THE USE OF ELECTRONIC SYSTEM FOR MONITORING WATER QUALITY IN KAINJI LAKE

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ABSTRACT

Monitoring of water quality in lakes to meet the requirement of the water framework directive poses a significant financial burden using conventional sampling and laboratory based techniques. This observed situation prompted the development of this locally made low cost multi-parameter monitoring system based on wireless network to achieve remote real-time monitoring of water quality in order to improve the quality of lakes, dams and rivers.

The developed monitoring system 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 on Kanji Lake in Nigeria. A microcontroller chip was used for processing data collected, GPRS modules were also used for data transmission to the remote monitoring center; where the data were stored and displayed on the Liquid Crystal Display (LCD) unit. Various parameters of the lake such as dissolved oxygen, temperature, electrical conductivity, pH, turbidity and depth were successfully logged into the memory card and sent through GSM module for auto-monitoring.

The water pH was found to range from 7.1 to 7.43 with a mean temperature range of 27.3°C to 29.8°C. Other physicochemical parameters values monitored did not exceed the recommended values for surface water quality. The comparison between the physicochemical parameters studied in Kanji Lake and the standard values showed that all the parameters exhibited positive relationship. Experimental results obtained using this locally developed low cost multi-parameter monitoring system showed that the system is more reliable for large scale deployments on water quality in lakes. The cost ($23,423= #8,409,622) of imported ones is 30 times in price compared with the cost ($708.33= #255,000) of locally made multi-parameter monitoring system. It is recommended that locally made multi-parameter should be used by water researchers instead of the imported ones so as to reduce and avoid unnecessary financial burden due to conventional sampling and laboratory based techniques.

Keywords: Multi-parameters, water quality, real-time monitoring, measurements, wireless sensor network.

INTRODUCTION

Population growth, urbanization and industrialization have led to the decline of quality of surface waters globally (Martinez et al., 2011; Walakira and Okot-okumu, 2011; Owa, 2013). The quality of surface water has deteriorated in many countries in the past few decades due to extensive anthropogenic inputs of nutrients and sediments (Tessema et al., 2014). Most rivers in the urban areas of the developing world are the end points of discharges from the municipal and industrial treatment facilities (Bernard, 2010; Suthar et al., 2010; Ljee, 2011) rendering surface waters the most polluted water resources (Kadewa et al., 2005). According to the Pan African Chemistry Network (PACN), Africa's population exceeded 1.1 billion in 2014 and continues to increase at a rate of 2.4 % annually (PACN, 2015). Of this population, more than 341 million lack access to clean drinking water and a further 589 million have no access to adequate sanitation, resulting in loss of productivity due to water-related illnesses (PACN, 2015).

Water for human use requires sustaining an adequate water quality standards and changes in water quality threatens human health (Massoud, 2012). The effects of environmental factors such as climate change make the challenge of conserving water resources even more difficult (PACN, 2010). Climate change has a major impact on water quality and water management. Increases in water temperature produce unfavourable changes in surface-water quality, which has detrimental effects on human and ecosystem health (IPCC, 2008). Africa's water resources are being degraded due to discharge of untreated wastewater from industrial and domestic sources (Corcoran et al., 2010). Pollution from natural and anthropogenic processes also threatens available fresh water resources in most Africa countries (Nyakungu et al., 2013).

