SENSOR BASED METHOD FOR WATER MONITORING IN SMALLHOLDER IRRIGATTED AGRICULTURE TANZANIA.

Kevin Njuu

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Information and Communication Science and Engineering of the Nelson Mandela African Institution of Science and Technology.

Arusha, Tanzania

April, 2016

ABSTRACT

Monitoring water use in traditional irrigation canals is critical for any water management best practice to function. In Tanzania, water basin authorities and users association have been created to distribute and levy water usage fee in view of avoiding conflicts.

Although much has been done over the years, the authorities have so far failed to ensure the desired equity, fairness and transparency. This is largely attributed to high deployment cost which constrains the uptake of various technologies. In agriculture, one of the commonly used technologies is sensors. Effective utilization of sensors requires a design that matches the physical and connectivity environment of the area.

In this dissertation, we present such a system of wireless sensor network designed for the purpose of improving water management in farmer-led irrigation. The system consist of a low-cost design of a sensor system that measures water depths at specific canal points and transmits the measurements to a central system. The central system transforms the measurements into discharge values using a locally established rating curve. For the end user, we have provided a web based application for administering the canals; visualize canal discharge values; and generating reports. The system can easily be scaled up to monitor larger networks of canals, and can therefore be a game changer when deployed.

DECLARATION

I, **Kevin Njuu** do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Kevin Njuu

Name and signature of candidate **Date**

The above declaration is confirmed

Dr.Khamisi Kalegele 13/04/2016

Name and signature of Supervisor 1 **Date**

Dr. Hans Komakech

Name and signature of Supervisor 2 **Date**

COPYRIGHT

CERTIFICATION

The undersigned certify that has read and found the dissertation acceptable by the Nelson Mandela African Institution of Science and Technology.

Dr.Khamisi Kalegele 13/04/2016

Name and signature of Supervisor 1 **Date**

Dr. Hans Komakech

Name and signature of co-supervisor 2 **Date**

ACKNOWLEDGEMENT

This dissertation could not have been completed without the blessing of my Almighty God, I thank him for keeping me physically fit and mentally healthy throughout the period of my studies. I believe that this work makes him proud.

I feel honoured to have been supervised by Dr. Khamisi Kalegele and Dr. Hans Komakech, I have learned a great deal from them. Their efforts in leading and shaping my research towards the right direction were instrumental. I will always remain thankful for the way they have helped me improve in my career and as a person.

Special thanks to my family, my dear parents, sister and brothers, nephews and nieces for their unconditional love and support in my life and during my studies. I pray to God that they all live long because their presence in my life is irreplaceable.

I am too thankful to the staffs of NM-AIST, especially CoCSE faculty members, their remarks and constructive criticism have helped improve my work significantly. I feel honored to have been a scholar of such a school. I owe them my heartfelt appreciation.

Many thanks to the support of friends during my studies. Special thanks to Bernard Mussa, Gideon Marandu, Neema Komba and Valerie Ayub just to mention a few. May the Almighty God bless all those who have, in one way or another contributed to successful completion of this work!

Lastly but not the least, appreciation to COSTHECH for sponsoring my master’s studies. I hope that, this work will motivate them to support more students. In addition, I thank the Manyire villagers, especially the canals leaders for providing me with their valuable time, material and non-material support during my research work.

DEDICATION

I would like to dedicate this work to my awesome God and my beloved family. My parents, Mr and Mrs Thadeus Njuu, sister Stella and husband Wilfred, brother Raymond and wife Rehema, and brother Patrick and wife Clara. Nieces Diana, Selina and Reiny, Nephews Alfred, Timothy, Ryan and Reinhard for their endless love, prayers and support. I love you all dearly.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICIES

