RESEARCH ARTICLE

Smart Electronic System for Prevention of Water Quality Problems in Fish Culture

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ABSTRACT

This paper presents the development of a smart electronic system for prevention of water quality problems in fish culture. The aim the work was to help fish farmers adequately prevent water quality problems and maintain optimum water quality in fish culture required for optimal fish production. The methods used in the development include designing and analysis, hardware implementation, program and application development and testing. The main components of the system are controller, water pump, solenoid valves, servo motors, GSM module, temperature, dissolved oxygen, pH and turbidity sensors and liquid crystal display. Arduino Mega 2560 was used as controller in the system. The developed system exchanges bottom dirty water with clean and more oxygenated water, replenishes pond whenever there is water shortage, erects sun shade and windbreak, discharges excess water caused by rain and adjusts whenever any of temperature, DO and pH reaches optimum level in fish culture. The system also provides information about water quality and preventive maintenance operation undertaken to operator of pond or tank via app installed in Smartphone. The developed system prevents air pollution and contamination of land, water bodies and crops associated with poor quality water usually discharged from ponds by fish farmers while controlling water quality. It was urged that this design should be adopted in developing water quality control system for fish culture in order to adequately prevent water quality problems and effectively maintain optimum water quality.

Keywords: Smart Electronic System; Fish Culture; Water Quality; Preventive Maintenance

Introduction

There has been increased awareness on the importance of food such as fish to humans globally and this has brought about sharp increase in demand of fish products. The increasing population pressure in the world has also contributed to increase in demand of fish products (De Silva, 2016; FAO, 2016). So, to meet this elastic demand of present food supply, fishes are raised in ponds and tanks (fish culture) by farmers. Successful fish culture 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 (Gatlin, 2010; Little, Newton & Beveridge, 2016). Optimum water quality maintenance is achieved by keeping the quad-essential water quality parameters (oxygen, temperature, pH and turbidity) in optimal condition (Coche, Muir, & Laughlin, 1996; GOK, 2016).

Conversely, non-maintenance of optimum water quality causes poor water quality recognized by water quality problems and this hinders achievement of optimal production. According to AFCD (2009) and FAO (2005), water quality problems are caused by environmental phenomena and mismanagement. Water quality problems may cause poor development and growth, weakness and poor health and death of fishes amongst others (Bhatnagar & Devi, 2013; Svobodová, Lloyd, Máchová, & Vykusová., 1993). 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 (Towers, 2015). 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).

Conventionally, water quality 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. These methods are strenuous, tiresome, time consuming (Bokingkito & Llantos, 2017) and pone to errors (Helfrich, 2021). Currently, most of the automated electronic systems developed for maintaining or managing water quality in fish culture only monitor water quality while few of them monitor and control water quality. Although use of these electronic control systems may lead to the achievement of optimal fish production and improvement of the basic environmental conditions (Wang, Qi, & Pan, 2012), they have not been commonly used in fish ponds (Mohammed & Al-Mejibli, 2018). These systems do not take adequate preventive measures against water quality problems. In addition, the systems carry out real-time water quality monitoring continuously and take action only when any of the water quality parameters reaches critical level (high or low level); so, they do not maintain optimum water quality. This work is aimed at developing a system that will help fish farmers adequately prevent water quality problems and maintain optimum water quality required for optimal production in fish culture.

Literature Review

The works reviewed in this section includes works on water quality problems, conventional methods of controlling water quality, preventive measures and their application by electronic systems used for water quality control in fish culture.

