

# Ubiquitous Mobile Sensing for Water Quality Monitoring and Reporting within Lake Victoria Basin

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## Abstract

As the human population growth and industry pressure in most developing countries continue to increase, effective water quality monitoring and evaluation has become critical for water resources management programs. This paper presents the ubiquitous mobile sensing system for water quality data collection and monitoring applications in developing countries. The system was designed based on the analysis of the existing solution. Open source hardware and software was used to develop the prototype of the system. Field testing of the system conducted in Nkokonjero, Uganda and Mwanza, Tanzania verified the functionalities of the system and its practical application in actual environment. Results show that proposed solution is able to collect and present data in a mobile environment.

## Keywords

Arduino, Android, Ubiquitous Mobile Sensing, Water Quality

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## 1. Introduction

The rapid development of society, economy and an increasing number of human activities in most developing countries speed-up contamination and damage to the water resources. As the result monitoring of water quality is essential in order to characterize water and identify changes or trends in water quality over time [1]. For decades, water quality monitoring and evaluation have depended on a low-resolution water quality monitoring. This approach is time-consuming and expensive and not appropriate for certain biological and chemical processes such as oxidation-reduction potential that need to be measured on-site to ensure accuracy [2]. Recently, Wireless Sensor Networks (WSN) have received considerable attention in water quality monitoring and control applica-

tions [3]-[7]. However, the practical application of WSN in water quality monitoring in developing countries is limited by following factors: 1) The initial investment cost of the WSN is considerably higher; 2) Physical security of the WSN nodes is also a challenge and 3) The sensor nodes are static over one particular location.

On the other hand, the rapid spread in mobile phone use in developing countries has increased the application of mobile data management [1]. Smart phones are becoming pervasive computing and communications platform [8]. The variety and number of mobile applications has also increased in recent years. This is because mobile phones are cheap, easy to use and can transmit multiple types of information including images and GPS points over long distances. The development and deployment of ubiquitous mobile sensing systems has become significant. However, the number of applications that leverage external sensing devices in water resources management is limited. The work presented by Aquaya [9] describes a water quality reporter system for data collection using featured phone. However, it doesn't provide the means to transfer the same data electronically to a central system and lacks sensing capability.

The use of ubiquitous sensor technologies and mobile data applications can improve the efficiency and accuracy of data reporting in the water sectors. This work extends the use of ubiquitous mobile sensing technologies by designing and developing mobile data capture and reporting applications that leverage external sensing devices in water resource management. It further discusses the role of this application in water quality management in rural and under-resourced areas in developing countries.

## 2. System Design

### 2.1. System Architecture

The proposed design for the Ubiquitous mobile Water quality Reporting system (u-WQR) for on-site sensing and reporting water quality data is presented. This system was developed as one component of the water governance system (WaGoSy) [10] designed to address water governance challenges around Lake Victoria Basin. Although more advanced techniques and technologies are already present in the world, u-WQR system is implemented using simpler and open source technology to reduce the system costs.

u-WQR system consists of four main components: 1) Ubiquitous Sensing Device (USD) which consists of Arduino microcontroller and sensor unit, 2) Communication module which connect the sensing device and the Android mobile phone, 3) The mobile application developed using the Android platform and 4) The WaGoSy web server. The Arduino microcontroller is the main controller that control and performs the necessary actions that need to be carried out by the system. The sensors and communication modules are directly interfaced to the main controller. The Arduino microcontroller communicate with mobile phone through a serial Bluetooth module. An overview of the proposed system architecture is shown in **Figure 1**.

### 2.2. Software Development of the u-WQR Mobile Application

Several platforms such as Windows Mobile, Symbian, iOS and Android can be used in the development of smart phone applications. The proposed u-WQR mobile application is developed using the Android platform. This is because Android platform is open source, supports background processes and rich inter-application communication and support most of the phones and handy devices on a market [8] [11]. Android Studio version 0.8.9 has been used for the development and implementation of the u-WQR mobile app. This is Android development environment based on IntelliJ IDEA [12].

