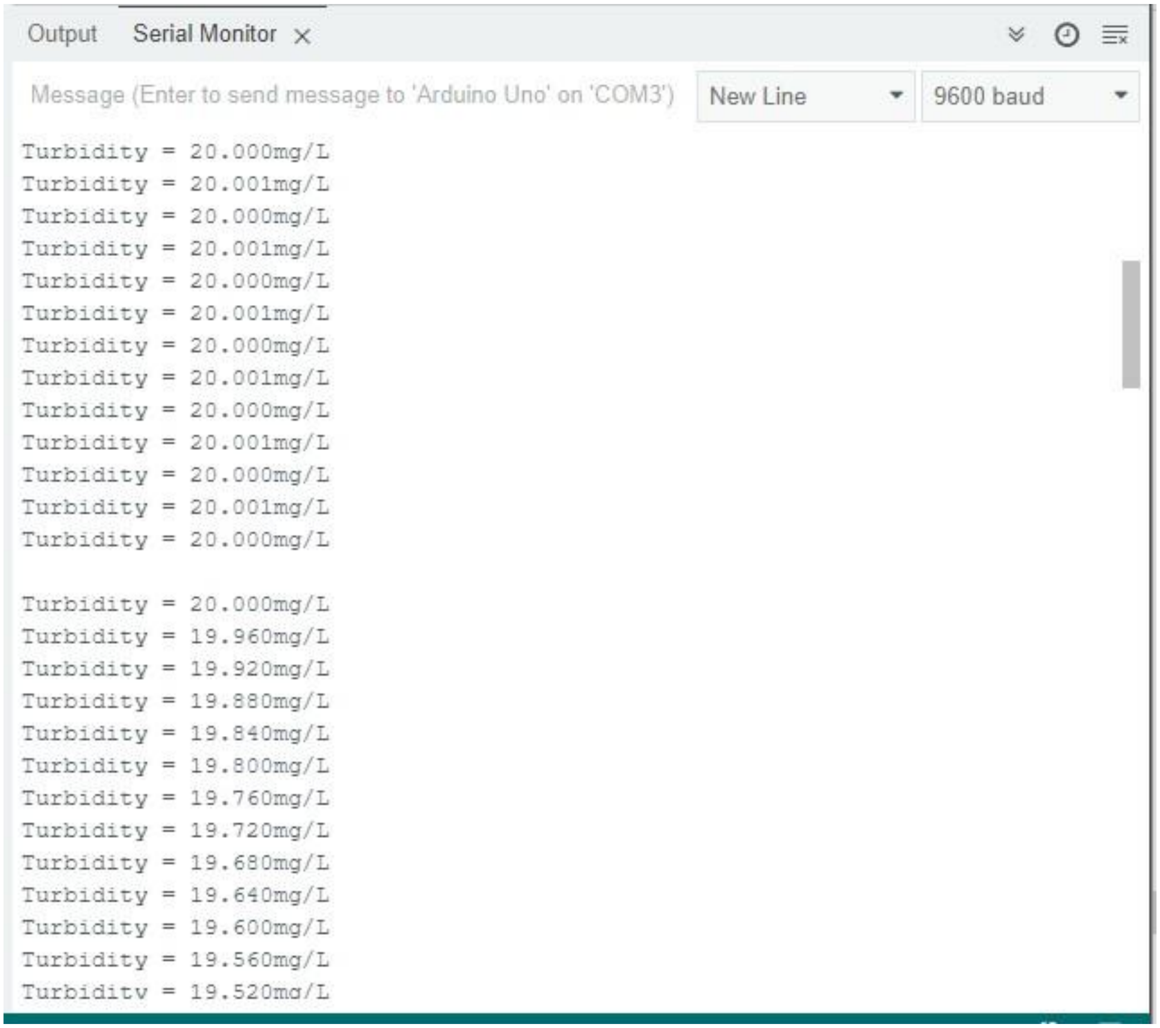
4.1.4 Preventive maintenance test result

(a) Optimum pond water turbidity maintenance test result

First result

The pond water turbidity levels during first optimum pond water turbidity test are shown in screen shot of Plate 4.13.




Output
Serial Monitor
Message (Enter to send message to 'Arduino Uno' on 'COM3')
New Line
9600 baud
Turbidity = 20.000mg/L
Turbidity = 20.001mg/L
Turbidity = 20.000mg/L
Turbidity = 20.001mg/L
Turbidity = 20.000mg/L
Turbidity = 20.001mg/L
Turbidity = 20.000mg/L
Turbidity = 20.001mg/L
Turbidity = 20.000mg/L
Turbidity = 20.001mg/L
Turbidity = 20.000mg/L
Turbidity = 20.001mg/L
Turbidity = 20.000mg/L
Turbidity = 20.000mg/L
Turbidity = 19.960mg/L
Turbidity = 19.920mg/L
Turbidity = 19.880mg/L
Turbidity = 19.840mg/L
Turbidity = 19.800mg/L
Turbidity = 19.760mg/L
Turbidity = 19.720mg/L
Turbidity = 19.680mg/L
Turbidity = 19.640mg/L
Turbidity = 19.600mg/L
Turbidity = 19.560mg/L
Turbidity = 19.520mg/L

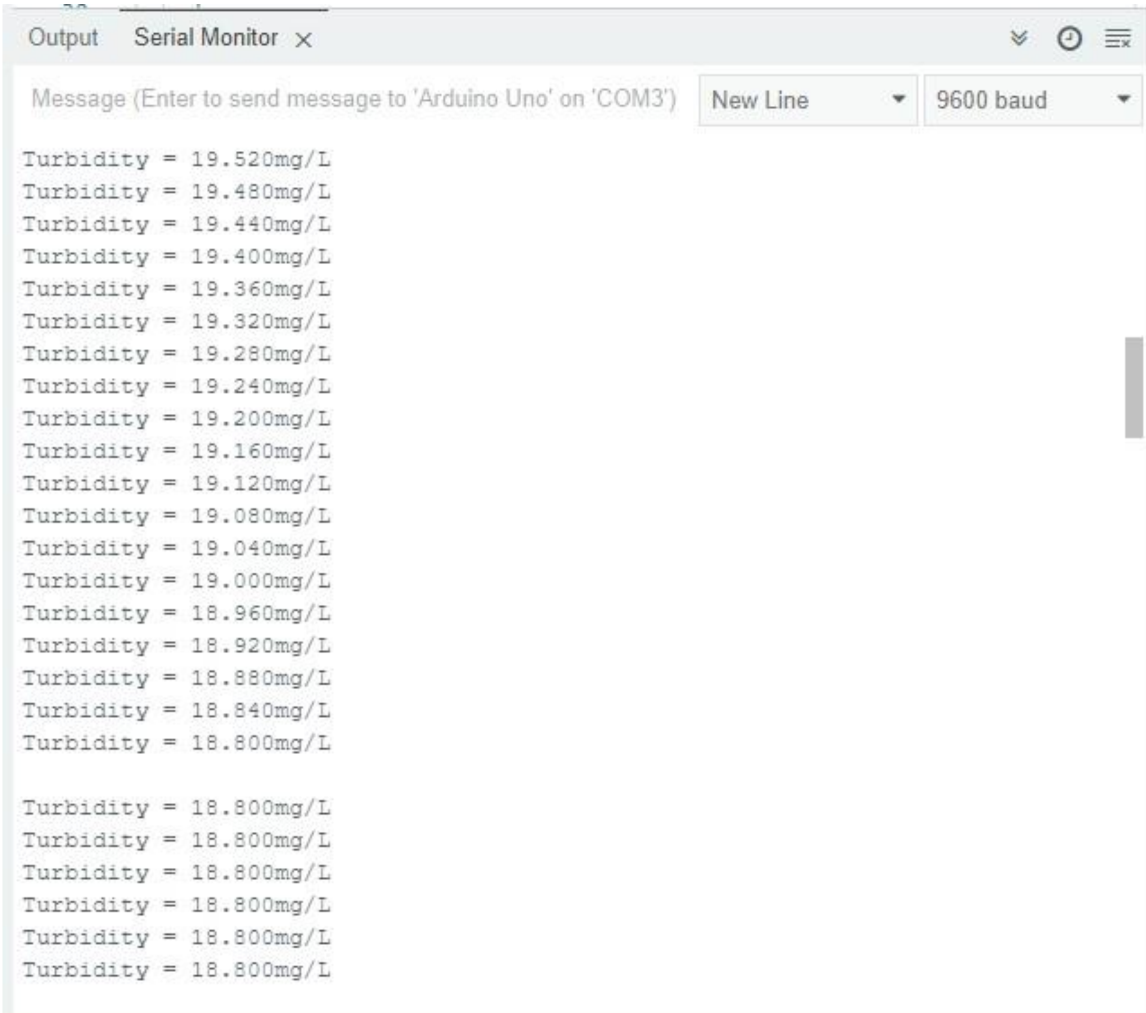


Plate 4.13: Turbidity levels during first test

The screenshots of pond water turbidity values/levels displayed on the LCD of the Serial Monitor of the IDE every 1minute during first optimum pond water turbidity maintenance test showed that the initial turbidity level was 18.2mg/L, the highest level was 20mg/L and the final level was 18.8mg/L**.** The graph of pond water turbidity variation during first optimum pond water turbidity maintenance test is shown in figure 4.7.