LIST OF ABBREVIATIONS

AES	Advanced Encryption Standard
DBA	Desktop Based Application
DFD	Data Flow Diagram
DSDM	Dynamic Software Development Methodology
DSSS	Direct Sequence Spread Spectrum
EDGE	Enhanced Data for GSM Evolution
EPS	Expanded polystyrene Technology
GSM	Global System for Mobile Communications
GPRS	General Packet Radio Services
ICT	Information and Communication Technology
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IT	Information Technology
IoT	Internet of Things
J2EE	Java 2 Enterprise Edition
MoSCoW	Must have, Should have, Could have, and Want to have
M2M	Machine to Machine
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
RAD	Rapid Application Development
SD	Secure Digital
SMS	Short Message Service
SQL	Structured Query Language
SIM	Subscriber Identity module
UML	Unified Modelling Language

URT	United Republic of Tanzania
USB	Universal Serial Bus
WBA	Web Based Application
WSN	Wireless Sensor Network
XLP	Extra Low Power
XP	Extreme Programming
2G	2nd Generation
3G	3rd Generation

CHAPTER ONE

Introduction

This chapter presents the general introduction of the research study covering the following sections: background information, research problem, justification, general and specific objectives, research questions and the research framework.

1.1 Background Information

Fresh water is continuously becoming a scarce and a more vulnerable resource. Globally, water stress is being driven by increasing demands and misuse in various water use sectors (agriculture, domestic, industries, energy etc.). This has triggered an urgent need for authorities to enhance water management practices. Kinzli (2012), pointed out that, irrigated agriculture is the largest water user, and is often targeted for increased efficiency to free water for other uses. In Tanzania, as stipulated by the National water policy of 2002, water resource management and development is divided into nine river basins water body authorities. These authorities are responsible for monitoring and regulating water resources at river level, while user associations or user groups are in charge at the canal level.

Although there are some automatic monitoring methods at the river level, operations are highly dominated by the manual methods. The manual methods require constant presence on fields and do not allow for remote monitoring. Furthermore, according to (Ahmad et al., 2013), manual methods are less accurate, not timely due to human factors involved in gauge readings and possess logistical problems in data collection, dissemination and interpretation. Fig.1 shows the stage boards installed at the river for monitoring water levels, a typical example of a manual methods. With the use of these methods in particular, data collection is primarily recorded by gauge readers who submit data to the respective basin sub-offices for further processing, analysis, storage and dissemination at every end of each month (Pangani Basin, 2014). The manual methods of monitoring water levels pose several challenges. The first challenge according to the environmental flow assessment report by Wami river basin (2013) is that, some gauge readers are not faithful; they do not go to the sites on time or even do not go at all and just guess the numbers and write. The second challenge is that data collection through daily readings of the stage boards installed at the rivers is highly constrained by the availability of funds (Hamerlynk *et al*, 2012). On the other hand, the automatic methods used at the river level, apart from being costly, some of them need replacement of missing or old instruments and many are not operational due to lack of funds for fully re-operationalizing as echoed by Pangani river basin (2014).

Figure 1: Stage boards for monitoring river water level

Meanwhile, at the canal level, there is no monitoring at all which in turn has led to limited availability of water resources data that are very important in regulating usage; farmers operate canals on off and on basis as shown in Fig 2. This situation of lacking of monitoring facilities at the canal level has been contributed by the high cost of off-the-shelves automatic monitoring methods. Extending such costly methods is not feasible to cost-prohibitive traditional irrigation canals.