Water Quality Problems

Water quality problems in fish culture are mainly recognized by problems of the quad-essential water quality parameters; temperature, DO, pH and turbidity (Coche et al., 1996; GOK, 2016). These parameters influence fish production and each other and they are influenced by many other factors such as surrounding environment (Somerville, Cohen, Pantanella, Stankus, & Lovatelli, 2014). The water quality problems include high or low temperature, DO, pH and turbidity and may develop suddenly from environmental phenomena or gradually through mismanagement. The effects of water quality problem or poor water quality in fish culture are numerous and include poor development and growth, weakness and poor health of fishes and death of fishes among many others. Moreover, the problems of other water quality parameters such as ammonia, salinity, alkalinity, hardness (Fowler et al., 1994), nitrite, carbon dioxide and hydrogen sulphide (Banrie, 2012; Kleinholz, 2017) are linked to the problems of the quad-essential water quality parameters (Bhatnagar & Devi, 2013) and can be solved by one or combination of the methods used in solving problems of the quad-essential water quality parameters.

Conventional Methods of Controlling Water Quality

The conventional methods of controlling water quality in fish culture involve measures such as taking of adequate precautions, monitoring and performing tasks that ensure the achievement of optimum water quality. While water quality is monitored by physical observation or with tools (Kleinholz, 2017), the tasks performed for ensuring optimum water quality include addition or subtraction of substances or removal and replenishment of pond. Water quality control can be effective only when adequate preventive measures are taken against water quality problems (AFCD, 2009; Bhatnagar & Devi, 2013; Coche et al., 1996). The preventive measures for water quality problems are taken against problems associated with pond design and water and environmental phenomena such as rain, sun and wind.

Preventive Measures against Problems Associated with Pond Design

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. The actual size of pond is decided with reference to the species to be stocked and age so that water quality and stocking are not affected negatively (FAO, 1987). Artificial ponds with depth of 1- 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 caused by water shortage due to the loss are prevented with pond bottom made up of a layer of clay

(Marine. 2015) or concrete or butyl liners (Boyd & Chainark, 2009). 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.

Preventive Measures against Problems of Pond Water

Problems associated with pond water are prevented by taking precautionary measures on water source and depth/volume, population of fishes, concentration of dissolved substances and suspended particles (turbidity) and feeding style. The use of good quality water such as underground water or groundwater and natural waters for filling and replenishing water lost through seepage and evaporation in ponds or tanks helps in preventing water quality problems such as turbidity, pH and DO problem. Groundwater has less impurities and pollutants, normal pH range of between 6 and 8.5 (AFCD, 2009) and low oxygen and temperature levels (FAO 2005). Natural waters (waters of lakes and rivers) containing less impurities and pollutants are also used as sources of water in fish culture especially in large ponds. On the other hand, pond is replenished with good quality water whenever there is water shortage caused by evaporation and seepage in order to maintain a constant level or volume. Replenishment of pond water helps in preventing water quality problems such as high temperature and turbidity caused by shortage of pond water resulting from water loss and problems associated with them. Optimum number of fish and turbidity and fish feeding rate are maintained in order to prevent problems of the quad-essential water quality parameters. According to AFCD (2009), most water quality problems are avoided by maintaining fish stocks less than 2,000 lbs/acre and feeding rates less than 30 lbs/acre, dissolved substances and suspended particles at optimum levels based on wildly accepted recommendation. Plankton population is maintained at approximately 3000-4500 plankton per liter which is seen as pale colour, light greenish or greenish waters (Kleinholz, 2017; National Agricultural Extension and Research, 1996). Maintenance of optimum turbidity is achieved by water exchange, filtering of pond water or use of settling basin or silt catchment basin (Carballo, Eer, Schie, & Hilbrands, 2008).