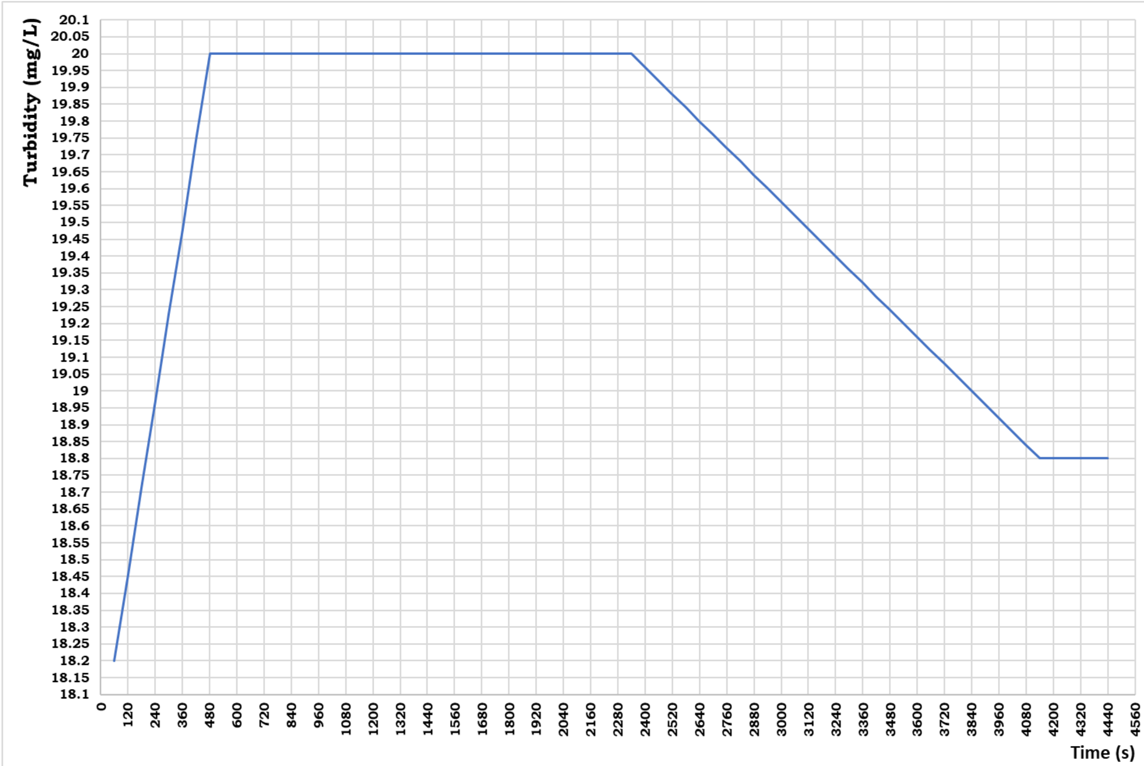


Plate 4.14: Turbidity variation during first test

The pond water turbidity was 18.2mg/L initially, rose to 20mg/L after about 7 minutes and remained at this level for about 31 minutes before falling. The pond water turbidity fell to 18.8mg/L (normalized level) after about 30 minutes.

In addition to the result from the Serial Monitor, the physical LCD displayed the turbidity level, smart phone provided notification on pond water turbidity condition and the lower water outlet discharged 20% of pond water through valve 2 of figure 3.19 when turbidity rose to 20mg/L. The system then refilled the pond with cool, oxygenated water through cool water inlet via valve 1 of figure 3.19.

Second result

The result of the second test showed that the system only displayed the turbidity level on physical LCD provided notification about pond water turbidity condition on smart phone when turbidity fell to lower optimum limit (10mg/L).

(b) Optimum water level maintenance test result

The pond water levels during first optimum pond water level test are shown in screen shot of Plate 4.15.

Plate 4.15: Water levels during first test

The screenshot of pond water values/levels displayed on the LCD of the Serial Monitor of the IDE every 1minute during first optimum pond water level maintenance test showed that the initial level was 119.4cmand the highest level was 120cm. The graph of pond water levels during first optimum pond water level maintenance test is shown in Plate 4.16.

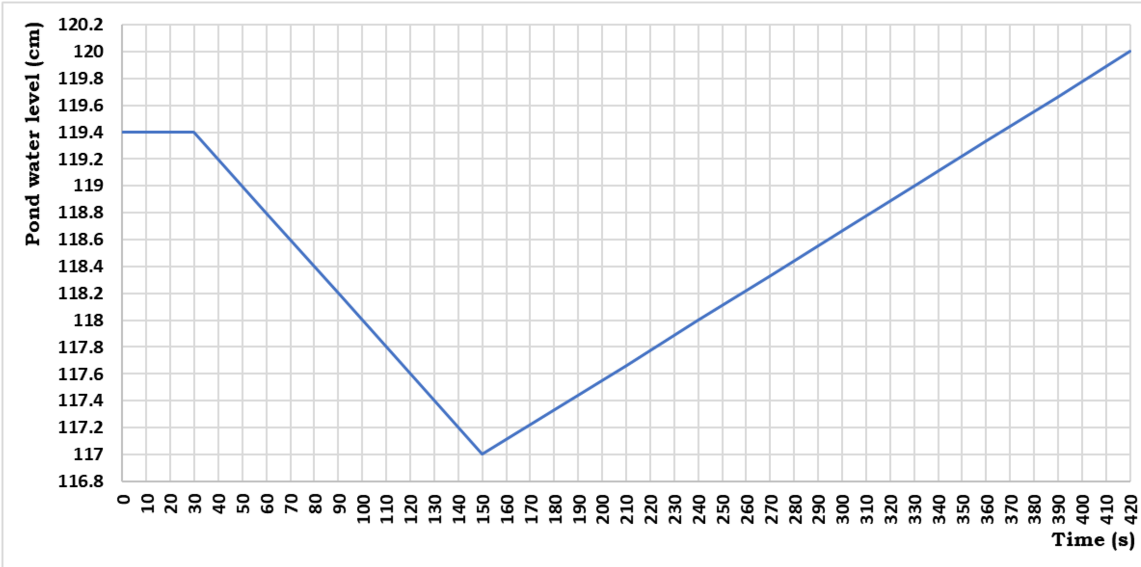


Plate 4.16: Water level variation during test

The pond water level was 119.4cm initially, remained at this level for 1 minute, fell to 117cm after 150 seconds and rose to 120cm (normalized level) after about 270 seconds (four and half minutes).

In addition to the result from the Serial Monitor, the physical LCD displayed the water level, smart phone provided notification on pond water level condition and the system refilled the pond with cool, oxygenated water through cool water inlet via valve 1 of figure 3.19.

(c) Sun radiation and wind control test result

(i) Sun radiation control test result

The sample temperature used in place of air temperature was 26.3^{o}C initially and rose to 28.00^{o}C before the system took preventive action. When the temperature reached 28.00^{o}C, LCD of the Serial Monitor of the IDE displayed the temperature value/level, **t**he physical LCD displayed the temperature level, smart phone provided notification on air temperature condition, the sun radiation and wind control system set sun shade and then the microcontroller sensed turbidity. The snapshot of the Smartphone app notification for 28^{o}C air temperature level is shown in Plate 4.17.

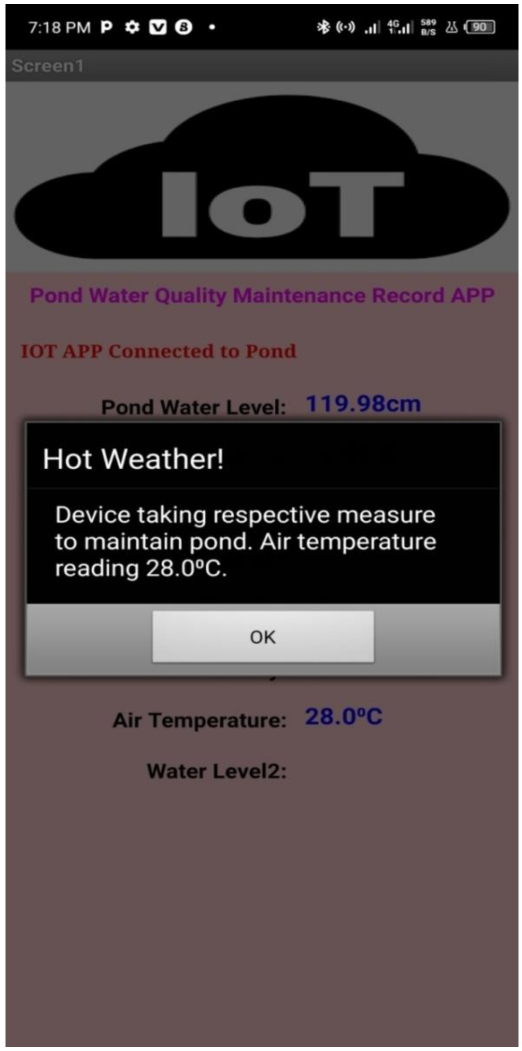


Plate 4.17: Screenshot of 28.00^{o}C air temperature notification

(ii) Wind control test result

In this test, the sample temperature used in place of air temperature was 23.50^{o}C initially and fell to 20.00^{o}C before the system took preventive action. When the temperature reached 20.00^{o}C, the Serial Monitor displayed the temperature value/level, **t**he physical LCD displayed the temperature level, smart phone provided notification on air displayed condition, and the sun and wind control system set windbreak and then the microcontroller sensed turbidity.