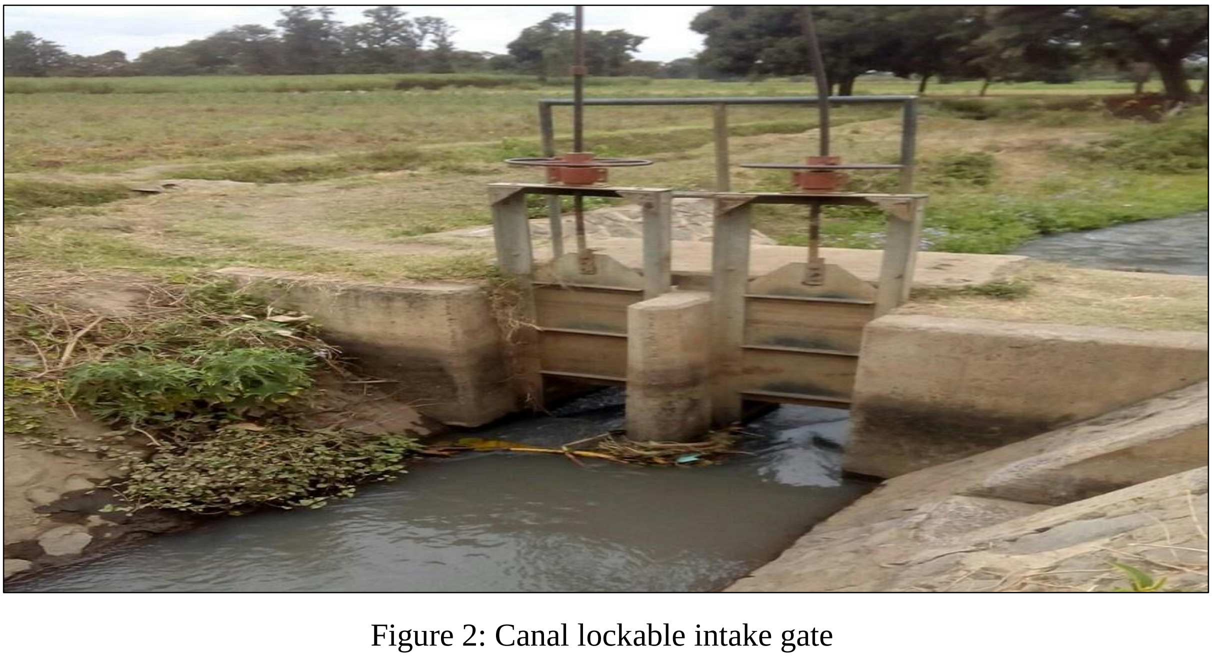


Figure 2: Canal lockable intake gate

The situation is even more acute in the closing river basin of Pangani. It is reported that water diversions by over 3000 traditional irrigation canals on the slope of Mt. Kilimanjaro and Mt. Meru contribute to the drying up of several tributaries of the Pangani river, They are also the main source of increasing upstream-downstream water competition and conflicts in the basin (Komakech et al., 2011).These irrigation canals are considered water wasteful by the basin authorities as most of them are unlined. In the past, the basin water board made an attempt to control abstractions in traditional canals by installing lockable intake gates. However, most of these intakes have since been vandalised by farmers. On the other hand Pangani Basin Water Board is also interested in collecting water user fees from the farmers using these traditional irrigation canals. Water user fee is a volumetric based surcharge calculated from the amount of water used by a farmer or entity over a given period, normally a year (URT, 2009). Since there is no metering system on the traditional canals, the annual user fees levied on smallholder irrigators is based on rough estimates and the assumption of continuous water use by the farmers.

In order to assist the traditional irrigation canals to become more efficient, it is important to monitor canal water discharge and provide the water basin board with decision support tools. These tools will give real time reports for supporting irrigation water management. The concept of monitoring irrigation water delivery in both dry and rainy season is necessary and has become quite realistic with a lot of research done in wireless sensing and prevalence of low cost ingredients. In recent times, sensor networks have become important for physical and environmental monitoring. They are considered to be the most efficient means of getting real time information. Currently, sensor networks are very promising in the realisation of internet of things (IoT) concept and in the automation and monitoring fields –such as home automation, health, industrial, and environmental monitoring. Sensor networks typically consist of sensor nodes that are embedded into the environment to collect data at user-defined intervals. These nodes are designed to operate unattended for periods of weeks to years (Watras et al., 2014). With this significant technological advancement, low-cost monitoring systems are increasingly becoming an attractive option for water monitoring in smallholder irrigated agriculture. Therefore, this dissertation presents a cost effective method for monitoring water allocations in traditional irrigation canals suitable for use in remote river basin of Sub-Saharan Africa. The method uses ultrasonic sensors for sensing water level and subsequently employs a locally customized rating curve to establish water discharges. In dealing with the issue of poor infrastructure, the method uses a GSM-based wireless sensor network that was designed specifically for Tanzanian conditions, particularly in Pangani river basin.

