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RIVER WATER QUALITY MONITORING EQUIPMENT AND CONTROL BASED ON WIRELESS SENSOR NETWORKS

Afolabi M. O.[1], Oluborode G. B.[2]* and Agbi J. I.[3]

[1,3]Department of Physics and Electronis, Adekunle Ajasin University, Akungba Akoko, Ondo State.

[2]National Institute for Freshwater Fisheries Research, P. M. B. 6006, New Bussa, Niger State.

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***Corresponding Author**
Oluborode G. B.
National Institute for Freshwater Fisheries Research, P. M. B. 6006, New Bussa, Niger State.

ABSTRACT

We have designed and presented a wireless sensor network monitoring and control equipment for Rivers. The developed monitoring equipment consisted of five units: data monitoring nodes, data base station, remote monitoring center, power supply unit and display unit. The power supply unit consisted of solar cells and lithium cells. The dissolved oxygen sensor, pH electrode, temperature sensor, turbidity sensor, conductivity sensor and depth sensor present in data monitoring mode were used to measure and monitor the water quality parameters of River Niger in Nigeria. A microcontroller chip was used for processing data collected; GPRS modules were also used for data transmission to the remote monitoring center. Various parameters of the River such as dissolved oxygen, temperature, electrical conductivity, pH, turbidity and water level were detected and control in real time. The water quality parameters were sent through short messages from the base station via the Global System for Mobile (GSM) module for notification. The water pH was found to range from 7.1 to 7.43 with temperature range from 27.3°C to 29.8°C. Other physicochemical parameters values monitored did not exceed the recommended values for surface water quality. Experimental results obtained using this locally developed monitoring equipment showed that the equipment is more reliable for large scale deployments on water quality in Rivers.

KEYWORDS: Microcontroller**,** water parameter, multiparameter, monitoring.

INTRODUCTION

Water is one of the basic needs for all living organisms on earth. For example, all plants and humans cannot survive without water. Thus, it is of utmost importance to maintain this valued resource so that it can be utilized by humans and others in a sustainable way (Juwana et al., 2014). However, the increased human population and anthropogenic activities have resulted in pressure on both quantity and quality of water resources (Ciavola et al., 2014; Goonetilleke and Thomas, 2003; Gray, 2005). Thus, nowadays there is not only a lack of water availability but water quality degradation is also a big challenge across the world. In terms of water quality, Biswas et al. (1997) highlighted that in many countries water quality considerations are receiving an increasing attention because of their adverse impacts on the health of people as well as on ecosystems. Therefore, to maintain and improve water quality, an adequate understanding of water quality management is required. Water quality management is a term used for all aspects of water quality problems relating to the suitability of various water uses (Krenkel, 2012). One of the important elements of water quality management is monitoring the quality of water resources. This monitoring is undertaken by collecting relevant information on the physical, chemical and biological categories of water quality (Asadollahfardi, 2014). Each category has a number of parameters (Swamee and Tyagi, 2007). The collected information obtained from these categories of water quality is then used to perform a complete assessment in evaluating quality of water bodies.

(Chapman, 1996). This assessment provides basic data for detecting trends, for providing water quality information to water authorities, and for making necessary decisions or recommendations for future actions (Sutadian et al., 2016). However, as discussed in Biswas et al. (2014), monitoring all water quality parameters with different sources of pollution (e.g. those entering a river basin) is a difficult task since it is laborious and expensive. Somlyódy (1995) has indicated that insufficient funding, particularly in developing countries, is one of the most common barriers to conduct regular monitoring programs. Considering the above facts, the water authorities should establish priorities for resource allocation and develop monitoring programs effectively for future development of sustainable water quality management. There are a few approaches to assess water quality. In river water, traditionally it is done through assessing its compliance with the permissible limit values as defined in the water quality guidelines or objectives (de Rosemond et al., 2009). This approach is carried out on a parameter by parameter basis (CCME, 2001). However, this traditional assessment cannot provide sufficient amount of information on the general status of water quality spatially and temporally (Kannel et al., 2007). Another approach, which is commonly used is the use of multivariate statistical techniques. These techniques include cluster analysis and principal component/factor analysis (PCA/PFA), which can also be used to assess river water quality.