In Zimbabwe, Lake Chivero is polluted due to nutrient loadings from sewage discharges through its main tributary, Manyame River (Masere et al., 2012; Nyakungu et al., 2013; Kibena et al., 2014). Ngerengere River in Wami/Ruvu basin in Tanzania is polluted due to agricultural and industrial wastewater from upstream sources (Mero, 2011) and with most affected communities located downstream of the catchment (Mero, 2011). Botswana's water resources are also under threat from various pollution sources that mainly include pit latrines, solid waste, agriculture, industrial and domestic wastes (DWA, 2013). River water quality is deteriorating due to pollutant loads from point and nonpoint sources, such as agricultural runoff, solid waste disposal, sewage and industrial effluent. Motloutse River has been polluted by discharges from mine effluent (Masamba and Mazvimavi 2006). Notwane River is heavily polluted with sewage effluent from Glen Valley and Mochudi wastewater treatment plants (Mladenov et al., 2005) rendering water from these rivers unfit for human use and in some cases not conducive for irrigation and environmental consumption. The Dikgathong Dam, located within the Limpopo River Basin (LRB), in the north east part of Botswana, is also under pollution threat from anthropogenic activities (EHES, 2002). The LRB main pollution threat comes from anthropogenic activities such as agriculture, mining and urbanization (MRC, 2009).

Water quality monitoring is essential for identifying sources of contaminants entering water resources (PACN, 2010). Monitoring offers key information for detecting and dealing with water quality problems, by identifying trends over time and comparisons between different water bodies (UNEP, 2010). The quality of water bodies is determined by its physicochemical features, hence the importance of long and short term analysis of water quality status (Adakole et al., 2003). There is inadequate information for water quality around the world, especially in developing countries. The little available information has challenges of inconsistency, rendering it not very useful for those who want to use it (UNEP, 2010). Water quality monitoring methods includes biological indicators, physicochemical analysis, water quality indices and use of water quality monitoring techniques. The use of GIS and multiparameter sensors in water quality monitoring has been long acknowledged (Usali and Ismail, 2010). The strength of multiparameter sensors techniques is their capability to capture the spatial and temporal variability of water quality parameters (Mohamed, 2015) and has been demonstrated to be effective at reduced cost (Schaeffer et al., 2013). Traditional methods of water quality monitoring are costly and time consuming. Traditional methods provide accurate measurements because of the direct measurements, but it is only at discrete points, not covering the entire water body (He et al., 2008). Thus it is advocated for the use of GIS and remote sensing to improve water quality monitoring. Besides climate change effects mentioned earlier, landuse changes have great impacts on water resources (Wagner et al., 2013). Land use classifications can be analysed to identify changes over a past period of time (Wagner et al., 2013). Understanding the relationship between upstream land use and water quality is useful for identifying principal threats to water quality (Ding et al., 2015). Landuse usually defines the concentrations of contaminants that flow into rivers and lakes (Larkin, 2014). Pollution is related to anthropogenic practices which can be measured in terms of population density and land use type (Yaakub et al., 2012). It is important to constantly determine point and nonpoint source of pollution loads for proper management of water quality (Yaakub etal., 2012). Urbanization, agricultural runoff, industrial and sewage disposal have affected the quality of water around the world and making it unfit for domestic purpose (Kadewa et al., 2005; Chatterjeeet al., 2010; Choudhary et al, 2011; Ullah et al., 2013). The Kainji Dam lies downstream from expanding urban, industrial and mining areas, which poses threats to the dam's water quality. It is imperative for the Kainji Dam to continue to sustain its water quality in order to serve its purpose of supplying drinking water. Measures need to be put in place to monitor the water quality of this dam with deliberate interventions to ensure it does not continue to deteriorate. The use of traditional methods for monitoring water quality alone is not adequate (Ritchie et al., 2003). Integration of traditional methods and remote sensing has demonstrated the practicality of remote sensing in monitoring of water quality Dlamini et al., 2016).

Previous studies on remote sensing applications on water quality have used empirical algorithms for predicting water quality parameters. The limitations of empirical methods of remote sensing applications in water quality are that the algorithms work best when applied to the site where sampling data was collected and the formulas derived and may not be applicable to other water bodies (Chang et al., 2014). The traditional method for water quality determination and monitoring is the laboratory method, in which samples from different location are collected and these samples are taken to laboratory followed by laboratory analytical technique for detecting the contamination in the water. This method however is tedious, expensive and time consuming (leading to delayed detection of and response to contaminants). Because of the economic value of some of the water bodies there is need for effective and efficient monitoring and control of water quality in Lakes and dams. So an advanced **low cost** multi-parameters electronic instrument for automatic monitoring and measurements water quality in lakes, reservoirs and dams will be developed.