1.2 Problem Statement and research justification

Although automatic monitoring methods exist at the river level, operations are highly dominated by manual methods. Meanwhile at the canal level, there is no monitoring, and farmers operate canals on off and on basis. The manual methods used at the river level are neither precise nor timely in data aggregation, processing and sharing among stakeholders. On the other hand, the automatic methods that are partially used at the river level are expensive off-the-shelf systems and extending such costly methods is not feasible to cost-prohibitive traditional irrigation canals.

This situation has led to limited availability of water resources data that are very important in regulating usage. Thus, there is a clear need for low-cost water monitoring method for supporting water management in traditional irrigation canals. On the other hand, the concept of monitoring irrigation water delivery during both dry and rainy seasons is necessary and has become quite realistic with the significant advancement in wireless sensing and the prevalence of low cost open source hardware and software platforms. The above situation forms the basis of the motivation to design an affordable water monitoring system suitable for use in farmer engineered irrigation canals to assist irrigated agriculture to become a more efficient water user.

1.3 Objectives

1.3.1 General objective

The main objective of this research is to develop a low-cost method for water monitoring in traditional irrigation canals.

1.3.2 Specific objectives

i. To review and analyze current technological developments in water monitoring methods.

ii. To design and develop a sensor based system for water monitoring in traditional irrigation canals.

1.4 Research questions

i. What are the strengths and weaknesses of the current technological developments in the building blocks for water monitoring methods?

ii. What are the factors to consider during design decisions when developing WSN for water monitoring methods?
iii. How can water delivery data for traditional irrigation canals be effectively gathered and communicated in real time?
iv. How can real time water delivery data be effectively aggregated, processed and presented to give meaningful information?

1.5 Significance of the study

While Irrigated agriculture in general, and smallholder irrigators in particular are reported to be the largest water users, efforts are being directed towards utilization of modern technologies in order to improve the management of water resources. This research is in line with such efforts as it has exploited the benefits of penetration and current advancements in information and communication technology (ICT). The availability of low-cost and low-power open source hardware and software platforms to build an affordable method for water monitoring that is compatible with cost prohibitive smallholder irrigators. The method will enhance the collection of water discharge data in the traditional irrigation canals. The underlying data are processed to extract more meaningful information such as water discharge reports generated in hourly, daily and monthly basis. This information is critical for supporting water management authorities' practises, particularly in enhancing the effective utilization of the diminishing resource, levying usage fee, and ensuring equity and transparency in water distribution. This information would also significantly minimize the increasing upstream-downstream water competition and conflicts in the basins, and concerns such as the justification for usage fee charged.

Furthermore, as explained by Ahmad et al. (2013) it can facilitate other operations and services such as volumetric metering and demand based delivery. It can also be the first step towards installing higher levels of automation such as controlled gates and other active structure.

CHAPTER TWO

Current Developments in WSN for Water Monitoring; Building Blocks and Factors to consider during Design Decisions.

Summary.

Nowadays, WSN based systems have progressively became an important technological advancement. Sensor networks are key in various aspects of life such as home automation, industrial process control, health and environmental monitoring. In order to build a sensor based network relevant to a particular application environment, it is important for one to be aware of the current technological developments, as well as available options and techniques in order to make sound decisions. This chapter discusses the main building blocks and factors to consider during design decisions of WSN for water monitoring. The chapter focuses on the technology alternatives on the WSN subsystems, which are sensing, communication, and storage and processing subsystems. The technological options that are available on each of the subsystems are carefully analysed and evaluated with regard to the water monitoring application environment. Furthermore, the factors that are important for the development and sustainability of sensor network systems - costs, power sources, and management are also discussed.