The screenshots of the u-WQR mobile app developed is shown in **Figure 2** while the processing of the u-WQR mobile app is shown in **Figure 3**. The designed mobile app for the water quality reporting system provide, user authentication, serial Bluetooth connection to the USD, remote connection (via internet) to the WaGoSy web server and history of the data reported. To successfully connect and access the u-WQR the user has to enter the correct user name and password as shown in **Figure 3**. The u-WQR mobile app is locally developed using open source and freeware development tools.

### 2.3. The Proposed Ubiquitous Sensing Device

The ubiquitous sensing device (USD) consists of Arduino microcontroller, sensor unit and power supply. The sensor unit as shown in **Figure 4**, consists of several sensors used to detect water quality parameters. Four types of sensor pH sensor, electrical conductivity sensors (EC), oxidation reduction potential (ORP) and temperature

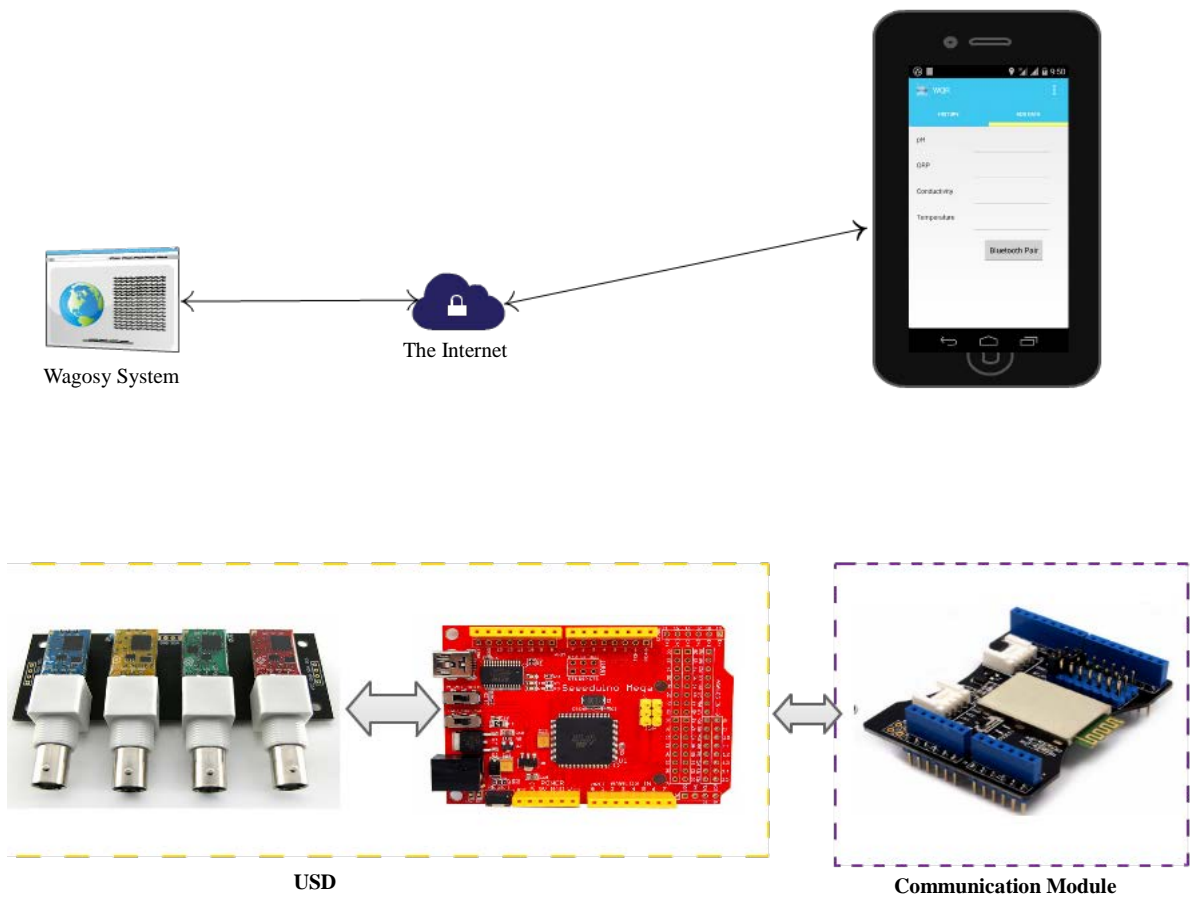


Figure 1. u-WQR system architecture.