4.1.5 Optimum pond water quality maintenance test result

The result of optimum pond water quality maintenance showed that turbidity reached its upper optimum limit of 20mg/L on February 6, 2023. When turbidity reached 20mg/L, the LCD displayed the turbidity value, smart phone received the pond turbidity information and the lower water outlet discharged 20% of pond water from valve 2 of figure of figure 3.7 and the upper cool water inlet with perforate screen refilled the pond via valve 1. The water replacement process for maintaining optimum pond water turbidity after discharging 20% of the bottom dirty water is as shown in screenshot of Plate 4.18.

Plate 4.18: Pond water replacement process

The air temperature reached its upper optimum limit of 28^{o}C on February 12, 2023 afternoon. When air temperature reached 28^{o}C, the LCD displayed the temperature value, smart phone received the pond temperature information and the sun shade was set. The notification received by the smart phone for the air temperature condition is as shown in screenshot of Plate 4.17.

The result also showed that the pond water level dropped on March 7, 2023. When water level dropped, the LCD displayed the level, smart phone provided notification and the cool water inlet poured water into the pond until level reached 1.2m. The notification received by the smart phone for the drop in water level (from 1.20m to 1.17m) is as shown in screenshot of Plate 4.19.

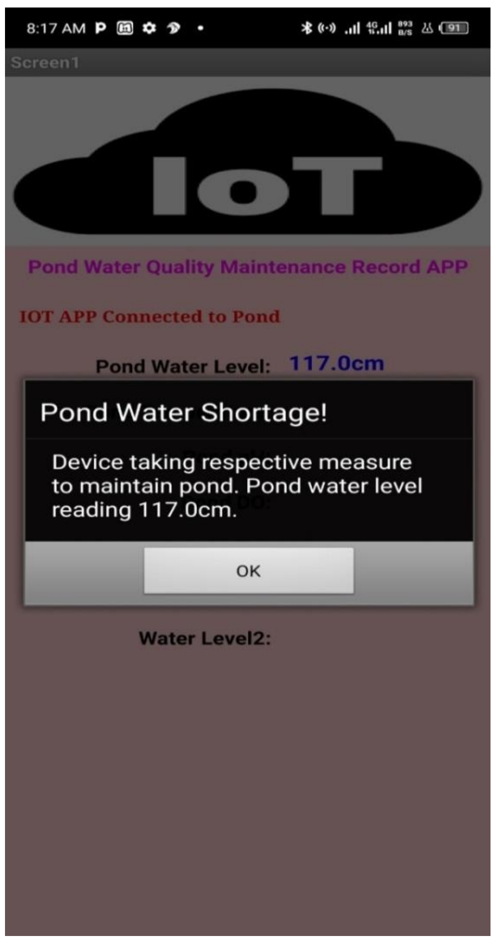


Plate 4.19: Screenshot of pond water 117cm level notification

4.2 Discussion

The results of all the tests conducted in section 3.9 are discussed in this section. The results discussed include optimum water temperature maintenance, optimum water DO maintenance test result, optimum water pH maintenance, preventive maintenance test result and optimum water quality maintenance test results.

4.2.1 Discussion of optimum water temperature maintenance test result

First result

The result of the first test on optimum pond water temperature maintenance showed that when the pond water rose to of 28^oC, the system displayed the temperature value on LCD, sent pond water temperature information to smart phone via app and discharged 20% of the upper pond water in 30 minutes and refilled the pond with cooler water through perforated screen via valve 1 in 30 minutes. The pond water temperature fell to its lowest level of 26.4^oC (normalized level) after about 30 minutes of refilling pond. The temperature variation is in line with the expected result because it takes the system 30 minutes to discharge 20% of its water and another 30 minutes to replenish the 20% lost water. The calculated flow rate of the inlet with perforated screen was 1.54m^3/h which is equivalent to 0.757m^3/30min. The 0.757m^3/30min flow rate fills the 20% (2m x 1.6m x 0.24m) of pond water in 30 minutes. It took the pond water temperature 2 minutes into refilling of pond to start falling and 30 minutes to normalize.

This first pond water temperature maintenance result is in line with the expected result. The system reduced temperature from 28^oC to between 20^oC and 28^oC by mixing 80% of pond water at 28^oC (warmer water) with 20% cool, more oxygenation water. While the pond water is mixed by water wave caused by water from the fountain, oxygenation produced by fountain helps in adding oxygen to the pond water (simple aeration) to ensure that oxygen that may have reduced because of the 28^oC temperature level is replenished. In addition, adding water from borehole to pond in order to reduce water temperature is proper because groundwater is cooler than pond water (Coche et al., 1996). In addition, the normalized temperature is maintained as the sun shade would be set at this temperature condition (28^oC).

Second result

The result of the second test on optimum pond water temperature maintenance showed that when the pond water rose to of 20^oC, the system displayed the temperature value on LCD, sent pond water temperature information to smart phone via app and discharged 20% of the bottom pond water in 30 minutes and refilled the pond with warmer water through valve 4 in 30 minutes. It took the pond water temperature 1 minute into refilling of pond to start rising and 30 minutes to normalize.

This second pond water temperature maintenance result is in line with the expected result. The system increased temperature of pond water from 20^oC to between 20^oC and 28^oC by mixing 80% of pond water at 20^oC (cooler water) with 20% warmer water. This action is effective as warming of pond water aids in normalizing ponds with low temperature **(**Kutty, 1987, Warish et al., 2017**)**.

The system performed the optimum pond water temperature maintenance efficiently in real time.

4.2.2 Discussion of optimum pond water DO maintenance test result

First result

The result of the first test on optimum pond water DO maintenance showed that when the pond water rose to 7.5mg/L, the system displayed the temperature value on LCD, sent pond water temperature information to smart phone via app and discharged 20% of the upper pond water in 30 minutes and refilled the pond with cooler water through perforated screen via valve 1 in 30 minutes. It took the pond water DO 1 minutes into refilling of pond to start falling and 39 minutes to normalize instead of 30 minutes.

This first pond water DO maintenance result is in line with the desired result. The system reduces DO from 7.5mg/L to between 5mg/L and 7.5mg/L by mixing 80% of pond water of 7.5mg/L DO with 20% warm water. While the pond water is mixed by water wave caused by water fall from the inlet, the warm water entering the pond causes low solubility of oxygen in water thereby reducing concentration of oxygen in the pond water (deoxygination). This action is effective as warming of pond water aids in normalizing ponds with high DO (Bhatnagar & Devi, 2013). The extra 9 minutes was the time taken for the DO to circulate properly in the pond.

Second result

The result of the second test on optimum pond water DO maintenance showed that when the pond water fell to 5.0mg/L, the system displayed the temperature value on LCD, sent pond water temperature information to smart phone via app and discharged 20% of the upper pond water in 30 minutes, refilled the pond with cooler water through perforated screen via valve 1 in 30 minutes. It took the pond water DO 40 minutes to normalize.

This result is in line with the desired result except for the little time delay. While oxygenated water produced by the fountain (inlet with perforated screen) via valve 1 helps in adding oxygen to the pond water or aerating the pond water (Coche et al., 1996), the pond water is mixed by water wave caused by water fall from the fountain. The extra 10 minutes was the time taken for the DO to circulate properly in the pond.

The system performed the optimum pond water dissolved oxygen maintenance efficiently.

4.2.3 Discussion of optimum pond water pH maintenance result

First result

The result of the first test on optimum pond water pH maintenance showed that the system displayed the pH value on LCD, sent pond water pH information to smart phone via app and discharged 20% of the pond water through the lower water outlet and refilled the pond with cool water through the cool water inlet (valve 1) when the pond water pH was about 8.5. The pond water pH fell to 7.9 (normalized level) just at the last second of refilling pond water. The pH variation is in line with the expected result because it takes the system 30 minutes to discharge 20% of its water and another 30 minutes to replenish the discharged 20% water.

Second result

The result of the second test on optimum pond water pH maintenance showed that the system displayed the pH value on LCD, sent pond water pH information to smart phone via app and discharged 20% of the pond water through the lower water outlet and refilled the pond with cool water through the cool water inlet (valve 1) when the pond water pH fell to 6.8. The pond water pH fell to 7.1 (normalized level) after about 30 minutes. The pH variation is in line with the expected result because it takes the system 30 minutes to discharge 20% of its water and another 30 minutes to replenish the 20% lost water.