2.1 Introduction.

In recent times, sensor networks have become an important tool for physical and environmental monitoring. They are considered to be the most effective means of collecting real time data, and one of the main contributors towards the enormous amount of data called the “Big data”. Currently, sensor networks are very up-and–coming in automation and monitoring fields; they are used in various aspects such as home, health, industrial, and environmental monitoring. Typically, a sensor network consists of sensor nodes that are embedded in the environment to collect data at user-defined time intervals (Watras et al., 2014). Researchers around the world are working on improving various aspects of sensor networks such as power consumption, cost reduction, sensing accuracy and transmitting and receiving range. While these are essential factors to consider during design of sensor systems, they are also compelling criteria in evaluating their relevance within an application area. Although it is desirable to have a sensor network function at a low cost and power consumption while maintaining performance and remote flexibility, optimizing each of these aspects may be contradictory to each other. The major challenge is to achieve both the effectiveness (building the right system) and efficiency (building the system right) at an optimal tradeoff between the two. Therefore, the purpose of this chapter is to review the main building blocks and factors for consideration during WSN design and implementations for water monitoring application context. The building block includes the sensing subsystem, communication subsystem and storage and processing subsystem, while factors for consideration are the costs and power sources management.

2.2 The building blocks of WSN for water monitoring.

There are various techniques for liquid level sensing, however, identifying the most appropriate one that is suitable for a particular application can be very challenging and time consuming. This segment discusses the major techniques for liquid level sensing, theory behind them and their advantages and disadvantages.

The first technique is the use of ultrasonic based measurements. As echoed by the Process Industry Forum (2013), the ultrasonic works by emitting high frequency acoustic signals that are reflected back and detected. The transit time of the signal, from the sensor to the target and back again, is correlated to the liquid level. Ultrasonic measurements are taken without physical contact with the product that is being measured and are suitable for a wide range of liquids and bulk products. However ultrasonic measurements are unsuitable for higher pressures or in vacuum application environments and require the product measured to give a good reflection and not to absorb sound waves as pointed out by the Instrumentation toolbox (2015). Works by (Ahmad et al., 2013) and (Rowe et al., 2009) have clearly presented the application of ultrasonic sensors for monitoring river and stream flows measurements.

A second technique is by the use of radar method, sometime reffered as microwave whereby a pulse of radiation is transimmited down to the surface and some proportion is bounced back by the reflecting interface formed at the surface, the same way as the ultrasonic based level measurements. The fundermental difference between radar amd ultrasonic method is the type of wave used; radar uses radio waves instead of sound waves used in ultrasonic. Thereafter, with a relatively sophisticated electronic circuit, it is possible to measure the flight time and given that the velocity of the waves is known, the distance may then be calculated as stipulated by (Boyes, 2009) and (Instrumentation toolbox, 2015). This technique is easy to install, and can be used with liquids and solids. Although it is not affected by emulsification, dust, foam or vapours, it is usually an expensive option (Process Industry Forum, 2013).

Hydrostatic pressure is another technique that is based on the principle that fluids exert pressure that is a function of height. This technique can be used to determine the liquid level in a tank, well, river or other body of liquid. (Nikolov and Nikolova, 2008). Usually, a gauge pressure sensor has one side connected to the pipe (pressure side) and the other side open to ambient (in this case, atmospheric) pressure. The sensor measures the pressure difference, which corresponds to the change in the tank level. Therefore, the hydrostatic pressure depends on the air pressure, fluid density and height of the column of fluid and it can be expressed as $P = P_{atm} + \rho gh$, where P is pressure in Pa, P_{atm} is atmospheric pressure in Pa, ρ is mass density of fluid in kg/m3, g is standard gravity which is 9.8066 m/s2, and h, is height of fluid column in metres (Boyes, 2009). This technique is suitable for applications that contain vapour, foam or any form of agitation but limited to applications with low viscosity liquids with a specific measuring range as Process Industry Forum (2013) remarked.

