International Journal of Engineering and Environmental Sciences | *ISSN 1694-4372*
Published by AIR JOURNALS | *https://airjournal.org/ijees*
16/18 Avenue des Longaniers, Quatre Bornes, Mauritius
airjournals@gmail.com; enquiry@airjournal.org

RESEARCH ARTICLE

AUTOMATION SYSTEM FOR OPTIMUM WATER QUALITY MAINTENANCE IN TROPICAL FISH CULTURE

Ezetoha, F. C.[1], Opara, F. K.[2], Chukwuchekwa, N.[3], Akande, A. O.[4], & Anyalewechi, C. J.[5]
Department of Electrical and Electronic Engineering, Federal University of Technology, Owerri, Imo State, Nigeria

Accepted: May 17, 2023	Published: May 31, 2023

Citations - APA

Ezetoha, F. C., Opara, F. K., Chukwuchekwa, N., Akande, A. O., & Anyalewechi, C. J. (2023). Automation System for Optimum Water Quality Maintenance in Tropical Fish Culture. *International Journal of Engineering and Environmental Sciences, 6(1), 32-41. DOI:* https://doi.org/10.5281/zenodo.8024681

ABSTRACT

This paper presents a design of an electronic system for maintaining optimum water quality in fish culture in the tropics. The aim of the work was to design an automation system that will maintain optimum water quality at low cost in tropical fish culture. Top-down design approach was adopted for designing the system. The subsystems or subunits of the optimum water quality maintenance system are power supply, sensing, control, water exchange, and communication and display units. Arduino Mega 2560 was utilized in this design for controlling the activities of the entire system. The system takes preventive measures against water quality problems in fish culture by weekly exchange of 10-20% of the water and replenishment of pond whenever water level decreases. The automation system controls pond water quality by exchanging 20% of the water with appropriate water whenever turbidity, temperature, dissolved oxygen or pH level reaches optimum limit. The system also sends an SMS message to the pond manager/farmer mobile phone to inform him of water quality condition and instruct him to erect sun screen in pond during summer and wind shelter during winter. The electronic model provides an efficient, low-cost automation method for maintaining optimum water quality and improving environmental conditions in tropical fish culture. The authors recommended that the system be developed and used in tropical fish culture in order to maintain optimum pond water quality and achieve optimal fish production at low cost.

Keywords: *Fish Culture; Automation System; Optimum Water Quality Maintenance; Tropical Fish Culture*

Introduction

Fish farming is one of the ways of producing animal protein. Fishes are raised or reared in ponds and tanks (fish culture) in order to meet increase in demand of fish products as a result of increasing population pressure in the world (De Silva, 2016; FAO, 2016). Quite often, fish pond develops water quality problems recognized by problems of oxygen, temperature, pH and turbidity or the quad-essential quality parameters (Coche, Muir, & Laughlin, 1996; GOK, 2016). The problems may develop suddenly from environmental phenomena such as heavy rains or gradually through mismanagement (AFCD, 2009; FAO, 2005) especially in the tropics. According to Kottek, et al. (2006), tropical climate is a region where the mean temperature of the coldest month is greater than or equal to 18°C and features hot temperatures. So, tropical fish culture is associated with temperature related water quality problems such as high temperature, low DO and high pH. The surface temperature of shallow water bodies such as ponds and tanks in the tropics can occasionally rise to 40°C or above in peak summer which can cause oxygen depletion and mortality of fishes especially if the depth of water body is less than 1m and the summer daily maximum can be up to 30–35°C (Kutty, 1987). The increase in water temperature is due to increase in solar radiation which is the main source of heat for pond water. In fish culture, pond water quality problems may cause poor development and growth, weakness and poor health of fishes and death of fishes amongst others (Bhatnagar & Devi, 2013; Kleinholz, 2017; Svobodová, Lloyd, Máchová, & Vykusová, 1993) thereby affecting production negatively. So, water quality management is necessary for achieving optimum production and sustainable fish culture (Gatlin, 2010; Little, Newton, & Beveridge, 2016). Water quality management or maintenance is effectively achieved by keeping the quad-essential quality parameters within optimal range (Coche et al., 1996; GOK, 2016).