The two test results are in line with the desired result. Exchanging portion of fish pond dirty water (bottom water) with clean, more oxygenated water helps in normalizing the pH level (Lynn, 2018). Adding water from borehole to pond through perforated screen as inlet with the help of wind helps in aerating the pond. Aeration removes CO_2 from pond and therefore aids in increasing pH which occur as a result of net addition of CO_2 in pond water while discharging 20% of bottom portion of pond water helps in reducing plankton turbidity of pond water which causes release of more CO_2 from their respiration during cool weather. On the other hand, discharging portion of bottom pond water helps in reducing plant plankton of pond water which causes use of more CO_2 from water during hot weather (net withdrawal of CO_2) which in turn cause high pH (Bhatnagar & Devi, 2013).

The system performed the optimum pond water pH maintenance efficiently in real time..

4.2.4 Discussion of preventive maintenance test result

The preventive maintenance test results discussed in this section include optimum turbidity maintenance test result, optimum water level maintenance test result and sun radiation and wind control test result.

(a) Optimum pond water turbidity maintenance test result

First result

The result of the first test on optimum pond water turbidity maintenance showed that the system displayed the turbidity value on LCD, sent pond water turbidity information to smart phone via app and discharged 20% of the pond water through the lower water outlet and refilled the pond with cool water through the cool water inlet (valve 1) when the pond water turbidity rose to 20mg/L. The pond water turbidity fell to 18.8mg/L (normalized level) after about 30 minutes of refilling pond. It took the pond water turbidity 30 minutes to normalize. The turbidity variation is in line with the expected result because it takes the system 30 minutes to discharge 20% of its water and another 30 minutes to replenish the 20% lost water.

This first pond water turbidity maintenance result is in line with the desired result. Exchanging portion of fish pond dirty water (bottom water) with clean, more oxygenated water helps in reducing turbidity level and preventing water quality problems (high temperature, low and high pH and low DO) caused by high turbidity of water (Coche et al., 1996).

Second result

The preventive maintenance system displayed the turbidity value on LCD, sent pond water turbidity information to smart phone via app when the pond water turbidity was about 10mg/L. In this case, which is rare in ponds for growing fish, the fish pond operator or owner on receipt of notification from smart phone, removes portion of the pond low turbid water and adds more turbid water. The test on lower optimum turbidity limit was included in the systems test in order to verify that the system only displays level of turbidity on LCD and sends information to smart phone and then send command to sense pond water level.

(b) Optimum water level maintenance result

The result of the test on optimum pond water level maintenance showed that the system displayed the water level on LCD, sent pond water level information to smart phone via app when the pond water level was about 117cm. The pond water level was 119.4cm initially, fell to 117cm after about two and half minutes and rose to 120cm (optimum level) after about four and half minutes into refilling of pond with cool, oxygenated water. The water level variation is in line with the expected result because it takes the system between 7 minutes to 10 minutes to replenish pond when there is loss of water due to evaporation, seepage and fish feeding.

This result is in line with the desired result. Replenishing pond water with clean, more oxygenated water helps in preventing water quality problems (high temperature, low and high pH and low DO) caused by high turbidity resulting from lower volume of water in the pond. Water replenishment also prevents rapid pond water temperature variation caused by reduced volume of water.

(c) Sun radiation and wind control test result

(i) Sun radiation control test result

The preventive maintenance system displayed the air temperature value on LCD, sent air temperature information to smart phone via app, set sun shade or screen when the air temperature rose to 28^oC. The system unset sun shade when the air temperature was less than 28^oC. This result is in line with the expected result because whenever air temperature is equal to 28^oC, as in the case, the microcontroller sends command to LCD to display air temperature level, send air temperature condition to smart phone via GSM module and set sun shade via servo motor 1 and then send command to sense air temperature. The amount and angle of incidence of sunlight decides the energy entering the pond/tank and thus the temperature of pond/tank (Harun, et al., 2018). Erecting sun shade or screen on part of the pond/tank helps in preventing rise in temperature (AFCD, 2009) and in reducing light penetration that causes increase in pH.

(i) Wind control test result

The preventive maintenance system displayed the air temperature value on LCD, sent air temperature information to smart phone via app, set windbreak when the air temperature fell to 20^oC. The system unset windbreak when the air temperature was more than 20^oC. This result is also in line with the expected result because whenever air temperature is equal to 20^oC, as in this case, the microcontroller sends command to LCD to display air temperature level, send air temperature condition to smart phone via GSM module, set windbreak via servo motor 2 and then send command to sense air temperature. Provision of windbreak during cool weather causes increase in temperature of ponds (Barange et al., 2018) and helps in controlling oxygen diffusion into pond water.

The system performed the preventive maintenance efficiently in real time.

4.2.5 Discussion of Optimum pond water quality maintenance test result

The smart electronic system for optimum water quality maintenance in warmwater fish culture showed that turbidity reached its upper optimum limit of 20mg/L on February 6, 2023 while air temperature reached its upper optimum limit of 28^{o}C on February 12, 2023 afternoon. The upper optimum turbidity received on February 6, 2023 is in order because the fishes in the pond were fed for about five weeks and enough unused feed had decayed in the pond and planktons had also grown and multiplied thereby increase the turbidity of the pond water. The system exchanged 20% of the dirty bottom pond water with clean, more oxygenated water in order to maintain optimum turbidity and prevent water quality problems associated with high turbidity.

On the other hand, the upper optimum temperature (28^{o}C) detected by air temperature sensor on February 12, 2023 is in order because people living in south east of Nigeria during that period experienced more environmental heat caused by high temperature. So, the optimum water quality maintenance system set sun shade in order to prevent the fish pond temperature from reaching its upper optimum temperature which would have led the system to initiate pond water maintenance operation. The system via air temperature sensor did not detect temperature of 20^{o}C or lower during this test period. This result is in order because the average lowest night temperature in south east of Nigeria in the past 20 years was about 21^{o}C (World Data, 2023).

The drop in pond water level (from 1.20m to1.17m) detected on March 7, 2023 was due to excessive evaporation that took place in the pond due to increase in the environmental temperature and water used by the fishes and other activities in the pond. The drop in pond water level is in order because there was increase in environmental temperature during February and March when the test was conducted, and this was confirmed by the 28^{o}C detected by the system on the 12th of February 2023. The LCD displayed the level and smart phone provided notification to further confirm the drop in pond water level. The cool water inlet poured water into the pond until level reached 1.2m and this action confirmed that the system performed it optimum water level maintenance efficiently.

This result implies that the system performed the optimum water maintenance efficiently in real time

4.3 Performance Validation

In fish culture, optimum water quality is required for optimal production and this can be achieved by taking adequate preventive measures against the problems of the quad-essential water quality parameters, regular monitoring of pond and taking action when any of the parameters reaches optimum level. So, the developed smart electronic system for optimum water quality maintenance in warmwater fish culture and other water quality control systems reviewed in section 2.8 should be capable of performing these functions efficiently. The extent to which these systems maintain optimum water quality is summarized in Table 4.1 to Table 4.4.

4.3.1 Temperature quality maintenance validation

The temperature quality maintenance performed by each of the water quality control systems for fish culture and their effects are summarized in Table 4.1

Table 4.1: Temperature quality maintenance validation

S/NO	SYSTEM	TEMP. RANGE CONTROLLED	CONTROL METHOD	EFFECT
1	The developed smart electronic system for optimum water quality maintenance in warmwater fish culture.	20ºC to 28ºC (optimum range)	i. Cool water exchange and simple aeration for upper optimum temperature. ii. Warm water exchange for lower optimum temperature	i. Maintenance of optimum water temperature. ii. Aids control of DO and pH.
2	Real Time Fish Pond Monitoring and Automation using Arduino (Harun *et al*., 2018)	Nil	Nil	i. Non-maintenance of optimum water temperature and quality ii. Poor growth and production and death of fish .
3	Smart Monitoring and Controlling System to Enhance Fish Production with Minimum Cost (Mohammed & Al-Mejibli, 2018)	20ºC to 28ºC	i. Heating of pond water with heater for lower optimum temperature. ii. Use of axial fan for upper optimum temperature.	i. Temporal control of temperature. ii. Poor growth of fish and production.
4	IoT Based Real Time Fish Pond Water Quality Monitoring Model (Obado, 2019)	15ºC to 35ºC (acceptable range)	i. Water exchange for high temperature.	i. Non-maintenance of optimum water temperature and quality ii. Poor growth of fish and production.
5	A Novel Method for Monitoring and Controlling of Water Quality in Aquaculture using IoT (Abinaya *et al*., 2019)	Prescribed low level	i. Heating of pond water with heater.	i. Non-maintenance of optimum water temperature and quality iii. Poor growth and death of fish
6	IoT-based Automatic Fish Pond Control System. (Azhra1 & Anam, 2020)	15ºC to 35ºC	ii. Use of axial fan for high temperature.	i. Non-maintenance of optimum water temperature and quality ii. Poor growth and production of fish.