Capacitive sensors is yet another method for measuring liquid levels that utilises low radio frequency to measure the conductivity of current in a closed circuit that varies proportionally to the level of the application. It is a function of the dialectic constant of the fluid, the surface area of the capacitor, the probe and the separation distance (Process Industry Forum, 2013). It is typically used in industries where the level of powered and granular solids, liquid metal, corrosive materials etc. is to be measured (Mathews et al., 2013). Likewise, liquid level in rivers and reservoirs can be monitored by measuring the electrical capacitance between two electrodes immersed in the liquid. Its advantages are, low-cost (i.e. sensors can be built with affordable technologies), low power consumption, high linearity and works well with both the liquids and solids (Reverter et al., 2007). However, due to the fact that capacitance is a contact based measurement system, is not always suitable for use with sticky fluids. Works by (Mathews et al., 2013) and (Reverter et al., 2007) depicts typical applications of capacitive based liquid level measurements. Table 1 summarizes techniques for liquid level measurements.

Table 1: Liquid level measurement techniques

Sn	Technique	How it works	Advantages	Disadvantages
1	Ultrasonic based method	Emits high frequency acoustic signals that are reflected back and detected. The transit time of the signal, from the sensor to the target and back again, is correlated to liquid level	Measurements taken without physical contact and suitable for a wide range of liquids and bulk products	Unsuitable for highly pressurised, high turbulence or applications with steam or foam. Require product to give a good reflection and not absorb sound waves
2	Radar (microwave) method	Works the same way as ultrasonic. The fundermental difference is that radar uses radio waves instead of sound waves used in ultrasonic	Easy to install, can be used with liquids and solids. Not affected by emulsification, dust, foam or vapours	Usually an expensive option
3	Hydrostatic pressure method	Based on the principle that fluids exert pressure that is a function of height.	Suitable for applications that contain vapour, foam or any form of agitation	limited to applications with low viscosity liquids and with a specific measuring range
4	Capacitive based method	Measures conductivity of current in a closed circuit that varies proportionally to height. It is a function of dialectic constant of the fluid, the surface area of the capacitor and the separation distance	low-cost, low power consumption, high linearity and works well with both the liquids and solids	Capacitance is a contact based measurement not always suitable for use with sticky fluids

Nowadays, a number of communication standards are available. There is no perfect technology and each one represents a compromise between different factors, like range, data rate, costs, coverage, power consumption etc. The choice of one particular technology depends on what we want to do with it (Fourty et al., 2005).

Wired sensor networks are very reliable and stable communication systems. Although you can connect sensors to a wired network, often sensors are located in areas where running wires is impractical. The wireless sensor networks are feasible and possible for installation in places where cabling is impossible; WSN also promises lower installation costs than the wired sensor network (Ruiz-Garcia et al., 2009). This is why the application of WSN often precludes the use of wired sensors. Most importantly, sensor networks require use of wireless technology, a more versatile medium to transmit data from the sensors to other nodes in the network (Bell, 2013). One form of wireless communication is a Wi-Fi (IEEE 802.11), a flexible data communication protocol implemented to extend or substitute wired local area network, such as Ethernet (Wang et al., 2006). Although this protocol is usually utilized in computer based networks, it is possible to create WSN with it, however higher power consumptions makes battery use infeasible and remains an important disadvantage for use within WSN.