This approach aims to identify dominant sources of river pollution spatially and temporally using the similarity of water quality characteristics (Juahir et al., 2011; Kowalkowski et al., 2006; Petersen et al., 2001; Shrestha et al., 2008; Wang et al., 2013). These techniques are suitable to be used with large and complex water quality data obtained from different monitoring stations. But the results of this approach are not always easy to interpret. Moreover, the interpretation of the results tends to be based on assumptions or priori knowledge that may be difficult to obtain. One of the very important approaches considered in water quality assessments is the use of time series analysis. It is commonly used for forecasting the future value of the investigated parameters, based on time series data of other water quality parameters (Asadollahfardi, 2014 and Georgakarakos et al., 2006). Nevertheless, this approach needs high observation frequency and long periods of monitoring data (Chapman, 1996). Another approach used to assess river water quality is through the use of water quality simulation models in order to predict impacts of water management policies and practices on the water quality (Loucks et al., 2005). Nevertheless, using water quality simulation models is not easily applicable as it requires significant efforts (Koçer and Sevgili, 2014). This difficulty is caused mainly due to the need for a large amount of data, significant financial resources, and expertise for model development and application.

II Impact of Water Quality Parameters

In this research work, the most important water quality parameters such as dissolved oxygen, pH, temperature, conductivity, water level and turbidity are described with insights on how these parameters influence each other. Table 1 gives an overview of the water quality parameters with their standard values.

Table 1: Designated use and Standard values

Parameters	Designated Use	Standard values	Recommended Agency
PH	General Agriculture	6.0 – 8.5	USEPA
	Irrigation water	4.5 – 9.0	USEPA
	Human Consumption	5.0 – 9.0	WHO/ICMR
	Freshwater aquatic life	6.5 – 9.0	WHO/ICMR
	Marine aquatic life	6.5 – 8.5	USEPA
Turbidity	Human Consumption	1 – 5	WHO/ICMR
	Freshwater aquatic life	1 – 50	USEPA
Conductivity	Human Consumption	30 – 80	WHO/ICMR
Dissolved Oxygen	Human Consumption	5	WHO/ICMR
	Freshwater aquatic life	5 – 7	USEPA
Temperature	Freshwater aquatic life	26 – 30	Literature
Depth	-	-	-

A. Dissolved Oxygen (DO)

The relevance of monitoring the level of dissolved oxygen in rivers is very important. For the African catfish, a farmer should try as much as possible to maintain dissolved oxygen levels at between 4mg/liter to saturation levels in the rivers. Gas bubble disease can happen to the fish when DO levels are consistently too high and the water is super-saturated to well above 300 per cent. When DO level is consistently between 1.5mg/liter to 5mg/liter, fish will be alive, but feed intake will reduce. Growth rate will also reduce and high Feed Conversion Ratios (FCR) will be recorded. When DO levels are lower than 1.5mg/liter, fish will be stressed and they will die. The periods of achieving desired weights in fish will be lengthened and ultimate loss on investment will occur. Infact, I can categorically emphasize that with consistently low levels of DO in rivers, the use of low quality feed might even be a waste of money. This is simply because of the fact that fish breathe in oxygen for general body metabolism. DO is needed to help breakdown any potentially harmful metabolic waste into less harmful forms, e.g ammonia (NH_3) broken down into nitrites (NO_2) and then into nitrates (NO_3).

B. Temperature

Unlike man that is warm blooded, fish are cold blooded. The metabolism which occurs in their bodies is greatly influenced by the water temperature. For the Freshwater aquatic life, an acceptable temperature range is between 26ºC to 32ºC. When water temperature in the rivers consistently stays between 16ºC and 26ºC, feed intake reduces and fish growth rate also drags tremendously. A farmer will record high FCR, and the fish will also be stressed. Prolonged stress can open up the fish to opportunistic infections. When fish are consistently exposed to temperatures below 15ºC, fish growth will ultimately stop and death is just around the corner. Low temperature negatively affects rates at which wastes are converted in the water. However, when water temperature is above 32ºC, the resultant effect on the Freshwater aquatic life in not good at all. This is because of the fact that Oxygen is not readily soluble in very warm water. High temperature in ponds will stress the fish and eventually lead to death.