The smart electronic system for optimum water quality maintenance in warmwater fish culture maintains optimum water temperature while other systems do not. The other five systems do not maintain optimum water quality because they control temperature temporarily and take control action only when temperature reaches critical level instead of optimum level. The other systems control either low temperature or high temperature temporarily except Smart Monitoring and Controlling System to Enhance Fish Production with Minimum Cost that controls low and high temperature temporarily. The non-maintenance of optimum water temperature leads to non-maintenance of optimum water quality and non-achievement of optimal production in fish culture.

4.3.2 Dissolved oxygen quality maintenance validation

The DO quality maintenance performed by each of the water quality control systems for fish culture and their effects are summarized in Table 4.2

Table 4.2: Dissolved oxygen quality maintenance validation

S/NO	SYSTEM	DO RANGE CONTROLLED	CONTROL METHOD	EFFECT
1	The developed smart electronic system for optimum water quality maintenance in warmwater fish culture.	5mg/L to 7.5mg/L (optimum range)	i . Cool water exchange and simple aeration for lower optimum DO ii. Warm water exchange for upper optimum DO.	i. Maintenance of optimum water DO and quality ii. Optimal production
2	Real Time Fish Pond Monitoring and Automation using Arduino (Harun *et al.*, 2018)	3mg/L to 8mg/L	i. Use of mechanical aerator for low DO.	i. Non-maintenance of optimum water DO and quality ii. Poor growth of fish and production.
3	Smart Monitoring and Controlling System to Enhance Fish Production with Minimum Cost (Mohammed & Al-Mejibli, 2018)	3mg/L to 8mg/L	i. Use of air pump for low DO.	i. Non-maintenance of optimum water DO and quality ii. Poor growth of fish and production.

4	IoT Based Real Time Fish Pond Water Quality Monitoring Model (Obado, 2019)	Nil	Nil	i. Non-maintenance of optimum water DO and quality ii. Poor growth of fish and production.
5	A Novel Methodology for Monitoring and Controlling of Water Quality in Aquaculture using IoT (Abinaya *et al*., 2019)	3mg/L to 8mg/L	i. Use of mechanical aerator for low DO.	i. Non-maintenance of optimum water DO and quality ii. Poor growth of fish and production.
6	IoT-based Automatic Fish Pond Control System (Azhra1 & Anam, 2020)	3mg/L to 8mg/L	i. Use of mechanical aerator for low DO.	i. Non-maintenance of optimum water DO and quality ii. Poor growth of fish and production.

The smart electronic system for optimum water quality maintenance in warmwater fish culture maintains optimum water DO while other systems do not. The other systems control low DO temporarily except IoT Based Real Time Fish Pond Water Quality Monitoring Model that does not control low and high DO. The non-maintenance of optimum water DO leads to non-maintenance of optimum water quality and non-achievement of optimal production in fish culture.

4.3.3 pH quality maintenance validation

The pH quality maintenance performed by each of the water quality control systems for fish culture and their effects are summarized in Table 4.3

Table 4.3: pH quality maintenance validation

S/NO	SYSTEM	pH RANGE CONTROLLED	CONTROL METHOD	EFFECT
1	The developed smart electronic system for optimum water quality maintenance	6.8 to 8.5 (optimum range)	i . Water exchange and simple aeration for lower optimum pH.	i. Maintenance of optimum water pH and quality ii. Optimal

	in warmwater fish culture.		ii. Warm water exchange for upper optimum pH.	production
2	Real Time Fish Pond Monitoring and Automation using Arduino (Harun *et al*., 2018)	Nil	Nil	i. Non-maintenance of optimum water pH and quality ii. Poor growth of fish and production.
3	Smart Monitoring and Controlling System to Enhance Fish Production with Minimum Cost (Mohammed & Al-Mejibli, 2018)	Nil	Nil	i. Non-maintenance of optimum water pH and quality ii. Poor growth of fish and production.
4	IoT Based Real Time Fish Pond Water Quality Monitoring Model (Obado, 2019)	Nil	Nil	i. Non-maintenance of optimum water pH and quality ii. Poor growth of fish and production.
5	A Novel Methodology for Monitoring and Controlling of Water Quality in Aquaculture using IoT (Abinaya *et al*., 2019)	6.5 to 9.5 (acceptable range)	i. Aeration for low pH	i. Non-maintenance of optimum water pH and quality ii. Non-achievement of optimal production.
6	IoT-based Automatic Fish Pond Control System (Azhra1 & Anam, 2020)	6.5 to 9.5 (acceptable range)	i. Water drainage.	i. Non-maintenance of optimum water pH and quality ii. Non-achievement of optimal production.

The smart electronic system for optimum water quality maintenance in warmwater fish culture maintains optimum water pH while other systems do not. The other systems control low pH temporarily except Smart Monitoring and Controlling System to Enhance Fish Production with Minimum Cost and IoT Based Real Time Fish Pond Water Quality Monitoring Model that do not control either low or high pH. The non-maintenance of optimum water pH leads to non-maintenance of optimum water quality and non-achievement of optimal production in fish culture.

4.3.4 Preventive maintenance validation

The preventive maintenance performed by each of the water quality control systems for fish culture and their effects are summarized in Table 4.4.

Table 4.4: Preventive maintenance validation

S/NO	SYSTEM	PARAMETERS CONTROLLED	CONTROL METHOD	EFFECT
1	The developed smart electronic system for optimum water quality maintenance in warmwater fish culture.	i. Turbidity (10-20mg/L). ii. Water level. iii.Wind and sun radiation.	i. Water exchange for high turbidity. ii. Pond replenishment. iii. Sun shade for high temperature and windbreak for low temperature	i. Adequate prevention of water quality problems. ii. Maintenance of optimum water quality
2	Real Time Fish Pond Monitoring and Automation using Arduino (Harun *et al.*, 2018)	Nil	Nil	i. Non-prevention of water quality problems. ii. Non-maintenance of optimum water quality
3	Smart Monitoring and Controlling System to Enhance Fish Production with Minimum Cost (Mohammed & Al-Mejibli, 2018)	i. Turbidity (<10 mg/L to >20 mg/L). ii. Water level.	i. Water exchange for high turbidity. ii. Pond replenishment.	i. Inadequate prevention of water quality problems. ii. Non-maintenance of optimum water quality
4	IoT Based Real Time Fish Pond Water Quality Monitoring Model (Obado, 2019)	i. Turbidity (<10 mg/L to >20 mg/L). ii. Water level.	i. Water exchange for high turbidity. ii. Pond replenishment.	i. Inadequate prevention of water quality problems. ii. Non-maintenance of optimum water quality
5	A Novel Methodology for Monitoring and Controlling of Water Quality in	i. Water level.	i. Pond replenishment.	i. Inadequate prevention of water quality problems. ii. Non-maintenance of optimum water

	Aquaculture using IoT (Abinaya *et al*., 2019)			quality iii. Poor growth of fish and production.
6	IoT-based Automatic Fish Pond Control System (Azhra1 & Anam, 2020)	i. Turbidity (<10 mg/L to >20 mg/L). ii. Water level.	i. Water exchange out ii. Pond replenishment.	i. Inadequate prevention of water quality problems. ii. Non-maintenance of optimum water quality

The developed smart electronic system for optimum water quality maintenance in warmwater fish culture meant to be used in ponds with overflow pipe takes adequate preventive measures against water quality problems while others do not. The preventive measures taken by the developed smart electronic system include replenishment of lost water, exchange of bottom dirty water and erection of sun screen/shade or windbreak and discharging of excess pond water through overflow pipe (overflow pipe must be in the pond before the system is used). The other systems control turbidity and water level except (draining of dirty water and replenishment of pond) A Novel Methodology for Monitoring and Controlling of Water Quality in Aquaculture using IoT that controls only water level and Real Time Fish Pond Monitoring and Automation using Arduino that does not take any preventive. Preventive measures such as erection of sun shade and windbreak for preventing temperature and pH variations are not undertaken by the systems. Recommendation that these other five systems should be used in ponds that have overflow facility are not made by the developers, so water quality problems caused by rain are not prevented by them when used in ponds that do not have this facility. The inadequate preventive measures against water quality problems leads to non-maintenance of optimum water quality and non-achievement of optimal production in fish culture.

The smart electronic system for optimum water quality maintenance in warmwater fish culture has efficiency of 96%.

4.4 Cost Analysis

The cost of developing the smart electronic system for optimum water quality maintenance in warmwater fish culture is about five hundred and seventy-nine thousand, one hundred and eighty naira (₦579,180). This cost includes cost of components and miscellaneous such as cost of piping and transportation. The cost of developing the smart electronic system is fairly cheap when compared to the cost of developing the other fish pond water quality control systems that use multiple AC-based controllers such a mechanical aerator and axial fan. The detailed cost of developing the smart electronic system is presented in Table 4.5.