STUDY AREA

River Niger is a principal river in Western Africa with the length of 2,600 miles (4,200 km), it is the third longest river in Africa, after the Nile and the Congo.

The River rises from Guinea (9°05′ N, 10°47′ W) on the eastern side of the Fouta Djallon highlands, 150 miles (240 km) inland from the Atlantic Ocean. It flows due north over the first 100 miles (160 km). It then follows a northeasterly direction, during the course of which it receives its upper tributaries and enters Mali. From Mali, the river takes a more east-northeasterly direction, and its bed becomes fairly free from impediments for about 1,000 miles (1,600 km) and flows about 1,100 miles (1,770 km) in all to enter Niger. From Niger it flows flowing east-southeast and enter Nigeria through Kebbi state. In Nigeria, the river was dammed in New Bussa which results into kainji dam. Kainji Dam is a dam across the Niger River in Niger

State of Northern Nigeria. It was one of the longest dams in the world. The dam was 136 km (84 mi) long, about 30 km (19 mi) wide; it was the first dam to be built in Nigeria as shown in figure 1. Construction of the dam was carried out by Impregilo (a consortium of Italian Civil Engineering Contractors) to designs by Joint Consultants, Balfour Beatty and Nedeco, and began in 1964 to be completed in 1968. The total cost was estimated at US$209 million (equivalent to about US$1.3 billion in 2018 dollars), with one-quarter of this amount used to resettle people displaced by the construction of the dam and its reservoir.