C. pH

pH is the level of the Hydrogen ion present in the water. For the fish in the rivers, acceptable pH value is between 6.5 to 7.5. When it is below 4, fish will die due to water acidity. When pH is constantly between 4 to 6, fish will be alive, but, due to stress, will experience slow growth. Feed intake will be highly staggered and reduced. FCR will also be very high. Infact, for the observant fish farmer, low pH in pond water is an indication of high CO_2, (carbon dioxide) in the water. High pH values of between 9 to 11 in pond water will also retard fish growth. Fish will ultimately die when pH levels rise above 11. Low pH aids higher proportions of ionized ammonia which is less toxic to fish. The reverse is the case with high pH in water. There is nothing as painful as being ignorant of these facts. These water parameters play a major role in the overall business of profitable fish farming. Making profit from fish farming really goes beyond just giving food to the fishes. Water Quality parameters must be monitored and acceptable ranges must be maintained. Growth time of fish in ponds must be within acceptable times. Nothing is as painful as keeping fish in ponds for an unnecessary long period of time while money is being wasted on feed.

D. Turbidity

Turbidity can be caused either by planktonic organisms or by suspended soil particles. The turbidity due to silt and clay particles is also known as inorganic turbidity and can interfere with the penetration of light and by absorbing nutrients present in the water and in turns affects the growth of benthos. This can cause uneasiness and stress to the shrimp leading to disease. Suspended clay particles (>4% by volume) damage the gills of prawns by clogging it. In certain cases, oxygen deficiency has also been reported as a result of sudden increase in turbidity. Turbidity due to both plankton density and suspended silt and clay particles can be measured in terms of transparency using Secchi disc. High value of transparency (>60 cm) is indicative of poor plankton density and therefore water should be fertilized with right kind of fertilizers. Low value indicates high density of plankton and hence fertilization rate and frequency should be reduced. The optimum range of transparency is 25 – 35 cm. Transparency less than 20 indicates that the water is unsuitable for shrimp culture and should be changed immediately to flush out excess bloom. It is wrong notion that intake of plankton rich water is good for initial filling. Clear water is best suited.

E. Conductivity

Conductivity is a good rough guide to the condition of rivers. It measures how much 'stuff' there is dissolved in the water. And water which are polluted usually have more 'stuff' dissolved in them than those that are clean. The good thing about conductivity is that with a portable meter you can get a result that's almost as good as a laboratory can produce. This isn't true for most other pollution measurements where to get a useful result you usually need to get an expensive laboratory test. Conductivity below about 250 and the water will usually turn out to be in pretty good shape. Over 600, and usually there will be problems. Between these two values and you need to look carefully. I was looking at village water with conductivity of 1100 the other day – and that definitely has problems. Not so far from here, we were looking at a possible. The water had a conductivity of 700 and so not much chance it would be unpolluted. As water chemistry specialists will know conductivity is only a rough guide to pollutant levels – but you can make surprisingly good assessments of the overall impact of pollution is you interpret it carefully.

III Releated Work

Nasser, Ali, Karim and Belhaouari (2013) proposed paper institute and developed a self-configurable, reusable and energy efficient WSN- based water quality monitoring system. Existing frameworks though have the applicability in water monitoring system, cannot be reused in other monitoring applications because of its static nature. Moreover this dynamic framework also improves the network life time, monitor the water quality real time, and store the information in a portal.

B O'Flyrm, R Martinez, J.Cleary, C.Slater, F.Regan, D.Diamond and H. Murphy (2007) developed a multisensory system measuring water parameters such as temperature, dissolved oxygen, conductivity, ph, turbidity, phosphate and water level for water quality monitoring. The market demand for novel, miniaturized, intelligent monitoring systems for freshwater catchments, transitional and coastal waters is high very across worldwide. Moreover they also work on building custom sensors and integration of Tyndall based integrated sensor network.

Barabde and Danve (2015) paper presented three layers of system architecture of water quality monitoring system. Those three are nodes for data monitorization, a base station and a remote station. They connected all the layers with wireless communication protocol and data being send to the base station from data monitoring nodes via microcontroller. Collected data was displayed on a local host PC. Matlab was used to create a GUI (graphical User Interface) for data visualization and water parameters such as ph, turbidity, conductivity were displayed. If the compared value exceeds standard value a SMS will be sent to the client.

Wang, Ma and Yang (2011) focus on theoretic issues such as routing algorithm, network lifetime, and so on and apply wireless network into online zigbee and GPRS based water monitoring system. Data transmission was done by zigbee protocol and data collected by GPRS shield. MySQL was employed in the database side.