Preventive Measures against Problems of Environmental Phenomena

Problems associated with environmental phenomena are prevented by taking precautionary measures against solar radiation entering pond, wind blowing towards pond and rainwater entering pond. Pond water quality problems associated with intense sun light such as high temperature and associated low DO and net withdrawal of carbon dioxide (high pH) as a result of photosynthesis especially when the phytoplankton turbidity is high are commonly prevented by shading part of the pond (AFCD, 2009; GOK, 2016). In addition, pond water temperature variations caused by sun light is prevented by exchanging whole or portion of the pond water with cool water during summer (FAO (2005). Conversely, pond water quality problems associated with excessive wind such as low temperature in winter and low pH especially during cloudy weather are commonly prevented by sheltering pond or use of windbreak or wind shade (Barange et al., 2018). On the other hand, water quality problems associated with heavy rain are prevented by use of overflow pipes in ponds and tanks. Rain makes pond water to be acidic and causes overturn of lower, less oxygenated water in deep ponds when it is heavy (Coche et al., 1996; GOK, 2016). Rain is acidic (pH of about 5.6) because of the dissolved carbon dioxide in the air (AFCD, 2009). The overflow pipe is a medium through which excess water such as rain water falling into the pond can flow out.

Preventive Measures taken by Electronic Systems used for Water Quality Control in Fish Culture

Various designs of automated electronic systems have been proposed or developed for controlling water quality in fish culture. Preventive measures taken by some of the electronic systems on pond water and against environmental phenomena such as heavy rain, harsh sun and wind are reviewed herein. In one of the works, Idachaba, Olowoleni, Ibhaze, and Oni (2017) proposed Internet of Thing (IoT) enabled real-time fish pond management system. 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. This system does not replenish pond when there is water shortage, nor provide sun shade, windbreak and overflow facility for preventing water quality problems. In another work Harun and Hashim (2018) developed a real time fish pond monitoring and automation system using Arduino. 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 replenishes pond when

there is water shortage and does not discharge or drain dirty water nor provide sun shade, windbreak and overflow facility for preventing water quality problems.

A smart monitoring and controlling system were developed by Mohammed and Al-Mejibli (2018) to enhance fish production with minimum cost. The system monitors temperature, pH, DO, total dissolved solids (TDS) and water levels and controls all the parameters except pH. The system filters water when turbidity is high and replenishes pond when there is water shortage and does not provide sun shade, windbreak and overflow facility for preventing water quality problems. Obado (2019) developed a system for monitoring and controlling fish pond water quality titled IoT based real time fish pond water quality monitoring model. This system monitors and controls temperature, turbidity and water levels. The system exchanges water through water pump connected to a reservoir tank and outlet when turbidity is high and replenishes pond when there is water shortage and does not provide sun shade, windbreak and overflow facility for preventing water quality problems. Abinaya, Ishwarya and Maheshwari (2019) designed another version of 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. The system replenishes pond when there is water shortage and does not discharge or drain dirty water nor provide sun shade, windbreak and overflow facility for preventing water quality problems.

Azhra and Anam (2020) also designed another version of IoT based system for monitoring and controlling water quality. The system was titled IoT-based automatic fish pond control system. According to the authors the system monitors and controls temperature, pH, DO, turbidity, salinity, ammonia and conductivity levels. The system does not replenish pond when there is water shortage nor provide sun shade, windbreak and overflow facility for preventing water quality problems. In the works reviewed, none of the systems takes adequate preventive measures against water quality problems in fish culture; the common preventive measures taken by majority of them are replenishment of pond when there is water shortage and draining of dirty (turbid) water. Preventive measures such as erection of sun shade and windbreak for preventing temperature and pH variations, and discharging of excess water caused by rain in ponds are not undertaken by the systems. These systems provide temporary solutions to water quality problems because they do not eliminate or eradicate the cause of changes in water quality via adequate preventive measures.

System Development

The system was developed based on information gathered from literature review, visits to 42 fish farms and interviews conducted for 33 farmers with at least five years experience in fish culture in eastern part of Nigerian. The information gathered confirmed that fish farmers lack automatic electronic systems for prevention of water quality problems and maintenance of optimum water quality in fish culture and majority of them do not apply all the conventional preventive measures against water quality problems. The development of the preventive maintenance system involved designing and analysis, hardware implementation, program and application development and testing.