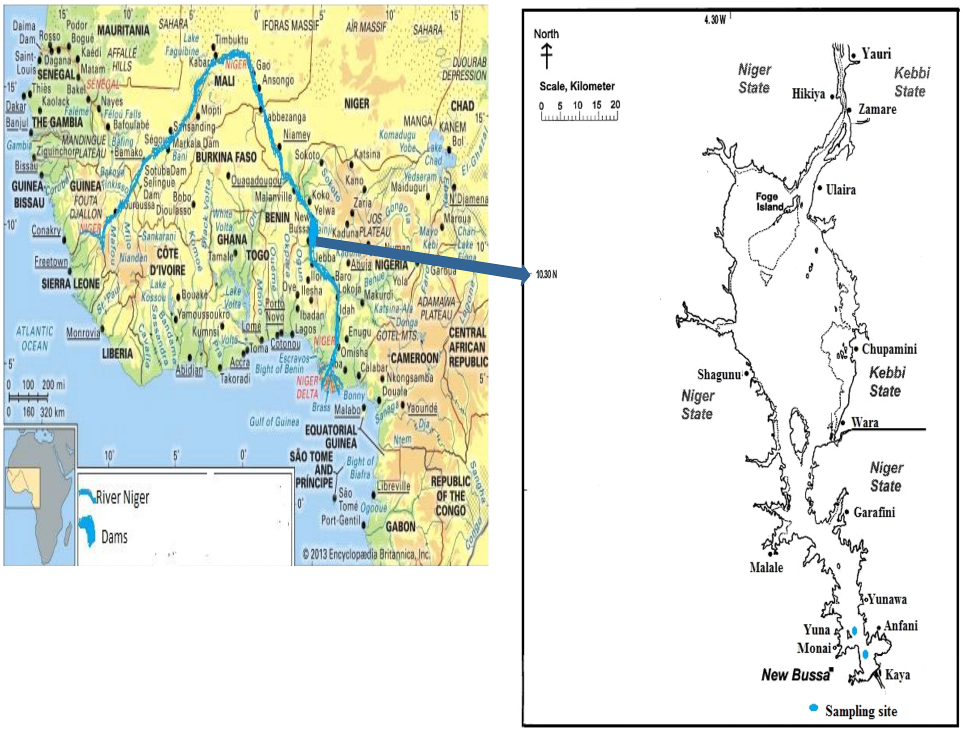


Figure 1: Map of the the study area

General structure of the system

The system consists of power supply, sensor detection part, controller, data transmission part, remote monitoring center, etc. The sensor detection part comprises the sensors for dissolved oxygen, pH value, temperature turbidity conductivity and depth. The controller is made up of Arduino microconroller and its peripheral circuits, and is responsible for processing the parameters of water quality acquired by the sensors and controlling the whole system to work properly in order. The data transmission part is composed of GSM and GPRS module, which transmits the parameters detected by the sensors to the user mobile phone number and www.thingspeak.com network.

Power supply module

The power supply module consists of Lead acid battery, solar panels, lead battery charge-managing circuit and DC/DC step-up/step-down converter circuit.

Power supply by LEAD battery

The polymer lead battery (nominal voltage: 7.2 V, cell capacity: 4.5 Ah) manufactured by New Energy Technology Co., Ltd. was used. In order to fulfill the requirement of working voltage of every module, step-up and step-down converters were used to change the output voltage of the Lead battery [15, 16]. Maximum power consumption of the system:

$P_{sys} = Psen + P_{GSM} + P_{GPRS} + P_{mcu}$ 1

Where, Psys is the maximum power consumption of the system, expressed in W; P_{sen} is the total maximum power of the sensors, expressed in W; P_{GSM} is maximum power of GSM module, expressed in W; P_{GPRS} is the maximum power of GPRS module, expressed in W; P_{mcu} is the maximum power of the controller, expressed in W.

$P_{sys} = (P_{Dsen}+P_{Tsen}+P_{DOsen}+P_{Csen}+P_{TUsen}+P_{PHsen})+P_{GSM}+P_{GPRS} + P_{mcu}$ 2

The structure diagram of power supply is shown in Figure 2.

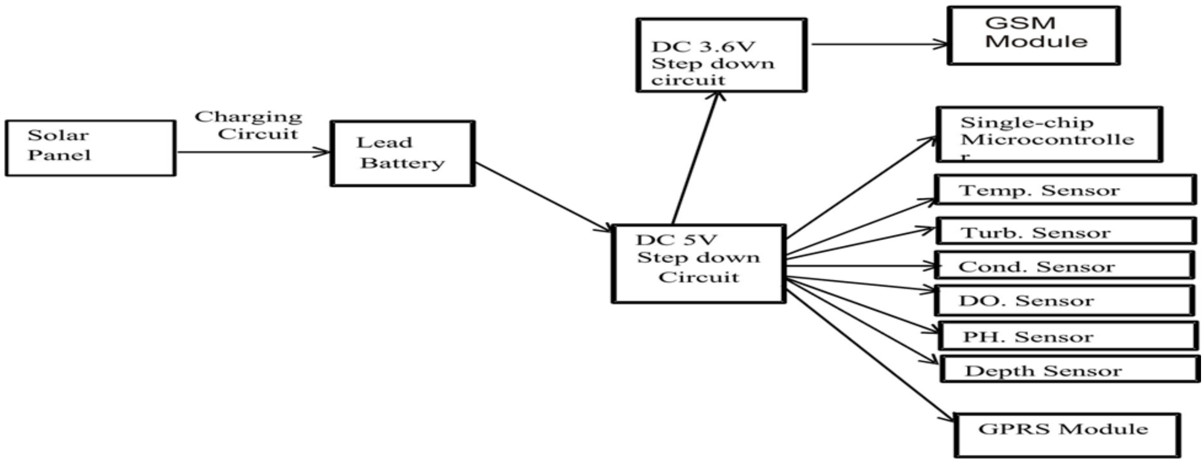


Figure 2: The structure diagram of power supply

Since the working voltage of the sensors are 5 V and working current is 100 mA, P_{sen}=3.0 mW. When GSM module is working properly, its working voltage is 3.6 V, the maximum working current is 100 mA, so P_{GSM} = 3.60 mW. When GPRS module is working properly, its working voltage is 5 V and the maximum working current is 500 mA, so P_{GPRS} = 2.5mW. When the controller is working properly, its working voltage is 5 V and working current is 15 mA, so P_{mcu}= 7.5 mW.:

The mean total power of the system is 10.231 mW. Based on 7.2 V voltage of the lead battery, the average load current of the system is calculated to be 3.1 mA. The correlation between load current and working duration is expressed by $C=I \times t \times \lambda$ (where C is battery capacity, λ is safety factor of service duration of the battery, which is taken as 1.2), so a 3. Ah battery can sustain 920 hrs operation of the system.

Solar panels

Polycrystalline silicon solar cells (max. current: 0.34 A, max. voltage: 9 V) manufactured by Guangdong Zhaotian Company is used as solar panel. The power output by the solar panel is charged into the led battery under the control of charging circuit.

The circuit is shown in Figure 3. The controller monitors the voltage of the lead battery in real time. When the discharge voltage of the lead battery is lower than 7.1 V, the solar panel begins to charge it. When the voltage reaches 7.4V, charging stops. The average charge current output by solar panel is 0.13 A. Calculating according to correlation expression $C = I \times t \times \lambda$, and taking 0.8 as the safety factor of charging duration, the average charge duration of the lead battery is 35 hrs, and it varies with weather condition.

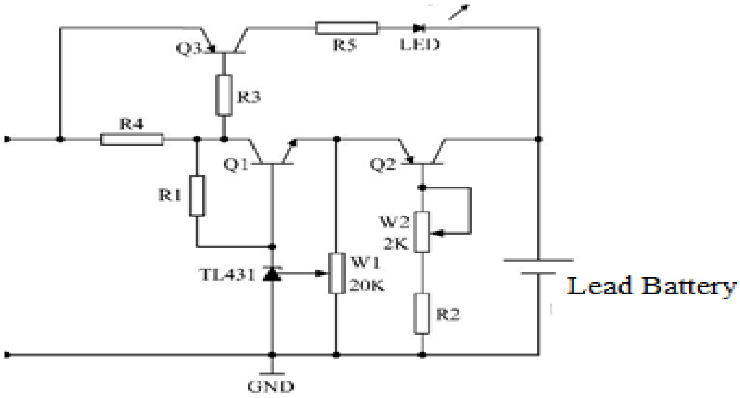


Figure 3 Charging circuit of a lead battery

The power supply module consists of lead battery, solar panels, lead battery charge managing circuit and DC/DC step-up/step-down converter circuit

Field Trials

Several field trials were conducted from February 2019 to April 2019 on Kainji dam in Niger State. Some of these trials were conducted between 11:00 am and 11:40 am. First of all, the system was switched on to take the ambient temperature before deployed it into the water. Two sites were selected for trials. Site S1 was the inlet and S2 was the outlet of the lake

During the period of each experiment, pH, temperature, turbidity, dissolved oxygen, conductivity and depth data were collected with a constant time interval. Figure 4 shows the field trials on Kainji dam. A long-hour (36 hours) field experiments was also conducted from 11 am to 5 pm from 29 March to 1st April 2019 in order to investigate and monitoring the diurnal changes of the water parameters as shown in figure 5.

Figure 4: Showing the measurement of water quality parameters of Kainji lake

Figure 5: Showing the monitoring of water quality parameters of Kainji lake

Stability analysis of network communication

Network communication was tested on 6 sensor nodes. The test was without obstruction. The sensor nodes were set to collect and send data once every 5 min and kept monitoring for consecutive 3 days. It can be found from the test results above that the system runs stably and reliably.