Yazhini and Maruthi (2017) proposed model showed us how internet of things platform can be used for water management. Remote Sensing techniques and Internet of things can be applicable for wider spectrum of research domain for monitoring, collecting and analyzing data.

Zhenan, kai and Bo (2013) developed an intelligent system combining remote sensing technology and control applications. In this system they monitored and controlled river and lake water quality. They overcome the technical challenges such as sensor selection and control over wireless network by adopting appropriate algorithm for system design.

N.Vijay Kumer, R Ramya [2013] developed a system for real time monitoring of the water quality parameters. In their research they measure the water parameter such as turbidity, conductivity, temperature, ph and dissolved oxygen. Instead of arduino they used the raspberry pi b+ model as core controller and send the sensor data on cloud platform**.**

IV System Design and Development

Figure 1 shows the general blocks diagram of water quality monitoring system. Three main subsystems identified include

1. Data collection subsystem consists of multi-parameter sensors and optional wireless communication device to transmit the sensor information to the controller. A controller gathers the data and processes the same.

2. Data management subsystem which accesses the data and displays the same to the end user.
3. Data transmission subsystem consists of a wireless communication device which transmits the data from the controller to data storage.

The following materials were used to develop the system for water quality monitoring, Sensors, Amplifiers, Analog-to-digital converters, Arduino Microcontroller, Transmitters, Receivers, Micro SD, shield +TF card, PC, Display unit and Timer.

All these components were connected together and appropriate embedded program using MickroC platform for decoding. Various parameters of water quality were automatically detected under the control of single chip microcontroller. The microcontroller will get signals from different sensors then process and analyze them as shown in block diagram in figure 1. Then, the data was instantaneously sent to monitoring center through GPRS (General Packet Radio Service) network. The system realize the automation of water quality monitoring, intelligence of data analyzing, networking of information transfer and fast dissemination of information to relevant stakeholders for making timely decisions.

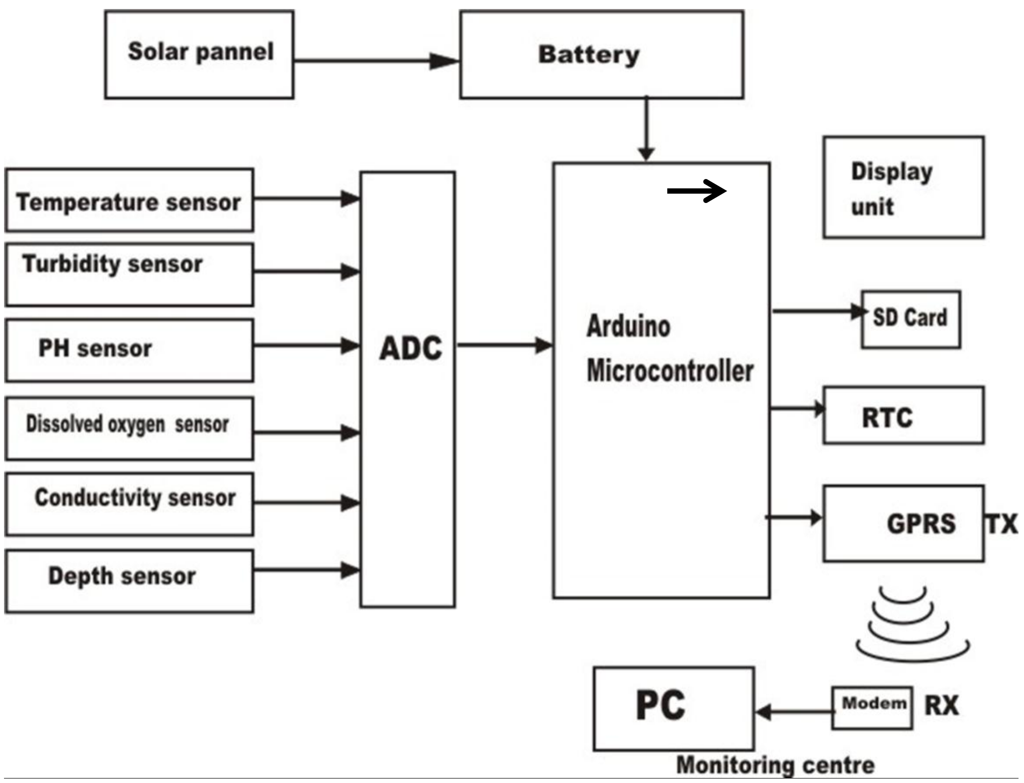

Figure 1: Block Diagram of multi-parameter water quality monitoring system.