Table 4.5: Bill of Engineering Measurement and Evaluation (BEME)

S/NO	COMPONENT	QUANTITY	UNIT PRICE (₦)	AMOUNT (₦)
1	Microcontroller	1	14,000	14,000
2	Temperature sensor	2	3,000	6,000
3	DO sensor	1	56,000	56,000
4	pH sensor	1	10,000	10,000
5	Turbidity sensor	1	8,000	8,000
6	Ultrasonic sensor	2	2,000	4,000
7	GSM module	1	8,000	8,000
8	Regulator	3	2,000	6,000
9	Liquid crystal display	1	2,000	2,000

10	Water pump	1	46,000	46,000
11	Solenoid valve	5	7,000	35,000
12	Servo motor	2	5,000	10,000
13	Solar panel	1	85,000	85,000
14	Battery	1	180,000	180,000
15	Charge controller	1	20,000	20,000
16	Transformer	1	16,000	16,000
17	Diode rectifier	1	2,000	2,000
18	Capacitor	1	1,500	1,500
19	Circuit breaker	1	3,500	3,500
20	Light emitting diode	1	20	20
21	Relay	8	300	2,400
22	Transistor	6	100	600
23	Resistor	8	20	160
24	Miscellaneous			65,000
TOTAL				579,180

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Smart electronic system for maintenance of optimum water quality in warmwater fish culture has been developed successfully in this work. The work has established that the smart electronic system developed maintains optimum water quality in warmwater fish culture with efficiency of 96%.

The objectives of the work have been achieved as the system block diagram and design specification were established and four subsystems were developed. The first system developed monitored pond water temperature regularly and adjusted whenever its value reached optimum level. The second system developed monitored pond water DO regularly and adjusted whenever its value reached optimum level. The third system developed, monitored pond water pH regularly and adjusted whenever its value reaches optimum level while the fourth system developed took adequate preventive measures against water quality problems.

The developed system maintained optimum water quality in warmwater fish culture by using simple and low-power consuming components for exchanging portion of the water with appropriate water when any of the quad-essential water quality parameter reached its optimum level and adequately preventing causes of water quality problems. The system exchanged 20% of upper pond water with cool, clean oxygenated water when temperature reaches 28^{o}C while it exchanged 20% of bottom pond water with warm, clean water when it fell to 20^{o}C. The system exchanged 20% of upper pond water with warm, clean water (deoxygenation) when DO reached 7.5 mg/L while it exchanged 20%

of bottom pond water with cool, clean oxygenated water when it fell to 5 mg/L. The system exchanged 20% of bottom pond water with cool clean and more oxygenated water when pH reached 8.5 or falls to 6.8. The system performs preventive maintenance by exchanging 20% of the bottom pond water with cool, clean and more oxygenated water when turbidity level reached 20 mg/L, replenishing pond with water, and erecting sun shade when air temperature level reached 28^{o}C and windbreak when air temperature level fell to 20^{o}C.

The system also displayed the level of any pond water maintenance parameter on LCD and sent information about water quality condition (level of pond water quality parameters and maintenance action taken) to smart phone application (PWQMR App) via GSM module. The system was fully developed and was more efficient, reliable and less expensive compared to other designs of water quality control or maintenance systems for fish culture.

5.2 Recommendations

The system developed in this work can be used in a variety of fish ponds and tanks and cannot be used in some ponds and tanks without additional components. The following recommendations are hereby made based on the operation of the system:

1. It is recommended that this system be used in fish ponds and tanks that have maximum area of $45m^2$and depth of 2m (shallow and small fish ponds and tanks) containing overflow pipe in order to achieve optimum water quality required for optimal fish production.
2. The system cannot function efficiently in ponds and tanks deeper than 2m because more sensors are required for determining water quality. So, it is recommended that a new system with more sensors be developed for deep ponds and tanks.
3. The system developed in this work is a prototype. In order to use the system in large shallow fish ponds, more outlets and inlets have to be integrated in the system.
4. The system was developed for warmwater fish culture. In order to use the system for coldwater fish culture, the levels of optimum water quality parameters should be changed in the program and pond water quality maintenance record (PWQMR) app to appropriate levels.
5. It is recommended that developers should adopt the design of this system in order to produce efficient systems for optimum water quality maintenance for warmwater fish culture.

5.3 Contribution to Knowledge

This work has provided a new and effective method of maintaining optimum water quality in fish culture. The knowledge the work contributes to the world are as follows:

1. The work has provided a new method of developing system that maintains optimum water quality in fish culture by exchanging portion of the pond water with appropriate water when any of the quad-essential water quality parameter reaches optimum level and adequately preventing causes of water quality problems.
2. The work has also provided a new method of developing water quality maintenance system where less expensive, DC-based low-power consuming components are used. The DC solenoid valves, servo motors and water pump consume less power.
3. The work has also provided a means of supplying regular electric power (dual power supply) needed for effective operation of any system used in maintaining water quality in fish culture.

5.4 List of Publications

1. Ezetoha, F. C., Opara, F. K., Chukwuchekwa, N., Akande, A. O. and Anyalewechi, C. J. (2023). Automation System for Optimum Water Quality Maintenance in Tropical Fish Culture, International Journal of Engineering and Environmental Sciences (IJEES), Vol. 6, No. 1, Pages 32-41.
2. Ezetoha, F. C., Opara, F. K., Chukwuchekwa, N., Akande, A. O. and Anyalewechi, C. J. (2023). Smart Electronic System for Prevention of Water Quality Problems in Fish Culture. European Journal of Engineering and Environmental Sciences, Vol. 7, No. 2, Pages 1-11.