System Design

In this design, the system exchanges pond bottom dirty (turbid) water with clean and more oxygenated water, replenishes pond when there is water shortage, erects sun shade and windbreak, discharges excess water caused by rain in fish pond, adjusts whenever any of temperature, DO and pH reaches optimum level and provides information about pond water condition to operator or owner of fish pond. The adjustment is made by exchange of portion of the pond water. The value of optimum temperature, DO and pH levels used for the development of this system was based on the general ranges recommended by Bhatnagar and Devi (2013) and the value for turbidity was based on the range recommended by (Davis, 1993). The optimum level is reached before critical level; so, it is easier to control water quality or maintain optimum water quality at this level than at the critical level when problem is about to be established.

The subunits of the preventive maintenance system as shown in block diagram of figure 1 include power supply, sensing, control, water exchange, display, sun and wind control and communication units.
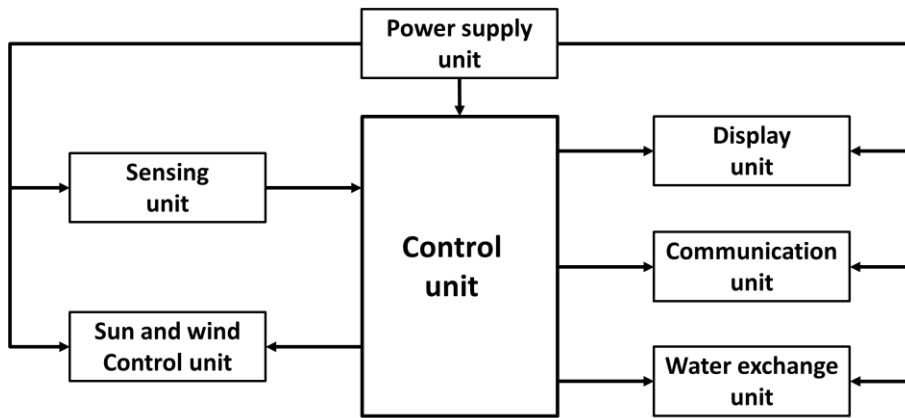
Figure 1: Block Diagram of the System

Power Supply Unit:

The power supply unit consists of dual power source (public power source and solar power system) that provides constant 24V DC power to water pump, 12V DC to seven relay circuits and six solenoid valves and 5V DC to microcontroller, liquid crystal display (LCD), two servo motors, GSM module and seven water quality monitoring and maintenance sensors. The input power of 24V is supplied by solar power system or public power supply via transformer through the help of automatic change-over switch.

Sensing Unit:

The sensing unit consists of SKU: SEN0189 (gravidity Arduino turbidity sensor) for monitoring turbidity, 2 DS18B20 temperature sensors for monitoring pond water and air temperatures, 2 HC-SR04 ultrasonic sensors for monitoring pond and reservoir water level respectively, 1 Atlas Scientific Gen 2 Dissolved Oxygen Probe for monitoring pond water dissolved oxygen and 1 SKU: SEN0169 pH meter pro for monitoring pond water pH and their interconnection network. The sensors are Arduino-based sensors; they have measurement ranges suitable for this design, consume less power (about 5V) and are easily calibrated and connected to Arduino microcontroller.

Control Unit:

Arduino Mega 2560 was used as control unit in this design. The control 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 26 input/output pins.

Water Exchange Unit:

This unit is responsible for exchanging portion of pond water whenever the water turbidity, temperature, DO or pH reaches its optimum level, replenishing pond when there is water shortage and discharging excess water caused by rain. The unit consists of 7 relay circuits, 6 valves (12V DC 3/4-inch diameter solenoid valves) and a 210W 24V DC borehole pump (water pump), and their interconnection network and piping system. First valve is connected to cool water inlet with perforated screen at its end fixed at right angle to the pipe and it controls the cool water inlet; the second valve controls pond bottom water outlet; the third valve controls pond upper water outlet, the fourth valve controls warm water inlet; the fifth valve controls warm water reservoir inlet and the sixth valve is connected to overflow pipe.