Conventionally, pond water quality maintenance in fish culture involve taking of preventive measures, regular monitoring of the essential water quality parameters using meters and test tools or through mere observation and performing tasks such as addition or subtraction of substances or removal and replenishment of part of pond water (AFCD, 2009; Bhatnagar & Devi, 2013; GOK, 2016; Kleinholz, 2017). Although the conventional method of monitoring water quality may be effective in solving pond water problems in fish culture, 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 therefore is strenuous, time consuming and prone to error (Bokingkito & Llantos, 2017). More so, 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 level of a parameter, 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 in developing countries do not monitor water quality parameters in their ponds or tanks as a result of their ignorance and cost of hiring workers who will monitor the quality daily (Obado, 2019). Some farmers monitor their pond water 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. Efficient automation system for maintaining fish pond water quality is therefore needed to overcome these drawbacks.

Currently, only few electronic automation systems have been developed for maintaining water quality in fish culture. Although these electronic systems carry out real-time water quality monitoring continuously and may have potential of achieving high-quality, yield, and productivity in fish farming and improved basic environmental conditions (Wang, Qi, & Pan, 2012), they have not been fully deployed in ponds and tanks (Mohammed & Al-Mejibli, 2018). These systems do not control all the water quality parameters nor maintain optimum water quality. More so, investment and operating costs of the automation systems are the biggest obstacles (Harun et al., 2018). Therefore, there is the need for an efficient, low-cost automation system for maintaining optimum pond water quality in fish culture.

The aim of the work is to design an automation system that will maintain optimum water quality at low cost in tropical fish culture.

Literature Review

Fish Pond Water Quality Maintenance

In fish culture, water quality problems are mainly caused by changes in the main characteristics of pond water (water quality parameters) which include chemical reaction of the water (pH), water temperature and turbidity and dissolved oxygen content of water. Other water quality parameters in fish culture include ammonia, salinity, alkalinity, hardness (Fowler et al., 1994), nitrite, carbon dioxide, hydrogen sulphide and Plankton (Banrie, 2012; Kleinholz, 2017). The problems of these other parameters are linked to problems of the quad-essential water quality parameters (Bhatnaga & Devi, 2013) and are solved by one or combination of the methods used in solving the problems of the any of the quad-essential water quality parameters. These quad-essential fish water quality parameters influence not only fish production but each other and they are influenced by many other factors such as surrounding environment (Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014). The fish pond water quality problems can be detected through monitoring of the essential water quality parameters.

Maintaining the essential water quality parameters within the optimum ranges prevent water quality problems and leads to achievement of sustainable fish culture (Gatlin, 2010). Water quality maintenance in fish culture involves measures that ensure the achievement of optimum water quality in the pond and they include taking of adequate precautions, monitoring of the essential fish pond water quality parameters and responding to contingencies (AFCD, 2009). So, the water quality problems are prevented by taking precautionary measures and solved by taking control action. 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 (Bhatnagar & Singh, 2010). On the other hand, monitoring of water quality involve detection of levels of the water quality parameters and comparing them with standard values/ranges. The levels of the essential water quality parameters are detected by physical observation of the pond water or use of meters/test tools or modern electronic systems. Conversely, automated water quality maintenance in fish culture involves use of electronic system in maintaining water quality at an acceptable/optimal range (Mohammed & Al-Mejibli 2018; Ujwala, Sunita, Yamuna, & Vandana, 2020). The methods applied in the automated fish pond water quality maintenance are based on the conventional methods.

Related Works

There are few researches on automated fish pond water quality maintenance or management. The following are some of the recently published works on electronic systems proposed or developed for maintaining fish pond water quality. Idachaba et al. (2017) proposed IoT enabled real-time fish pond management system. The objective of their work was to reduce cost of fish farming and increase yield. The system comprised of sensors for sensing the water quality parameters (pH, temperature, values and cleanliness), feeder mechanism for feeding the fish and CCTV cameras for capturing events around the fish pond. The system maintains water quality by monitoring the water pH and temperature levels and cleanliness, and changing the water in the pond when pH or temperature is high or water is dirty. SMS service is also utilized in the system for sending commands to controllers and to display the pond status. This system does not monitor nor control DO and water level and does not control low pH or temperature. Harun et al. (2018) developed a real time fish pond monitoring and automation system using Arduino. 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. The system monitors temperature, pH, DO and water levels and controls low DO, pH and water levels. The automation system pumps water into the pond when water level drops and operates mechanical aerator when DO levels falls outside acceptable range and pH is low. The system does not monitor turbidity nor control 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. The system monitors temperature, pH, DO, total dissolved solids (TDS) and water levels. Axial fan is switched ON when temperature is high and heater is switched ON when it is lower than 18^{o}C. TDS filter is switched ON via relay when TDS value is out of required range while the air pump supplies ponds with the oxygen when the oxygen value reduces in pond. Filter is switched ON when the amount of suspended solid (turbidity) is larger than the acceptable range while water pump is switched ON when the water level is less than the acceptable level (for instance 3 cm less) in order to increase the water level. SMS warning massage is sent to ponds operator via GSM when pH value is out of the acceptable range to enable him interfere immediately and when it is required. This system does not control pH level.