The system was built around Ardiuno mega microcontroller as the heart. This Ardiuno mega microcontroller because of its processor speed and core memory is capable of processing signals from sensors using a speed of 40Mhz. it consists of digitals and analogs pins which make interfacing (connections pheripherals) easy.

Six sensors were connected to ADC pins of the Ardiuno mega microcontroller. The circuit diagram of the system is shown in figure 2. The display unit, SD card, RTC and GSM module were also connected to the Ardiuno mega microcontroller. Arduino software (C++) were used to program the microcontroller, this made it possible for the microcontroller to supervised the sensors by collecting signal from them and fomite to data which are times stamped and stored in excel format or CSV. Figure 2 shows the completed system in which the sensors were connected to the Arduino Mega microcontroller board. A 15watt, 12v solar panel were connected to charge a LEAD acid battery rated 6v, 4.5Ah. This battery powered the entire system. A voltage regulator module LM 2596 DC-DC was used to limit the excessive voltage from sola panel to the required 7.2v.

Another voltage regulator LM7805 DC-DC was used to regulate the voltage from the battery to 5v which is the maximum required voltage for the system with the exception of GSM module which operates between 3.7v to 4v. A new method of powering a GSM module alone were devised by using two (2) silicon diode and one (1) resistor.

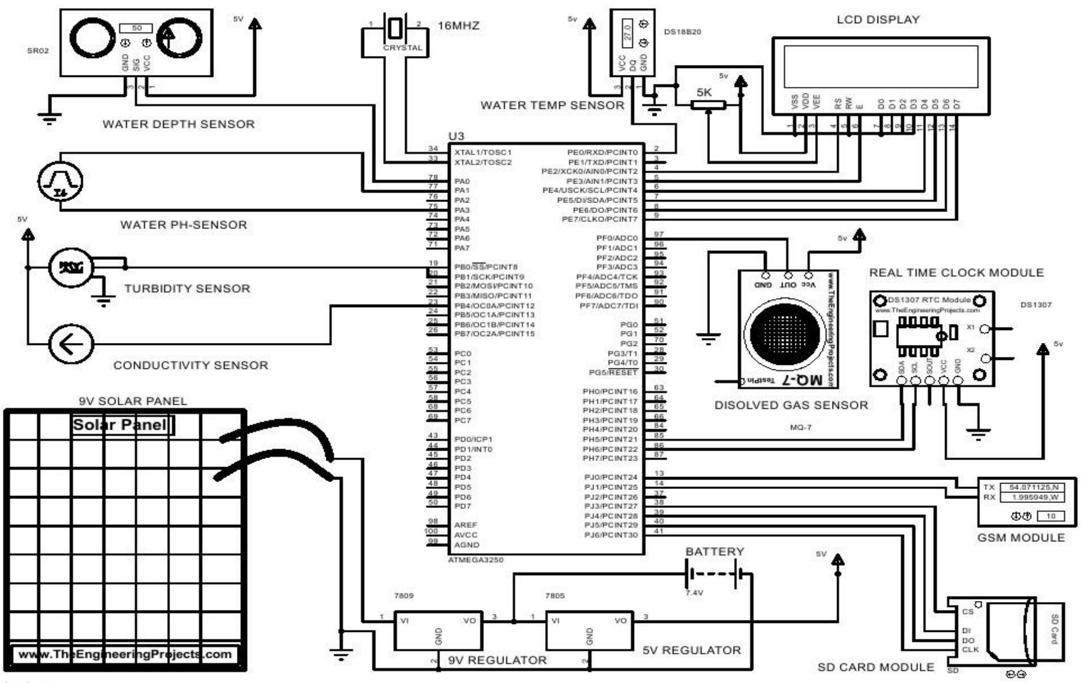

Figure 2: Circuit diagram of the multiparameter water monitoring system

A registered sim card with internet data and prepaid airtime were inserted into the GSM module. When the system is switches on, the display module (LCD display) will displayed the sensors reading for initial reading. The user will allow the sensors to get acclimatized with the water before recording the initial reading. After this the system will be switched off and formatted card will be inserted into the card reader slot where reading will be stored in every 1minute interval. The whole system was built and housing inside waterproof Styrofoam, this makes it buoyant to flow on water easily. Figure 3 shows the architecture designed of the System.