Sun and Wind Control Unit:

The sun and wind control unit consists of two servo motors and their interconnections. One of the servo motors is fixed to a sun shade system while the other motor is fixed to a windbreak system. The DS3218MG servo motor was selected for this work because it is a digital motor that has stall torque of 20.5kg-cm and operating voltage of 4.8V to 7.2V, **high precision, good heat dissipation** and rotation angle of 270° and draws only 100-250mA during movement. In this design, a servo motor rotates 90° to set sun shade or windbreak. The sun shade is erected whenever air temperature reaches the upper optimal limit of pond water temperature (28°C) to reduce solar radiation entering water and prevents high temperature problem while wind break is erected when air temperature reaches the lower optimal limit (20°C).

Display Unit:

The display unit is made up of 2x16 Liquid-Crystal Display (LCD) module. The unit displays levels of water quality parameters and water level. The 2x16 LCD was chosen because it displays meaningful information onto its screen, requires +5V power supply, easy to connect and can display 16 characters in each of the 2 rows at any instance of time.

Communication Unit:

This unit consists of GSM module and Smartphone with Application for communicating with the microcontroller. SIM900A GSM module was used as the GSM module for wireless communication between the microcontroller of the system and a Smartphone. The GSM module was chosen for this design because it has an on-board voltage level converter and operates in real time. Pond Water Quality Maintenance Record Application (PWQMR app); a mobile application was developed and used for providing information about the levels of water quality parameters and preventive maintenance operation performed. The circuit diagram of the preventive maintenance system is shown in figure 2.
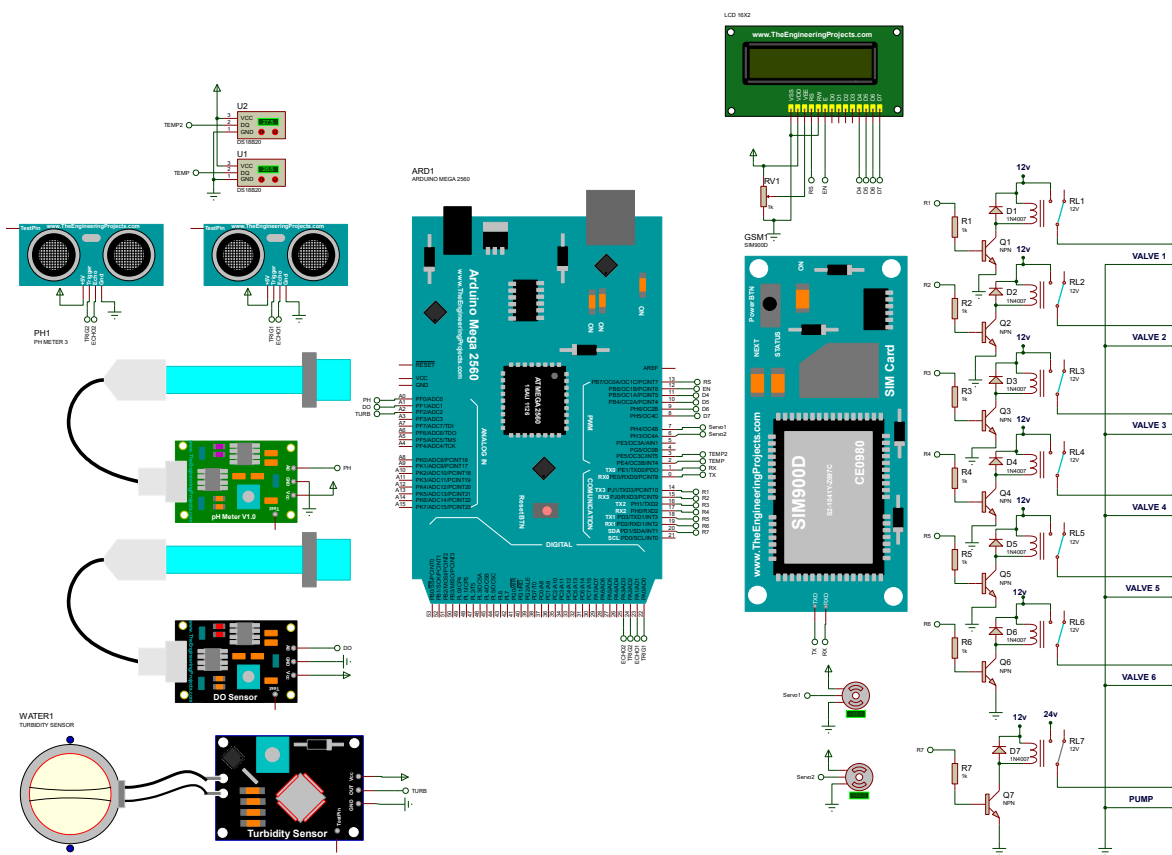