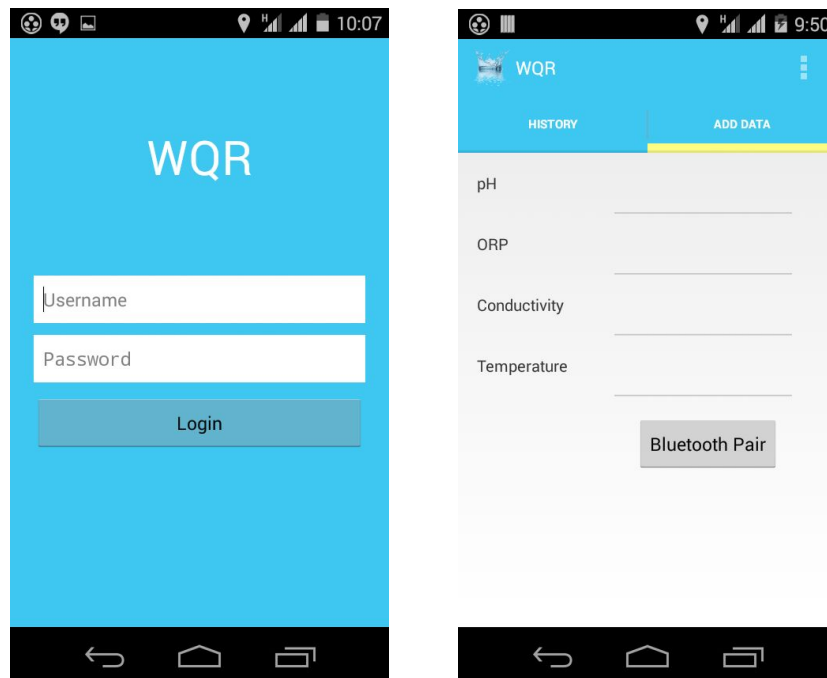


Figure 2. Screenshot of the proposed mobile app.