Obado (2019) developed Internet of Thing (IoT) based real time fish pond water quality monitoring model. The system monitors and controls temperature, turbidity and water levels. The status of the water quality aspects are 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 can then act based on the information relayed or the model can automatically act on behalf of the farmer based on predefined actions. The actions taken include 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 drops. The system does not monitor nor control DO and pH levels.

Abinaya, Ishwarya and Maheshwari (2019) designed an Internet of Thing (IoT) based system for monitoring and controlling water quality parameters in the aquaculture. The system monitors and controls temperature, DO, pH, ammonia and water levels and foul smell. When temperature is low, the heater will be turned ON till the temperature reaches prescribed level and when water level decreases, the water pump will be turned ON till the water level is normal. When dissolved oxygen level or pH level is low, aerator is turned ON till the level normalizes. The sensed values would also be sent to the cloud using Wi-Fi and can be accessed in the control room. The system does not monitor nor control turbidity level. Azhra1 and Anam (2020) designed an IoT-based automatic fish pond control system. In this model, fish pond water quality is monitored through seven parameters namely salinity, ammonia, conductivity, dissolved oxygen, temperature, pH and turbidity. 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 monitors and controls temperature, pH, DO, turbidity, salinity, ammonia and conductivity levels. Cooling actuator is activated in response if the water temperature is high. Aerator is activated to add oxygen in the pool if DO is low while salinity injectors are activated in response if water salinity is not normal. The authors did not specify parameters that are controlled by activating pump to drain water from pond to hydroponic. The systems reviewed do not control all the water quality parameters nor maintain optimum fish pond water quality (they take action only when level of any of the parameters reaches critical level instead of optimum level). The proposed system is an automation system for maintaining optimum fish pond water quality in the tropics.

Proposed System

The system maintains optimum water quality by taking adequate preventive measures, regular monitoring and control of the four essential water quality parameters using methods that provides permanent solutions to the problems of these parameters at low cost. The conceptual model of the system is shown in figure 1.