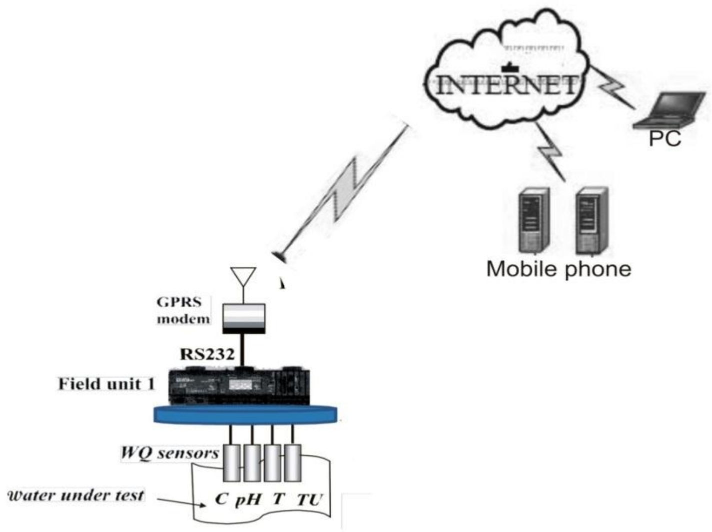

Figure 3: Architecture designed of the Water quality Monitoring System.

V. System Implementation

The system was implemented in River Niger, New Bussa, Borgu local government area of Niger State, Nigeria. Field trial was conducted in two sites (S1 and S2) in the River from February 6 to April 2, 2019. The operating effect of the test was described as below

1. During the trial, the power supply module of solar and lead battery worked stably, the battery charging happened once and its process lasted for approximately 2 d. So the power supply module satisfied the power demand of the system.
2. Data transmission function of the system was proper. After detecting, processing and analyzing, the data was communicated in four ways to the users

- Displayed on LCD display in 30secs interval
- The GSM module sent data through SMS message to the user every 30minutes interval. The sent data during the operation is shown in figure 5.
- The GPRS module sent data to internet in every 15minutes interval.

- The system login the data in excel format into SD card in every minute interval as shown in figure 4. During the period of trials, the total of 154,112 data was stored in the card.

RESULTS AND DISCUSSION

The variations in the physico-chemical parameters of study area River Niger were presented in Table 2. The air temperature of River varied throughout the sampling period. The air temperature of river ranged between 29.05^{0}c to 29.25^{0}c.

Table 2: Water quality parameters of River Niger.

Water quality parameters	Sites	
	S1	S2
Dissolved Oxygen(mg/l)	6.4	6.4
Conductivity(S/m)	43.3	43
PH	7.3	7.3
Turbidity(NTU)	4.9	5.1
Temperature(^{o}C)	28.5	28.5
Depth(m)	35.4	46.5

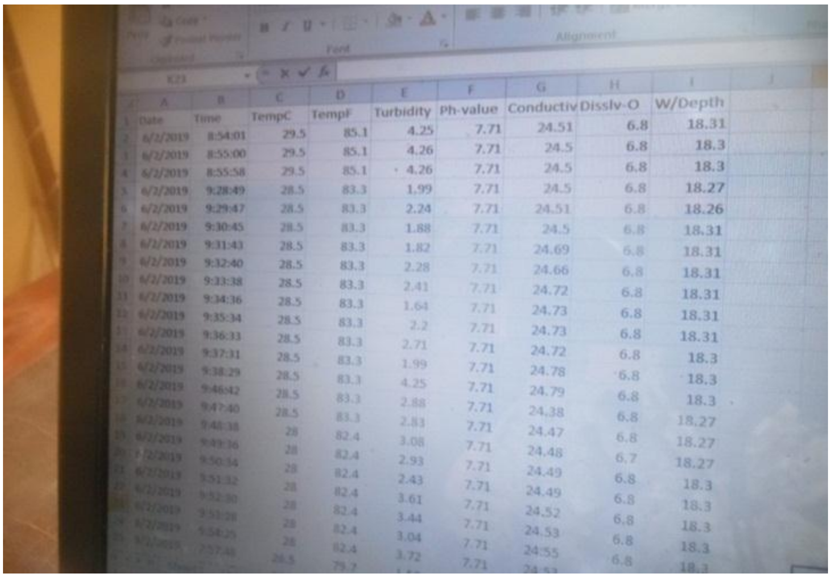

Figure 4: Data Login into the card.