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APPENDICES

Appendix A: System Program for Optimum Pond Water Quality Maintenance

```
#include<LiquidCrystal.h>
#include<OneWire.h>
#include<DallasTemperature.h>
#include<Servo.h>


// Data wire is plugged into digital pin 2 on the Arduino
#definewater_temp_pin2
#defineair_temp_pin3

// Setup a oneWire instance to communicate with any OneWire device
OneWirewater_temp_oneWire(water_temp_pin);
OneWireair_temp_oneWire(air_temp_pin);
Servo wind_shade;
Servo sun_screen;


// Pass oneWire reference to DallasTemperature library
DallasTemperaturewater_temp_sensor(&water_temp_onewire);
DallasTemperatureair_temp_sensor(&air_temp_onewire);
LiquidCrystalLCD(13, 12, 11, 10, 9, 8);
int valve1 = 14;
int valve2 = 15;
int valve3 = 16;
int valve4 = 17;
int valve5 = 18int pump = 19;

int trig1_pin = 22;
int echo1_pin = 23;
int trig2_pin = 24;
int echo2_pin = 25;
intPh_pin = A0;
intDO_pin = A1;
intturbidity_pin = A2;
intwind_shade_pin = 7;
intsun_screen_pin = 6;

intPh_data, DO_data, turbidity_data;
floatPh_voltage, DO_voltage, turbidity_voltage;
floatPh_value, DO_value, turbidity_value;
float travel_time1, travel_time2;
floatpond_water_level, reservior_water_level;
```

```
floatspeed_of_sound = 776.5;
floatpond_temp, air_temp;

voidsetup(){
 sensors.begin();
 wind_shade.attach(wind_shade_pin);
 sun_screen.attach(sun_screen_pin);
 wind_shade.write(30);
 sunscreen.write(30);
 LCD.begin(16, 2);
 pinMode(valve1, OUTPUT);
 pinMode(valve2, OUTPUT);
 pinMode(valve3, OUTPUT);
 pinMode(valve4, OUTPUT);
 pinMode(valve5, OUTPUT);
 pinMode(pump, OUTPUT);
 pinMode(Ph_pin, INPUT);
 pinMode(DO_pin, INPUT);
 pinMode(turbidity_pin, INPUT);
 pinMode(trig1_pin, OUTPUT);
 pinMode(trig2_pin, OUTPUT);
 pinMode(echo1_pin, INPUT);
 pinMode(echo2_pin, INPUT);

 Serial.println("AT");
 delay(1000);

 Serial.println("AT+CPIN?");
 delay(1000);

 Serial.println("AT+CREG?");
 delay(1000);

 Serial.println("AT+CGATT?");
 delay(1000);

 Serial.println("AT+CIPSHUT");
 delay(1000);

 Serial.println("AT+CIPSTATUS");
 delay(2000);

 Serial.println("AT+CIPMUX=0");
 delay(2000);
```

```
  Serial.println("AT+CSTT=\"airtelgprs.com\"");  //start task and setting the APN,
  delay(1000);
}

voidloop(){
  water_temp_function();
  DO_function();
  Ph_function();
  turbidity_function();
  maintain_water_function();
  air_temp_function();
}


voidwater_temp_function(){
  water_temp_sensor.requestTemperatures();
  pond_temp = water_temp_sensor.getTempCByIndex(0);
  if(pond_temp<20.0 || pond_temp>28.0){
    if(pond_temp>= 28.0){
      digitalWrite(valve3, HIGH);
      display_pond_temp();
      pond_water_level = get_pond_level();
      send_to_phone(pond_temp);
      while(pond_level>96.0){
        pond_water_level = get_pond_level();
        send_to_phone(pond_level);
      }
      digitalWrite(valve3, LOW);
      digitalWrite(valve1, HIGH);
      digitalWrite(pump, HIGH);
      pond_water_level = get_pond_level();
      send_to_phone(pond_level);
      while(pond_level<120.0){
        pond_water_level = get_pond_level();
        send_to_phone(pond_level);
      }
      digitalWrite(valve1, LOW);
      digitalWrite(pump, LOW);
    }else{
      digitalWrite(valve2, HIGH);
      display_pond_temp();
      pond_water_level = get_pond_level();
      send_to_phone(pond_level);
      while(pond_level>96.0){
        pond_water_level = get_pond_level();
```

```
      send_to_phone(pond_level);
    }
    digitalWrite(valve2, LOW);
    digitalWrite(valve4, HIGH);
    pond_water_level = get_pond_level();
    send_to_phone(pond_level);
    while(pond_level<120.0){
      pond_water_level = get_pond_level();
      send_to_phone(pond_level);
    }
    digitalWrite(valve4, LOW);
    digitalWrite(valve5, HIGH);
    digitalWrite(pump, HIGH);
    reservior_water_level = get_reservior_water_level();
    send_to_phone(reservior_water_level);
    while(reservior_water_level<100.0){
      reservior_water_level = get_reservior_water_level();
    }
    digitalWrite(valve5, LOW);
    digitalWrite(pump, LOW);
  }

  delay(3, 600, 000);
 }
}

voidDO_function(){

 DO_value = read_DO();
 if(DO_value<5.0 || DO_value>7.5){
  if(DO_value>= 7.5){
    digitalWrite(valve3, HIGH);
    display_DO();
    send_to_phone(DO_value);
    pond_water_level = get_pond_water_level();
    while(pond_water_level>96.0){
      pond_water_level = get_pond_water_level();
      send_to_phone(pond_level);
    }
    digitalWrite(valve3, LOW);
    digitalWrite(valve4, HIGH);
    pond_water_level = get_pond_water_level();
    while(pond_water_level<120.0){
      pond_water_level = get_pond_water_level();
      send_to_phone(pond_level);
```

```
      }
      digitalWrite(valve4, LOW);
      digitalWrite(valve5, HIGH);
      digitalWrite(pump, HIGH);
      reservior_water_level = get_reservior_water_level();
      while(reservior_water_level<100.0){
        reservior_water_level = get_reservior_water_level();
        send_to_phone(reservior_water_level);
      }
      digitalWrite(valve5, LOW);
      digitalWrite(pump, LOW);
    }else{
      digitalWrite(valve2, HIGH);
      pond_water_level = get_pond_water_level();
      while(pond_water_level>96.0){
        pond_water_level = get_pond_water_level();
        send_to_phone(pond_level);
      }
      digitalWrite(valve2, LOW);
      digitalWrite(valve1, HIGH);
      digitalWrite(pump, HIGH);
      pond_water_level = get_pond_water_level();
      while(pond_water_level<120.0){
        pond_water_level = get_pond_water_level();
        send_to_phone(pond_level);
      }
      digitalWrite(valve1, LOW);
      digitalWrite(pump, LOW);
    }
    delay(3, 600, 000);
  }
}

voidPh_function(){
  Ph_value = read_Ph();
  if(Ph_value<6.8 || Ph_value>8.5){
    digitalWrite(valve2, HIGH);
    send_to_phone(Ph_value);
    pond_water_level = get_pond_level();
    while(pond_water_level>96.0){
      display_Ph();
      pond_water_level = get_pond_level();
      send_to_phone(pond_level);
    }
```

```
    digitalWrite(valve2, LOW);
    digitalWrite(valve1, HIGH);
    digitalWrite(pump, HIGH);
    pond_water_level = get_pond_level();

    while(pond_water_level<120.0){
      display_Ph();
      pond_water_level = get_pond_level();
      send_to_phone(pond_level);
    }
    delay(3, 600, 000);
  }
}

voidturbidity_function(){

  turbidity_value = read_turbidity();
  if(turbidity_value<10.0 || turbidity_value>20.0){
    if(turbidity_value>= 20.0){
      digitalWrite(valve2, HIGH);
      send_to_phone(turbidity_value);
      display_turbidity();
      pond_water_level = get_pond_level();
      while(pond_water_level>96.0){
        pond_water_level = get_pond_level();
        send_to_phone(pond_level);
      }
      digitalWrite(valve2, LOW);
      digitalWrite(valve1, HIGH);
      digitalWrite(pump, HIGH);
      pond_water_level = get_pond_level();
      while(pond_level<120.0){
        pond_water_level = get_pond_water_level();
        send_to_phone(pond_level);
      }
      digitalWrite(valve1, LOW);
      digitalWrite(pump, LOW);
      delay(3, 600, 000);
    }
    display_turbidity();
  }
}

voidmaintain_water_function(){
  pond_water_level = get_pond_water_level();
```

```
  if(pond_water_level<= 117.0){
    digitalWrite(valve2, HIGH);
    digitalWrite(pump, HIGH);
    send_to_phone(pond_level);
    pond_water_level = get_pond_water_level();
    while(pond_water_level<120.0){
      pond_water_level = get_pond_water_level();
      send_to_phone(pond_level);
    }
    digitalWrite(valve2, LOW);
    digitalWrite(pump, LOW);
  }
}

voidair_temp_function(){
  air_temp_sensor.requestTemperatures();
  air_temp = air_temp_sensor.getTempCByIndex(0);
  if(air_temp<20.0 || air_temp>28.0){
    if(air_temp>= 28.0){
      sun_screen.write(120);
      display_air_temp();
      send_to_phone(air_temp);
      air_temp_sensor.requestTemperatures();
      air_temp = air_temp_sensor.getTempCByIndex(0);
      while(air_temp>28.0){
        air_temp_sensor.requestTemperatures();
        air_temp = air_temp_sensor.getTempCByIndex(0);
        send_to_phone(air_temp);
      }
      sun_screen.write(30);
    }else{
      wind_shade.write(120);
      air_temp_sensor.requestTemperatures();
      air_temp = air_temp_sensor.getTempCByIndex(0);
      while(aire_temp<= 20){
        air_temp_sensor.requestTemperatures();
        air_temp = air_temp_sensor.getTempCByIndex(0);
        send_to_phone(air_temp);
      }
      wind_shade.write(30);
    }
  }
}
```

```
floatget_pond_water_level(){
  floatwater_level;
  digitalWrite(trig1_pin, LOW);
  delayMicroseconds(2000);
  digitalWrite(trig1_pin, HIGH);
  delayMicroseconds(15);
  digitalWrite(trig1_pin, LOW);

  travel_time1 = pulseIn(echo1_pin, HIGH);
  travel_time1 = travel_time1 / 1000000.;
  travel_time1 = travel_time1 / 3600.;

  water_level = speed_of_sound * travel_time1;
  water_level = water_level / 2.;
  water_level = water_level * 63360.;

  returnwater_level;
}

floatget_reservior_water_level(){
  floatwater_level;
  digitalWrite(trig2_pin, LOW);
  delayMicroseconds(2000);
  digitalWrite(trig2_pin, HIGH);
  delayMicroseconds(15);
  digitalWrite(trig2_pin, LOW);

  travel_time2 = pulseIn(echo2_pin, HIGH);
  travel_time2 = travel_time2 / 1000000.;
  travel_time2 = travel_time2 / 3600.;

  water_level = speed_of_sound * travel_time2;
  water_level = water_level / 2.;
  water_level = water_level * 63360.;

  returnwater_level;
}

floatread_Ph(){
  float Ph;
  Ph data = analogRead(Ph_pin);
  Ph_data = 1023 - Ph_data;
  Ph = (14. / 1023) * Ph_data;

  return Ph;
```

```
}

floatread_turbidity(){
  float turbidity;
  turbidity_data = analogRead(turbidity_pin);
  turbidity_voltage = (turbidity_data / 1024.) * 5.;
  turbidity = -1120.4 * square(turbidity_voltage) + 5742.3 * turbidity_voltage - 4352.9;

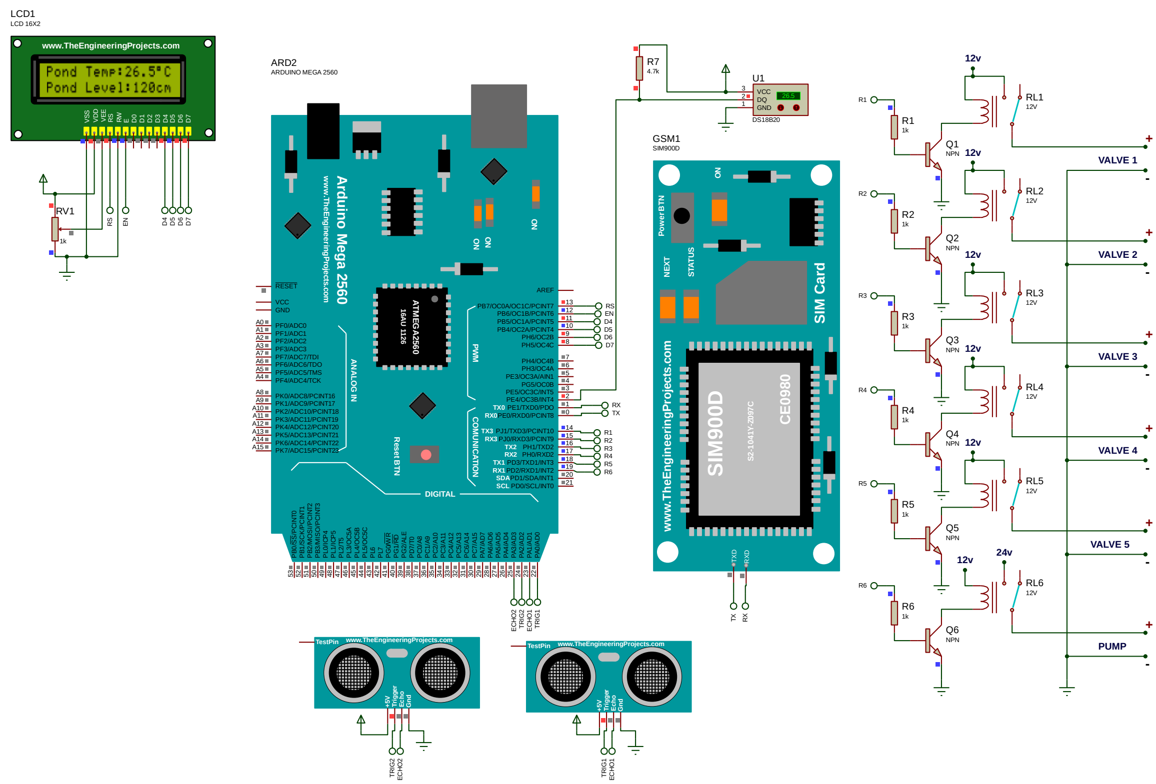
  return turbidity;
}

floatread_DO(){
  float DO;
  DO_data = analogRead(DO_pin);
  DO_voltage = (DO_data / 1024.) * 5.;
  DO = (DO_voltage / 5.0) * 20.0;
  return DO;
}

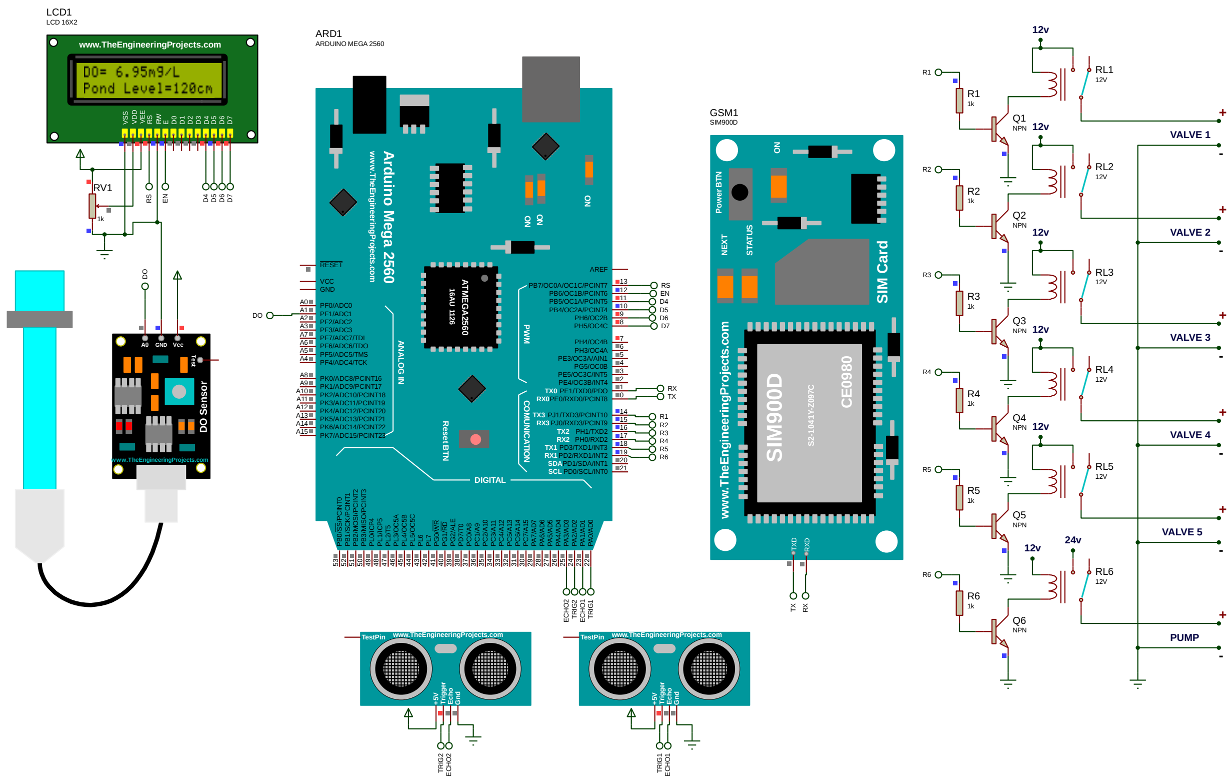
voidsend_to_phone(floatt)
{

  Serial.println("AT+CSTT=\"airtelgprs.com\"");  //start task and setting the APN,
  delay(1000);
  Serial.println("AT+CIPSTART=\"TCP\",\"api.thingspeak.com\",\"80\"");
  delay(6000);
  String str = "GET
https://api.thingspeak.com/update?api_key=OK0B05FUL6RGBCZR&field1=" +
String(t);
    Serial.println(str);
    delay(4000);
    gprsSerial.println((char)26);
    delay(5000);
}
```