Vol. 6, No. 1 | 2023 | pp. 32-41 | DOI: https://doi.org/10.5281/zenodo.8024681

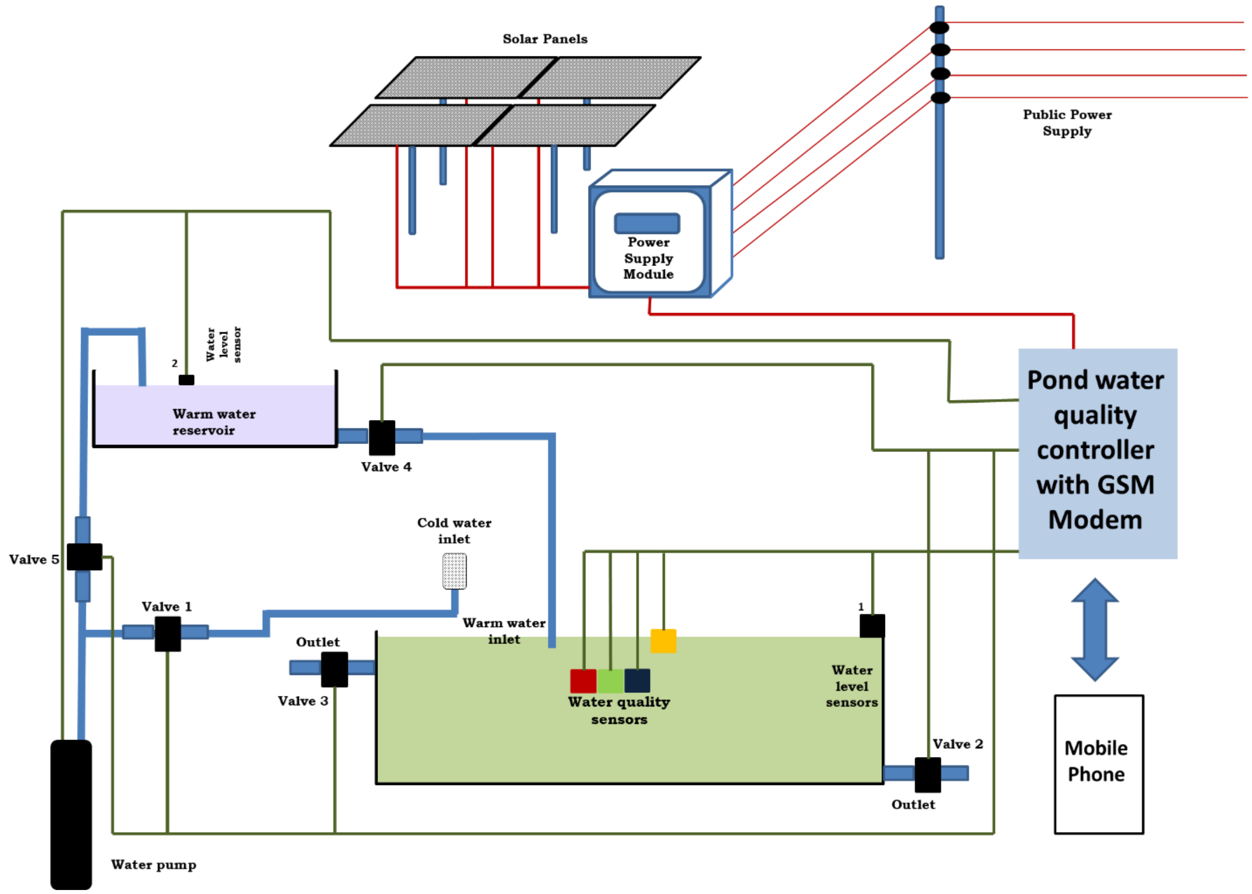

Fig. 1: Conceptual Model of Automated System for Maintenance of Optimum Water Quality in Tropical Fish Culture

Adequate preventive measures are taken by exchange of 10-20% of the pond dirty water with good quality, more oxygenated water on weekly bases and timely replenishment of lost pond water via water exchange facility/system. In monitoring water quality, sensors are used for detecting levels of the four essential water quality parameters and water level while LCD is used for displaying the levels/values. Water exchange facility/system is used for controlling level of the parameters and water level.

The system is designed for use for rearing warmwater fishes in tanks and ponds with **w**ater depth of 1.2 to 2m; pond bottom made up of a layer of clay or concrete or butyl liners; that have a good drainage system and orientation, overflow facility and strong pond bunds and well located.

Subunits of the System

The subunits of the proposed automation system for maintenance of optimum water quality in tropical fish culture are shown in block diagram of figure 2.

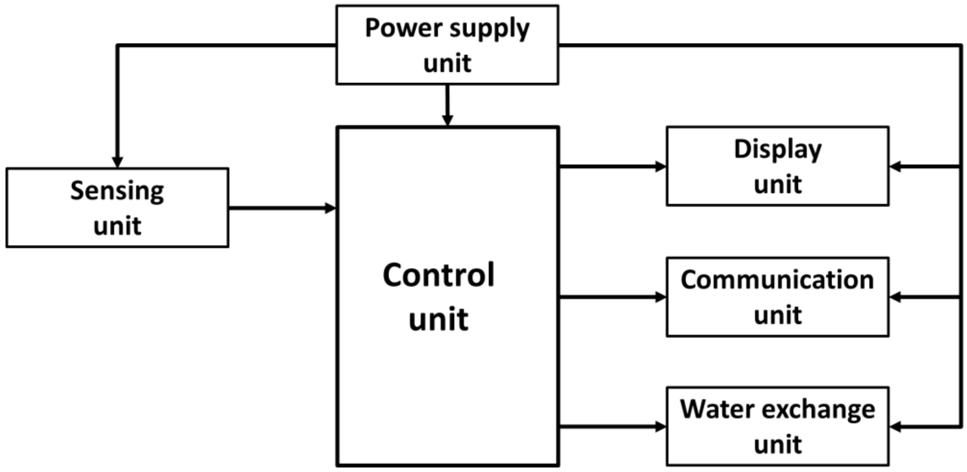

Fig. 2: Block Diagram of the System

Power Supply Unit:

The power supply unit/module of the system is dual power supply system which provides the entire system with regular electric power. The unit is made up of solar power and public power supply, transformer and other components that enable the unit provide the required voltages (5V, 12V and 24V DC) needed by other units of the system. The dual power source system was chosen for this design because it provides a regular supply of electric power even in remote areas where there is no public power supply.