Stability and reliability analysis of sensor measurement

Sensor stability and reliability analysis were implemented in laboratory by taking 100 L water from the dam and using HI83200 pH meters detector to test pH. We measured the temperature by JO-FRADTI1000 high-precision digital temperature detector made by AMETEC (of USA) as standard one. We used conventional method to detect the depth of the dam. The data was compared with the data of the developed monitoring system. The test data was shown in Table 1. Each water quality parameter measured by the system all fall in the confidence interval. So it is known that the confidence level of the data measured by the system is high and comply with the design requirement. The cost of the whole system is about 65% lower than the same water quality parameter device in the foreign market.

EXPERIMENTAL RESULTS

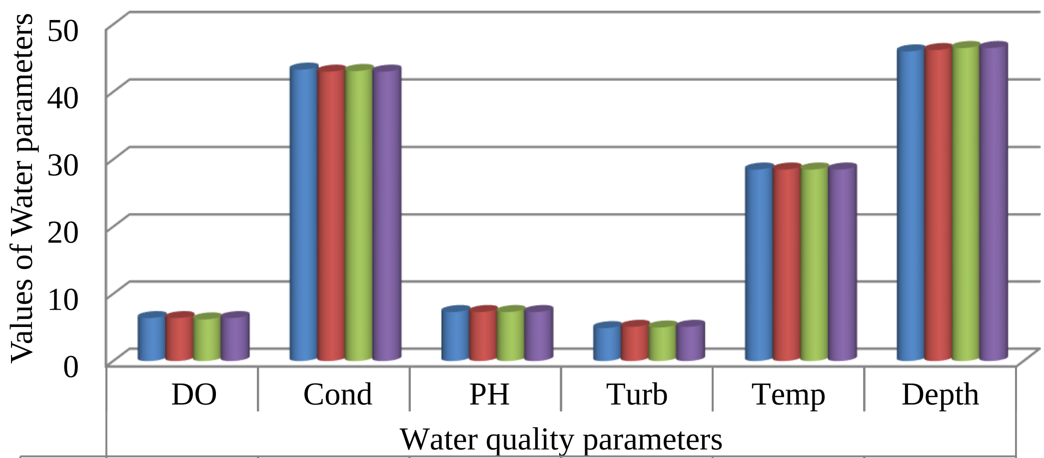
The physico-chemical parameters are important for assessing the water quality. The main purpose of analyzing the physical, chemical characteristics of water is to determine its pollution status. In fact, the final status of a water body is conditioned by these factors and the status of the water is really the result of interaction of these factors. The variations in the physico-chemical parameters of study area (Kainji dam) were presented in Table 2.

Table 1: Sensors stability test data

Parameters	**Meters Used**	**Standard values**	**System values**	**Standard deviation**
PH	HI83200 pH meters	7.7	7.31	0.02
Turbidity (NTU)		ND	ND	ND
Conductivity (S/m)	InoLab Multi 9310P	44.5	43.3	1.2
DissolvedOxygen (m/l)	InoLab Multi 9310P	6.8	6.4	0.4
Temperature (^{O}C)	JO-FRADTI1000 digital temperature detector (AMETEC)	29.6	28.5	0.06
Depth(m)	Conventional method	50.6	46.5	1.1

Table 2: Water quality parameters of Kainji dam

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(°C)	28.5	28.5
Depth(m)	35.4	46.5



	DO	Cond	PH	Turb	Temp	Depth
W1	6.4	43.3	7.3	4.9	28.5	46
W2	6.4	43	7.3	5.1	28.5	46.2
W3	6.2	43.1	7.3	5	28.5	46.5
W4	6.4	43	7.3	5.1	28.5	46.5