The measured data change consistently and reasonably reflecting the values from field sensors. The user interface allows us to convey the analyzed data in the form of a message to the end user in their respective local languages to their Mobile Phones and alerts them in unhygienic environmental conditions figure 5. With this even semi-literate farmers can interact with the system and can understand the information in order to take suitable actions.

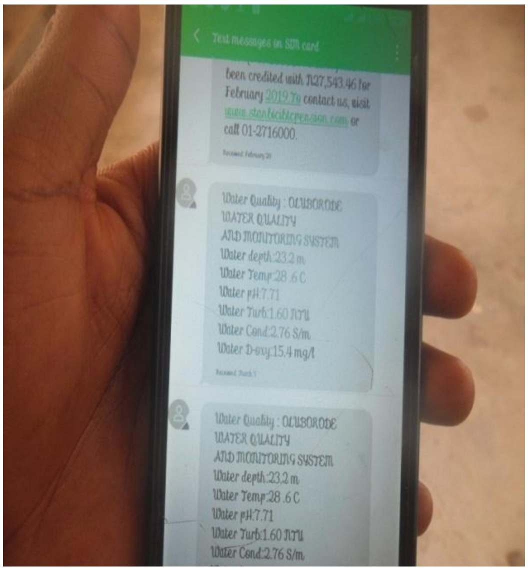

Figure 5: Data sent through SMS to Mobile Phone.

Data transmission of the system was function properly. After detecting, processing and analyzing, the data was communicated to the users. The GSM module sent data through SMS messages to the user every 30minutes interval. The sent data during the operation is shown in figure 5. The system also login the data in excel format into SD card in every minute interval as shown in figure 4.

Water temperature, dissolved oxygen, turbidity, conductivity, water depth and pH were regularly monitored by this system. The smart sensor nodes are small, low cost, efficient and suitable for deployment in harsh environment. The nodes were protective watertight housing and weatherproof. Making it resistant to environmental factors like rain and heat. It was easy to move the nodes to the desired point of interest whenever needed.

The experimental results monthly variations in the water quality of the River Niger were presented in Tables 2, figure 4 and 5. It shows that the power management and networking solutions were adopted to work in practice. This increased economic benefit for aquaculture by improving production process in quality and quantity, consumer confidence and safety. This system could prove to be helpful in the event of a failure to take rapid actions to prevent the damage that could be caused to the fish stock.

The turbidity of the river ranged from 4.9 to 6.0 NTU (Table 2) with an average of 6.28 NTU. Turbidity is a measure of the ability of the water to transmit light. Inability to transmit light may be caused by suspended clay particles, dispersed plankton organisms, particulate organic matter and pigments caused by decomposition of organic matter. A value of 30 to 40 NTU is considered optimum for a good fish culture. Turbidity levels as low as 5 NTU can begin to stress fish within a few hours (VWF, 2017). The turbidity values of the river were normal. Concentration of dissolved oxygen in the river ranged from the highest of 6.4 mg/l to the lowest of 4.6 mg/l (Table 2).

Lowest pH of 7.3 was obtained in the river (Table 2). Temperature fluctuations ranged between 28.0 to 28.9 °C in the river. The conductivity values of the river gave a good estimate of the condition of river in the different period. Conductivity is an index of the total ionic content of water.

CONCLUSIONS

This research work provides the development a low-cost River water quality monitoring and control system for aquaculture based on wireless sensor networks and single chip microcontroller technology as a base in the actual operation. It realizes the monitoring of the water environmental parameters for intensive aquaculture and alarm notification through short message when monitored variables take anomalous values and is suitable for long-term stability under growth conditions thus increasing yield per unit area. The system monitoring temperature, conductivity, turbidity, dissolved oxygen, pH, and water level continuously and in real-time. With the use of GPRS network and mobile phones platforms, the values of the parameters to be measured were displayed in easy-to-comprehend graphical and tabular formats anytime and anywhere. The sensor data, battery performance and network performance metrics have been analyzed and presented. Experimental results thus obtained using this system shows that the system is reliable for large scale deployments Future works should be enhancing the system remote access to the sensor nodes using internet and data transmission for further analysis.

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