Sensing Unit:

The sensing unit consists of sensors used for sensing (monitoring) levels of the quad-essential fish pond water quality parameters and water level. The sensors are temperature sensor (DS18B20) used for sensing water temperature, ultrasonic ranging module (HC-SR04) for sensing the water level, dissolved oxygen (DO) sensor (Atlas Scientific Kit), pH sensor (Analog pH Meter Kit SKU: SEN0169), and turbidity sensor (SKU: SEN0189). The temperature sensor is suitable for this design because it can detect water temperature from -55°C to 125°C with very good accuracy. The pH sensor's range is 1 to 14, DO sensor's range 0mg/L to 35mg/L and water level sensor's range is 2cm to 400cm.

Control Unit:

Arduino Mega 2560 was used as control unit in this design. The module controls all the subsystems and activities of the system. The Arduino Mega 2560 is a microcontroller board based on the ATmega 2560. Arduino Mega 2560 has 54 input/output pins, more sketch memory and RAM and therefore, suitable for this design that require 23 input/output pins.

Water Exchange Unit:

The water exchange unit or system is used for controlling fish pond water quality parameters. The system consists of water pump, 5 solenoid valves, 6 relay circuits, water pipes and their interconnections. The water pump used in this design is 24V DC type while valves are of12V. Each of the relay circuits consists of a 12V DC relay, diode, transistor and resistor. In this design, base resistor method of biasing is used. 12V DC relay was used in the design because of its mechanical strength to withstand current. As shown in figure 1, the pipe for cool water supply is bent at right angle and faced upwards and has perforated screen fixed on the water inlet (pipe) place high above the pond while pipe for warm water supply is positioned so that its inlet touches pond water. This pipe arrangement enables effective oxygenation and warming of pond water.

Communication Unit:

This unit is used for sending SMS to fish pond manager or farmer about water quality problem and action taken to maintain it, and instructions to erect sunscreen during summer and wind shelter during winter to aid prevention of water quality problems. SIM900A GSM module is used for wireless communication between the automation system and farmers' mobile phone with subscriber identity module (SIM) card while MAX232 IC is used for serial communication between the module and a DTE (data terminal equipment).

Display Unit:

The unit is used for displaying the levels of the quad-essential water quality parameters and water level. One 4 x 20 liquid crystal display (LCD) module was used in this design as display unit. This module was chosen because it has built-in controller (S6A0069 or equivalent), requires +5V power supply, can display 20 characters in each of the 4 rows and can be easily connected and controlled by microcontroller.

Maintenance Operation

The system takes preventive measures against pond water quality problems by weekly exchange of 10-20% of the water depending on the water turbidity and replenishment of water lost in pond or tank through seepage, evaporation and fish feeding whenever the level is about 3cm less than the required level. So, the system regularly monitors water level via pond water level sensor in order to achieve this. The system also sends instructions via SMS to fish pond manager or farmer to erect sunscreen during summer and wind shelter during winter to aid prevention of water quality problems. These preventive measures help in maintaining optimum water turbidity and temperature and these help in maintaining DO and pH since they are influenced by them (AFCD, 2009; Bhatnagar & Al-Mejibli*.,* 2013; Kleinholz, 2017). The system takes control action whenever turbidity, temperature, DO or pH sensor value reaches the optimum/desirable limit. The optimum level of turbidity used in this design is 10-20mg/L or 10-20 NTU (Davis, 1993), temperature is 20-28^{o}C, DO is 5-7.5mg/L and pH is 6.8-9 (Bhatnagar & Al-Mejibli*,* 2013). When any of the levels of these parameters reaches the optimum limit, this indicates a condition not favorable for achievement of optimal fish production and portion of the water will have to be changed. The system changes 20% of the water with appropriate water and then sends an SMS message to the pond manager/farmer's mobile phone informing him of the situation. The automation system exchanges of 20% of warmest surface water with good quality, cool water when temperature reaches its upper optimum limit and exchanges 20% of cooler bottom water with warm water when temperature reaches its lower optimum limit. The system exchanges of 20% of pond dirty bottom water with good quality, cooler and more oxygenated water when turbidity and pH reach their upper optimum limit and DO reaches its lower optimum limit. On the other hand, the system exchanges of 20% of pond dirty bottom water with good quality, more oxygenated water (aeration or oxygenation method) when pH reaches its lower optimum limit and exchanges of 20% of the surface water with warm water when DO reaches its upper optimum limit. In case of low turbidity which rarely occurs in fish culture (occurs in nursery), the system sends SMS to fish farmer to enable him take control action. The system automation checks the levels of water in the pond and reservoir and switches on valve and pump in order to replace lost water if level is less than 3cm. The system then checks whether it is time to exchange 10-20% of the water. If it is the time, it exchange 10-20% of the water and starts control operation on turbidity, temperature, DO or pH of pond water; if it is not the time, it starts control operation. During control operation, the system first checks turbidity level and controls it if it is at the optimum level and executes a longer delay process before repeating the reading of the sensor. If turbidity level is within range, the system then checks temperature level. If temperature level is at the optimum level, the system controls it and executes a longer delay process before repeating the reading of the sensor; if temperature level is within range, the system then checks DO level. The sequence continues till pH level is monitored and controlled. The system starts all over by checking the levels of water in the pond and reservoir.