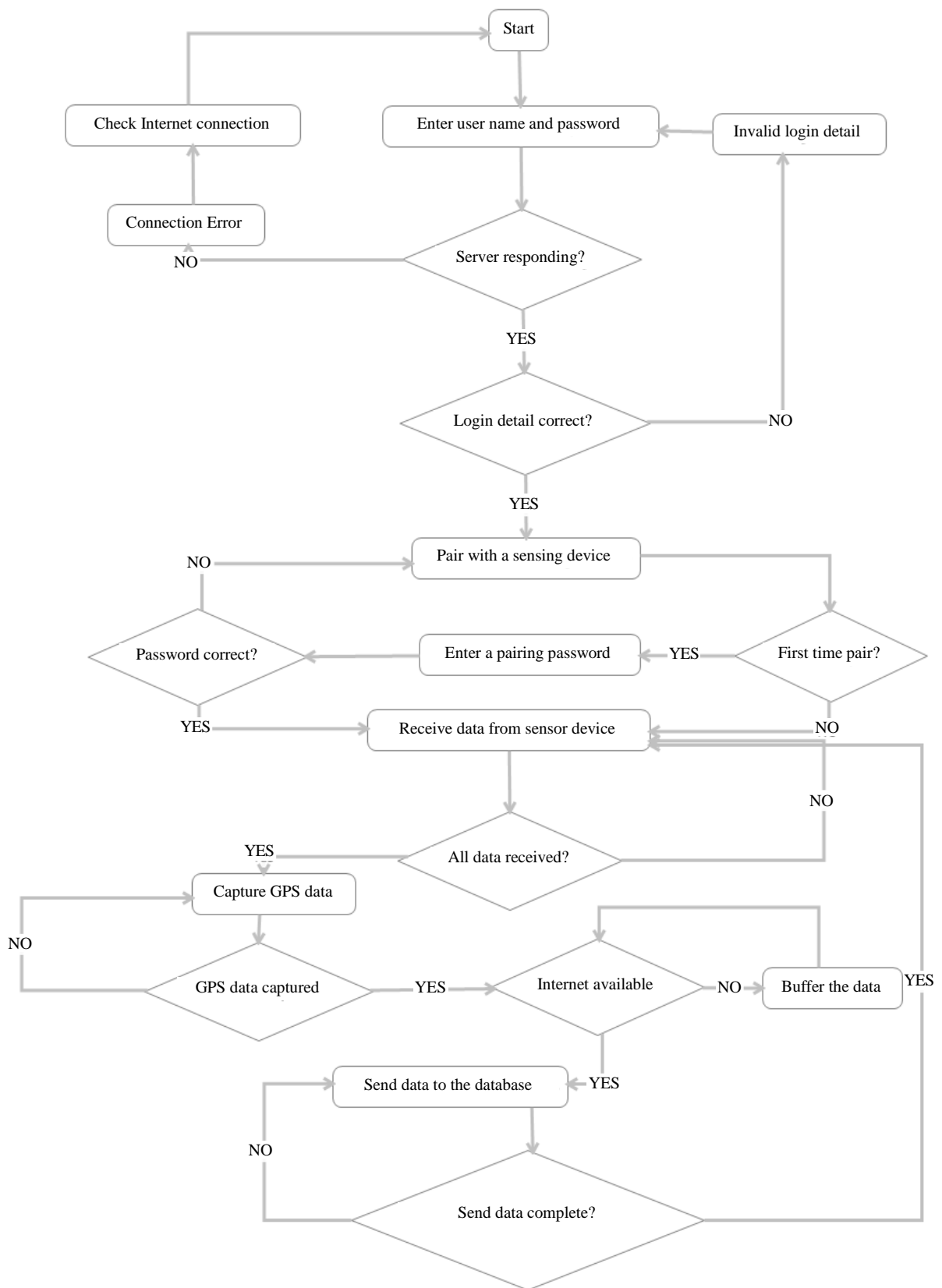


Figure 3. General processing of the proposed mobile app.

sensor are used to provide general characterization of water quality. Specification for these sensors is summarized in **Table 1**. The EC, pH and ORP sensors are interfaced to the microcontroller using their respective circuit from Atlas scientific with exception of the temperature sensor which is directly connected to the microcontroller. To connect all the sensors to the Arduino, multi circuit I2C carrier board Atlas scientific is used. The sensors were accurately calibrated to ensure that they operate correctly.

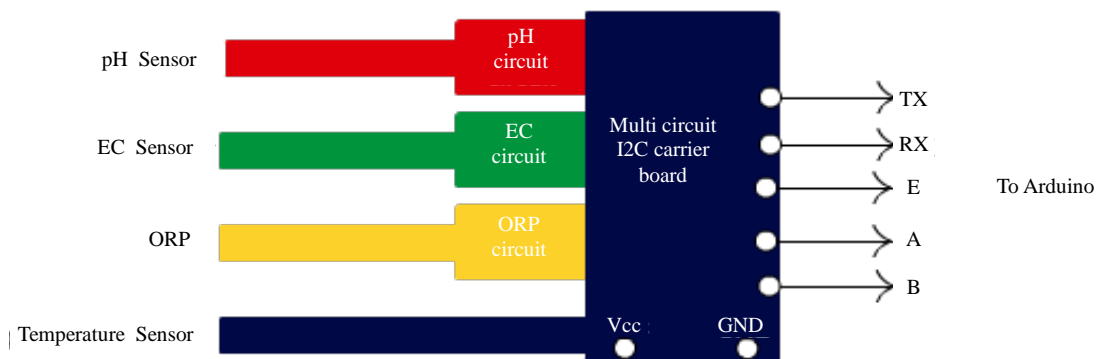
The process of acquiring data from sensors is shown in **Figure 5**. Seeeduino Mega [13] from Seeedstudio is used to acquire and process sensor data from the sensor unit. This microcontroller is derived from Arduino Mega and is based on the ATmega 256 having 70 digital input/output pins. In this work 3.7 V 6AH rechargeable polymer lithium ion battery is used to power this USD. The battery has longer life and excellent long-term and self-discharge rates. However it provide less than 5V required by most components on the USD. As the result the LiPo Rider Pro [14] is used to boost the output from a battery voltage to 5 V. LiPo Rider Pro, further allows to charge the lithium battery through USB.