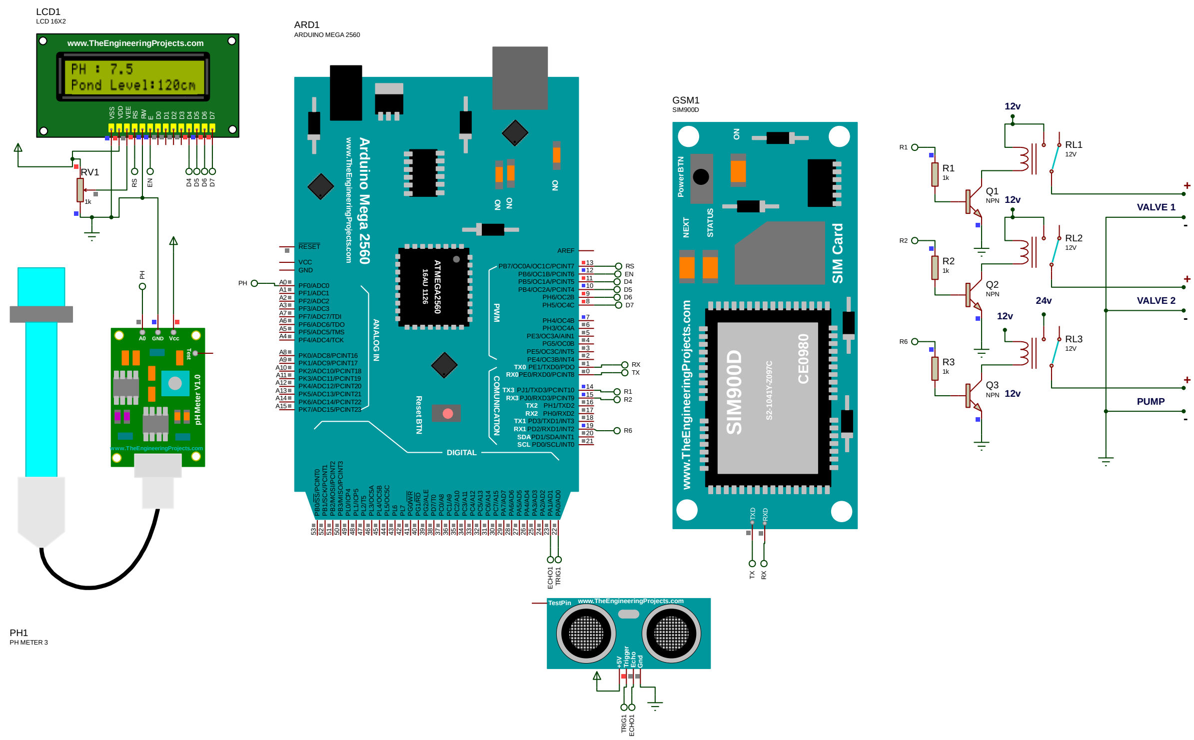
Appendix B: Optimum Pond Water Temperature Maintenance System Simulation Circuit



Appendix C: Optimum Pond Water DO Maintenance System Simulation Circuit



Appendix D: Optimum Pond Water pH Maintenance System Simulation Circuit



Appendix E: Preventive Maintenance System Simulation Circuit