Figure 2: Circuit Diagram of the Preventive Maintenance System

System Implementation

The system was implemented based on the design. The hardware component of the system was constructed before program and app were developed and installed in microcontroller and Smartphone respectively. The system was implemented by first testing hardware components (including calibration and validation of sensors), then constructing the circuit and finally installing sensors, valves and servo-motor system. The system is designed to be used in shallow and small fish ponds and tanks (not larger than 45m^2 ad deeper than 2m); so it was installed on a 1m x 1m x 1.2m concrete pond. One inch diameter pipes were used in connecting the pump's outlet to ground level while the valves were installed using ¾ inch diameter pipes and sitting. The cool water outlet has perforated screen fixed at right angle at its end to serve as water fountain. The water temperature, DO and pH sensors were installed inside a plastic basket at the middle of the pond via a lever while turbidity sensor was fixed above the surface of pond water near one edge of the pond. 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 installed in this same manner. The snapshot of the implemented system showing cool water and warm water inlets, air temperature sensor, pond water level sensor, turbidity sensor, water temperature, DO and pH sensors inside basket enclosure and windbreak (frame with white tarpaulin) is shown in figure 3.

Operation of the System

The system takes adequate preventive measures against water quality problems and maintains optimum water quality. The summary of the operation of the system is depicted in table 1.

Table 1: Summary of the operation of the system

S/No	Sensor	Parameter level	Action taken by system
1	Water temperature	28°C	Exchange of 20% of upper pond water with cool, clean water and oxygenation (cooling of pond water).
2	Water temperature	20°C	Exchange of 20% of bottom pond water with warm, clean water (warming of pond water).
3	DO	7.5 mg/L	Exchange of 20% of upper pond water with warm, clean water (deoxygenation).
4	DO	5 mg/L	Exchange of 20% of bottom pond water with cool, clean water and oxygenation.
5	pH	8.5	Exchange of 20% of bottom pond water with cool, clean water (carbonation).
6	pH	6.8	Exchange of 20% of bottom pond water with cool, clean water and aeration.
7	Turbidity	20 mg/L	Exchange of 20% of bottom pond water with cool, clean water and oxygenation.
8	Turbidity	10 mg/L	Communication of information about the condition (rare condition).
9	Water level	117cm to 120cm	No action.
10	Water level	117cm	Replenishment of pond
11	Water level	Greater than 120cm	Discharge of excess water from overflow pipe.
12	Air temperature	28°C	Setting of sun shade.
12	Air temperature	20°C	Setting of windbreak.

The system also displays the level of any pond water maintenance parameter on LCD and sends water quality condition (level of pond water quality parameters and maintenance action taken) to smart phone application (PWQMR app) via GSM module.

System Test

The system test was performed after implementation of the system. The 1m x 1m x 1.2m concrete pond was prepared and stocked with 60 tilapia fishes with average weight of 0.46kg each. Sixty fishes were stocked based on Food and Agricultural Organization (FAO) 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 observed for two months in order to assess its performance.