## 2.4. The Proposed Communication Module

The recently announced Android Open Accessory Protocol (AAP) from Google allows external sensors to interact with an Android-powered device in a special accessory mode [8]. To use this approach to connect Arduino and the mobile phone you need to implement USB Host stack on the Arduino board. However, the device board is more complicated as it must provide power for both devices. The USB host API of Android can also be used to enable Arduino board to interact with an android device. With this solution the device board is very simple but works only with Android devices that have an USB Host port.

In addition, there are APIs to access the Bluetooth, Wi-Fi, and Near Field Communication (NFC) radios on Android devices. These communication APIs allow Android devices to connect to an even wider variety of external sensors. However, building applications that utilize external sensors is relatively complex from the application developers' perspective [8].

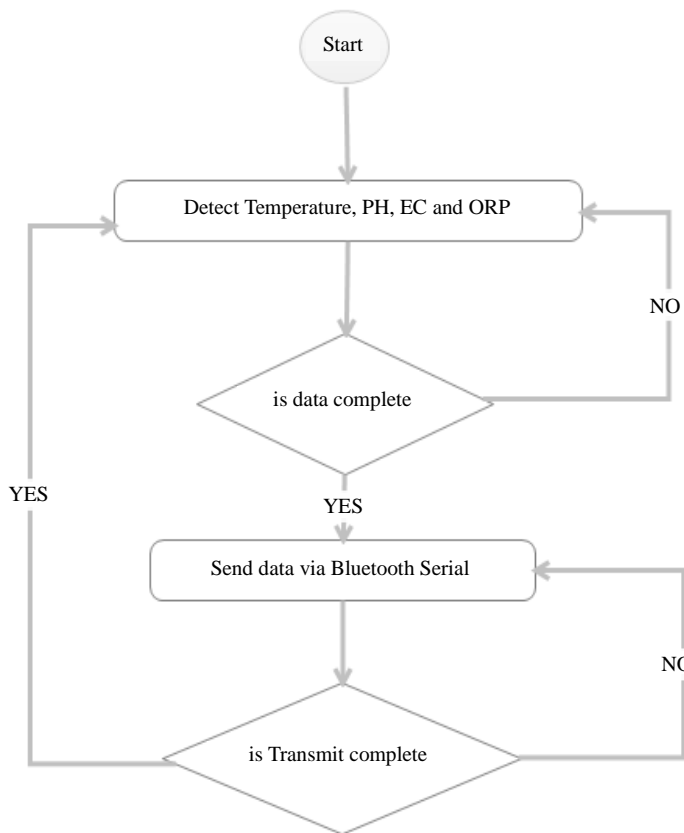
In this work, a serial Bluetooth module is used to provide communication between USD and the u-WQR mobile app. This is because Bluetooth is a popular method of communication between devices. Many smart phones today have the capability to communicate using Bluetooth and it is also easy to get cheap Bluetooth radio. The Bluetooth Shield from Seeedstudio is used to implement a communication. This shield integrates a serial



**Figure 4.** Sensor unit.

**Table 1.** Sensor specification.

Sensor	Manufacture	Model	Range
pH	Atlas Scientific	ENV-40-pH	0 - 14 (Na <sup>+</sup> error at >12.3 pH)
EC	Atlas Scientific	ENV-40-EC-K0.1	(K = 0.1) 0.1 - 0.5 $\mu\text{s/cm}$ to 50,000 $\mu\text{s/cm}$
ORP	Atlas Scientific	ENV-40-ORP	+/- 2000 mV
Temperature	Maxim Integrated	DS18B20	-55°C to +125°C



**Figure 5.** General processing of the proposed USD.

Bluetooth module which can be easily used with Arduino for transparent wireless serial communication. This module has two modes: master and slaver device and it is configured to operate in master mode in the proposed system.