Advantages

1. The system regularly monitors the four essential water quality parameters even in remote areas where there is no public power supply because it is provided with regular supply via dual electric power source.
2. The automation system controls all the essential water quality parameters via water exchange facility/system instead of controllers that are expensive and provide temporary solutions to the problems. Water exchange provides permanent solutions as it eliminate the root causes of the problems (high temperature, excessive plankton population, decayed and dissolved substances) through water exchange.
3. The system eliminates or reduces the root causes of water quality problems such as water shortage (low volume/depth of water) via replacement of pond lost water.
4. The system controls low temperature by exchanging pond water with warm water and this eliminate problem of mixing of the pond water by direct heating of pond water.
5. The system sends instructions via SMS to fish pond manager or owner to erect sunscreen during summer and wind shelter during winter. Erection of sunscreen during summer and wind shelter during winter in the pond helps in preventing temperature problems that affects other parameters such as DO and pH (AFCD, 2009; FAO, 2005).
6. The system provides optimum water quality for fish culture. It does not allow the parameters to reach critical levels before taking control action.
7. The automation system prevents air pollution caused by poor water quality of fish pond and contamination of land, water bodies and crops caused by poor water quality usually discharged from ponds by fish farmers while controlling water quality.

Conclusion

This work has presented the design of an automation system for optimum water quality maintenance in tropical fish culture. The system takes preventive measures against water quality problems by weekly exchange of 10-20% of the water and replacement of pond lost water and controls pond water quality by exchanging 20% of the water with appropriate water whenever turbidity, temperature, DO or pH level reaches the optimum limit. The system also sends an SMS message to the pond manager/farmer mobile phone informing him or her of the situation and to instruct him to erect sun screen in pond during summer and wind shelter during winter. The electronic system provides an efficient, low-cost automation method for maintaining optimum water quality and improving environmental conditions in tropical fish culture. It is necessary to develop and use the proposed automation system in order to maintain optimum water quality efficiently and achieve optimal fish production at low cost in tropical fish culture.

References

Abinaya, T., Ishwarya, J & Maheshwari, M. (2019). A novel methodology for monitoring and controlling of water quality in aquaculture using Internet of Things (IoT*). International Conference on Computer Communication and Informatics (ICCCI), 23-25 Jan. 2019. Coimbatore, India*

AFCD (2009). Environmental management of pond fish culture. Good Aquaculture Practices Series 3. Agriculture, Fisheries and Conservation Department (AFCD). Retrieved from http//www.afcd.gov.hk

Azhra1, F. H & Anam, C. (2020). IoT-based Automatic Fish Pond Control System. The 6th International Seminar on Science and Technology (ISST), July 25th, 2020, Surabaya, Indonesia. Retrieved from https://www.researchgate.net/ publication/ 343728769 IoTbased_ Automatic_Fish_Pond_Control_System.

Banrie. (2012). Monitoring pond water quality to improve production. The Fish Site. Retrieved from https://thefishsite.com/articles/monitoring-pond-water-quality-to-improve-production

Bhatnagar, A., & Devi, P. (2013). Water quality guidelines for the management of pond fish culture, *International Journal of Environmental Sciences*, *3*(6), 1980-2009.