Figure 6: Weekly variation of water quality parameter of the lake

Temperature is also very important in the determination of various other parameters such as pH, conductivity, saturation level of gases and various forms of alkalinity. The air temperature of Kainji dam varied throughout the sampling period from $29.05^{0}C$ to $29.25^{0}C$. In this study, the temperature in Kainji dam was recorded to be $28.5^{0}C$. Steady change in the atmospheric temperature with the change in the seasons results in the corresponding change in the water temperature. There is a very close similarity between the temperature of atmosphere and water due to the depth of the lake. The conductivity of Kanji Lake was found to be 43.3 S/m

Turbidity makes the water unfit for domestic purposes, food and beverage industries, and many other industrial uses. A reduction in turbidity is associated with a reduction in suspended matter and microbial growth. In the present investigation, the maximum turbidity value recorded for Kainji Lake was 5.0 NTU and pH range from 7.3 to 7.1

Dissolved oxygen is a very important parameter of water quality and index of physical and biological process going on in water. There are two main sources of DO in water: (i) diffusion from air, and (ii) photosynthetic activity within the water. Diffusion from air to water is a physical phenomenon and depends upon solubility of oxygen, which in turn is influenced by factors like temperature, water movement. Photosynthetic activity depends upon autotrophic population i.e., mainly phytoplankton in water, light condition and available gases etc. In the present study, the level of DO was recorded to be 6.4 m/l. The standard value for DO for freshwater aquatic life is between 5 to 7 mg/l (Table 2). This shows that Kainji was favourable for freshwater aquatic life and other aquatic living organism

The depth of lake varied significantly between stations or sites. The highest depth (46.5m) is at the site S2 and the lowest depth (35.4m) is at site S1 (Table 2). Shallower lakes tend to warm more rapidly with higher surface water temperatures compared to deep lakes that have greater heat storage capacities

Table 3: Showing standard values and the parameters of Kainji dam

Parameters	Designated Use	Standard values	Recommended Agency	Kainji lake
PH	General Agriculture	6.0 – 8.5	USEPA	7.3
	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 (NTU)	Human Consumption	1 – 5	WHO/ICMR	5.0
	Freshwater aquatic life	1 – 50	USEPA	
Conductivity (S/m)	Human Consumption	30 – 80	WHO/ICMR	43.3
Dissolved Oxygen (m/l)	Human Consumption	5	WHO/ICMR	6.4
	Freshwater aquatic life	5 – 7	USEPA	
Temperature (°C)	Freshwater aquatic life	26 – 30	Literature	28.5
Depth (m)	-	-	-	46.5

The weekly variation of water quality parameter was presented in figure 6. Six parameters namely conductivity, pH, turbidity, temperature dissolved oxygen and water level were measured using the system. The measured results was compared with standards values defined by WHO, ICMR and USEPA (Table 3)

CONCLUSIONS

Water is one of the basic elements supporting life and the natural environment, a primary component for industry, a consumer item for humans and animals and a vector for domestic and industrial pollution. Effective water monitoring and an early warning system would bring great economic and social benefits to humanity. This Supplement summarized the requirements to develop water quality and early warning systems. The needs for water quality monitoring and early warning systems are for greater confidence in the data, better reliability, better sampling, lower skill requirements, lower cost of ownership, valid and timely prediction of possible hazards, better communication of data and warning information. Measuring techniques is still an open field for some variables, particularly in which concerns in-situ and on-line measurement systems. However, some remarks about measuring techniques for different water quality parameters were introduced by the authors according to their experience in the field. In this work, the development and demonstration of a low cost, continuous water quality monitoring system prototype were developed. The system used low cost sensors and open source hardware aiming at providing continuous water quality measurements at substantially reduced cost. Field test results demonstrations with appropriate calibration of the system were carried out to ensure continuous measurement of water quality parameters including water levels and transmit them to a database in real-time. With the use of GPRS network and mobile phones platforms, the values of the parameters to be measured was displayed in easy-to-comprehend graphical and tabular formats anytime and anywhere.

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