### 3. Results and Discussion

The ubiquitous mobile sensing for water quality test and reporting system proposed in this paper was fully developed and tested to demonstrate its feasibility and effectiveness. **Figure 6** show the complete u-WQR system during field test. The proposed system has all the necessary feature for mobile data reporting in water quality management applications. It allows decentralized actors to submit water source monitoring data via cell phones to a central database. The system provides visualization module which enable administrator to visualize the datasets. Users can view different parameters of water quality data from different locations in graphical forms as shown in **Figure 7**. From the graphs, user can observe the behavior of each parameter and alert the public in case of abnormality. The system can be configured to send SMS and or email alerts to managers when data reveal problems. The system total cost including sensing device, mobile phones and the Bluetooth module stands at \$750.

Field testing of the system conducted in Nkokonjero, Uganda and Mwanza, Tanzania verified the functionalities of the system and its practical application in actual environment. Through pilots in these two sites we have identified opportunities and challenges associated with the implementation of the u-WQR system in developing countries. For example, we noted that mobile data coverage is weak in many rural areas which limit instant data delivery. The system has a distinct advantage over traditional paper based reporting. Since it use electronic data collection which is relatively inexpensive, allow a well-coordinated and continuous monitoring of water quality from remote locations to centralized managers. Most stakeholders find the u-WQR system easy to use and require little training. On the other hand administrators and government authority managers were excited to see this system in place.



Figure 6. Field test of the u-WQR system.

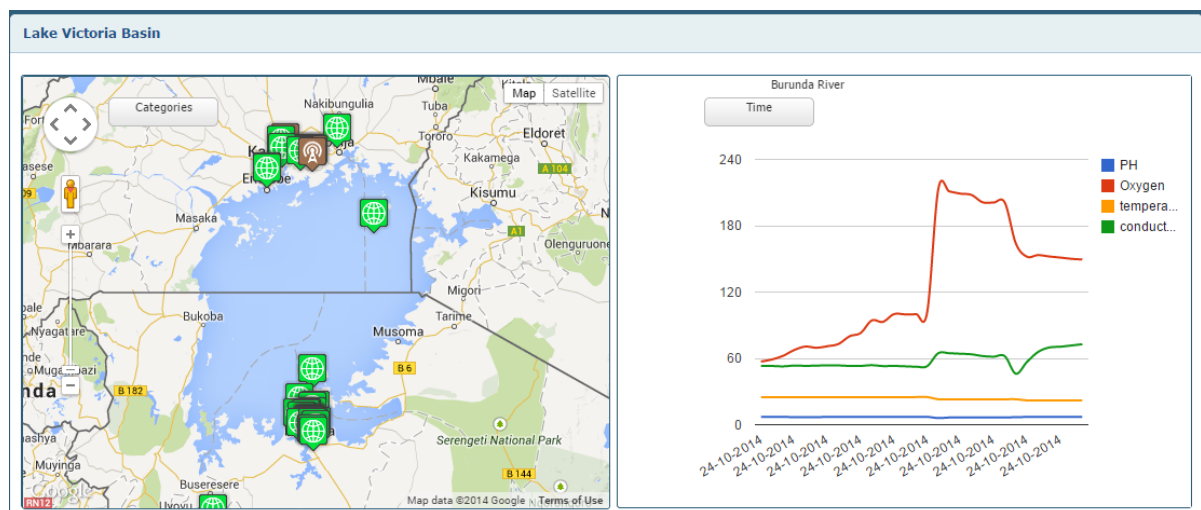


Figure 7. Visualizations of the u-WQR data.

## 4. Conclusion

The objective of the work presented in this paper was to realize the ubiquitous mobile sensing system for water quality monitoring and reporting. The system has been successfully designed and prototyped to capture and report the water quality parameters using an Android Bluetooth-enabled phone and Arduino based sensor device. The use of ubiquitous mobile sensing application in water quality monitoring and reporting has important implications for water resources management programs in developing countries. Prospective future works include incorporating water image processing and stabilizing the sensor device for field data collection.

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