Bhatnagar, A., & Singh, G. (2010). Culture fisheries in village ponds: a multi-location study in Haryana, India. *Agriculture and Biology Journal of North America*, *1*(5), 961-968.

Bokingkito, P. B., & Llantos, O. E. (2017). Design and implementation of real-time mobile based water temperature monitoring system. *Procedia Computer Science*, *124*, 698–705.

Coche, A. G., Muir, J. F., & Laughlin, T. (1996). Simple methods for aquaculture: management for freshwater fish culture ponds and water practices. Food and Agriculture Organization of the United Nations (FAO) Training Series 21/1.

Davis, J. (1993). Survey of aquaculture effluents permitting and 1993 standards in the South. Southern Regional Aquaculture Centre, SRAC publication, no 465 USA, 4PP.

De Silva, S. S. **(**2016). Culture-based fisheries in Asia are a strategy to augment food security. *Food Security*, *8*(3), 585–596.

FAO. (2005). Fish pond construction and management. A field guide and extension manual. Food and Agriculture Organization of the United Nations (FAO). Retrieved from http://www.fao.org/3/ak506e/ak506e.pdf#page=3&zoom=auto,-12,828

FAO. (2016). The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all. Food and Agriculture Organization of the United Nations (FAO), Rome.

Gatlin, D. M. (2010). *Principles of Fish Nutrition*, Southern Regional Aquaculture Center, SRAC Publication No. 5003.

GOK. (2016). Water quality management for fish farming. State Department of Fisheries. Retrieved January 25, 2017, from http://www.kilimo.go.ke /fisheries/ index .php/ waterquality-management-for-fish-farming

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

Helfrich, L, A. (2021). Fish kills: their causes and prevention. Virginia cooperative extension. Retrieved from https://www.pubs.ext.vt.edu/420/420-252/420-252.html

Idachaba, F. E., Olowoleni, J. O., Ibhaze, A. E., & Oni, O. O. (2017). IoT enabled real-time fishpond management system. Proceedings of the World Congress on Engineering and Computer Science (WCECS), Vol. I, San Francisco, USA.

Kleinholz, C. (2017). Water quality management for fish farmers. Retrieved from http://www.langston.edu/water-quality-management-fish-farmers

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrift, 15(3), 259–263. doi:10.1127/0941-2948/2006/0130.

Kutty, M. N. (1987). Site selection for aquaculture: physical features of water, *Nigerian Institute for Oceanography and Marine Research, Food and Agriculture Organization of The United Nations. Retrieved February 21, 2017, from http://www.fao.org/documents/en/detail/ 69895/*

Lee, P. G. (1995). A Review of automated control systems for aquaculture and design criteria for their implementation, *Aquacultural Engineering*, *14*(3), 205-227.

Little, D. C., Newton, R. W., & Beveridge, M. C. M. (2016). Aquaculture: a rapidly growing and significant source of sustainable food? Status, transitions and potential. *Proceedings of the Nutrition Society, 75*, 274–286.

Mohammed, H. A., & Al-Mejibli, A. (2018). Smart monitoring and controlling system to enhance fish production with minimum cost, *Journal of Theoretical and Applied Information Technology, 96*(10), 2872-2884.

Obado, S. A. (2019). IoT based realtime fish pond water quality monitoring model (Thesis, Strathmore University). Retrieved from http://su-plus.strathmore. edu/ handle/11071/ 6710

Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2014). Small-scale aquaponic food production integrated fish and plant farming, Fisheries and Aquaculture Technical Paper No. 589, 262 pp, Food and Agriculture Organization (FAO) of the United Nations, Rome.

Svobodová, Z., Lloyd, R., Máchová, J., & Vykusová, B. (1993). Water quality and fish health. EIFAC Technical Paper, No. 54. Food and Agriculture Organization of the United Nations (FAO) Rome. Retrieved from http://www.fao.org/3/t1623e/ t1623e.pdf

Ujwala, T. S, Sunita, G. D., Yamuna, S., & Vandana, S. (2020). A review on fish farm aquaculture monitoring & controlling system. *International Research Journal of Engineering and Technology (IRJET), 7*(2), 2880-2887.

Wang, Y., Qi, C., & Pan, H. (2012). Design of remote monitoring system for aquaculture cages based on 3G networks and ARM-Android embedded system. *Procedia Engineering*, *29*, 79–83.