Results

The result of the system test showed that the pond water turbidity reached its upper optimum limit of 20mg/L on February 6, 2023 while air temperature reached its upper optimum limit of 28°C on February 12 and 24 2023 afternoon. When turbidity reached its upper optimum limit; the LCD displayed the turbidity value, smart phone received the turbidity information and the system exchanged 20% of the dirty bottom water with clean, more oxygenated water in order to maintain optimum turbidity and prevent water quality problems associated with high turbidity. The process of replenishing discharged 20% of the dirty bottom water with clean, more oxygenated water is shown in figure 3.

Figure 3: Snapshot of the Process of Replenishing Discharged Pond Bottom Water by the System

When air temperature reached its upper optimum limit the LCD displayed the temperature value, smart phone received the pond turbidity information and the sun shade was set. The snapshot of the notification received by the Smartphone when sensed air temperature was 28°C is shown in figure 4.

Figure 4: Air Temperature Condition Notification

Conclusion

The smart electronic system for prevention of water quality problems in fish culture developed in this work exchanges bottom dirty (turbid) water with clean and more oxygenated water, replenishes pond when there is water shortage, erects sun shade and windbreak, discharges excess water caused by rain and adjusts whenever any of temperature, DO and pH reaches optimum level in fish culture. The system also provides information about pond water quality and preventive maintenance operation undertaken to operator or owner of pond via app installed in Smartphone. The developed 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. The system therefore, helps in improving the basic environmental conditions of fish culture sites.

Recommendations

The system developed in this work can be used in a variety of fish ponds and tanks with or without additional components.

1. It is recommended that this system be used in fish ponds and tanks with area and depth not greater than $45m^2$ and 2m respectively in order to adequately prevent water quality problems and achieve optimum water quality required for optimal fish production.
2. The system cannot function efficiently in ponds and tanks that are deep and large because more sensors are required for determining water quality. So, it is recommended that more sensors and components are integrated in the system for deep ponds and tanks.
3. 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 PWQMR app to appropriate levels.
4. It is recommended that developers should adopt the design of this system in order to produce efficient water quality control systems for 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. 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

Azhra, 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

Barange, M., Bahri, B., Beveridge, M. C. M., Cochrane, K. L., Funge-Smith, S., & Poulain, F. (2018). Impacts of climate change on fisheries and aquaculture- synthesis of current knowledge, adaptation and mitigation options. *Food and Agriculture Organization of the United Nations (FAO). Technical Paper. No.627, 491-500.*

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

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.

Boyd, C. E., & Chainark, S. **(**2009). Advances in technology and practice for land-based aquaculture systems: ponds for finfish production. *In* G. Burnell & G. Allen, eds. *new technologies in aquaculture*, pp. 984–1009. Boca Raton, USA, CRC Press.

Carballo, E., Eer, A. V., Schie, T. V., & Hilbrands, A. (2008). Small-scale fresh water fish farming. Agrodok 15.

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.*

Fowler, P., Baird, D., Buklin, R., Yerlan, S., Watson, C., & Chapman, F. (1994). Microcontrollers in Recirculating Aquaculture Systems, University of Florida, EES-326.

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*

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.

Marine, S. (2015). A technical standard for Scottish finfish aquaculture. Edinburgh, UK, The Scottish Government, pp 103.

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.

National Agricultural Extension and Research. (1996). Water quality management in fish culture, Extension Bulletin No. 98 Fisheries Series No 3, Nigeria: Liaison Services Ahmadu Bello University, Zaria.

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. Retrieved from http://www.fao.org/3/ai4021e/i4021e02.pdf

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*

Towers, L. (2015). How to achieve good water quality management in aquaculture. Retrieved March 18, 2019, from https://thefishsite.com/articles/how-to-achieve-good-water-quality-management-inaquaculture

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.