Another form is Bluetooth (IEEE 802.15.1), a wireless protocol that is used for short-range communication (Wang et al., 2006) and considered a cable replacement for mobile devices. Although products based on the Bluetooth standard are often capable of operating at greater distances, the targeted operational area is the area around an individual, e.g. within 10 meters of the user (Shuaib et al., 2006). Some of its common functions are passing and synchronizing data, e.g. between a PDA (personal digital assistant) and a computer (Ruiz-Garcia et al., 2009). Therefore for applications requiring high data rates over short distances, Bluetooth remains the best technology (Kooker, 2008). On the other hand, Bluetooth is probably the nearest possible option for use in WSNs, but the fact that its power consumption has not been primary priority in its design, makes it unsuitable for applications that require ultra-low power consumption.

There is yet another form of wireless communication at our disposal, the Zigbee (IEEE 802.15.4) technology. It is a low data rate, low power consumption, low cost, wireless networking protocol targeted toward automation and remote control applications (Garg, 2010). ZigBee protocol places primary importance on power management as it was developed for applications that require low power consumption and years of battery life. It does not require data transfer rates as high as those enabled by Bluetooth. ZigBee technology can transmit 10 meters in the indoor, while in the outdoor transmission distance can reach 200 meters; in other uses spectrum, the indoor distance is 30 meters, while outdoor transmission distance can reach 1000 meters. The actual distance will be based on the size of the transmission power (Quan-Xi and Gang, 2010). ZigBee can be implemented into various topologies such as star, cluster and mesh and possible to build networks larger than with Bluetooth making it ideal for building of WSN. (Watras et al., 2014) suggested that, Zigbee networks are a useful, relatively low-cost option for obtaining continuous and high-quality data. The work by (Ahmad et al., 2013) has also clearly demonstrated Zigbee based WSN to be extremely low-power, field deployable and scalable with respect to cost and numbers. Table 2 summarizes the comparison between wireless standards.

Table 2: Comparison between Wi-Fi, Bluetooth and ZigBee

Sn	Feature	Wi-Fi	Bluetooth	ZigBee
1	Standard	IEEE 802.11b/g/n	IEEE 802.15.1	IEEE 802.15.4
2	Data rate	11/54/320 Mb/s	1-2 Mb/s	250Kb/s
3	Coverage	A building	Personal area network (usually 10m). Although can greater distances.	Up to 30m indoor, 1000 outdoor depending on transmission power
4	Power consumption	Higher (Battery last in hours)	High (Battery could last in Days)	Low(Period of weeks to a year)
5	Costs	High	Average	Low cost
6	Applicability	Computer based networks	Exchanging data between PDA, phone and Computer	Wireless sensor network

On the other hand, sensor data can be uploaded to the cloud/web server and be accessed and manipulated from anywhere at any time with internet access. Therefore, connection of sensor networks to the internet will give them additional value, which is the remote flexibility. ZigBee and Bluetooth sensor networks can integrate with other networks such as Global System for Mobile Communication (GSM), General Packet Radio Service (GPRS), Enhanced Data Rated for GSM Evolution (EDGE) or Third Generation (3G) technologies to create wide area coverage and offer ubiquitous wireless connectivity (Eddabbah et al., 2015).

The GSM is a European standard that was developed to provide a common second-generation technology for all Europe(Garg, 2010). It is a circuit switched network and operates at 900 MHz and 1800 MHz. and considered among the most secure communication networks. It has the advantage of being the worlds' most deployed communication technology after the fixed line telephone network and present in the remotest of locations (Usman and Shami, 2013), making it suitable for remote monitoring applications. With GSM technology, Short Message Service (SMS) based alerts and controls of things can be done. (Balaji and Ganesan, 2012) has proposed a water pollution monitoring system that uses GSM to send an automated SMS alerts in case of inference value above the threshold value. However data transmission rates in the GSM networks are insufficient and the connection set-up time is relatively long.

The second is the GPRS technology, which can be considered a major improvement of the GSM system; it takes into account the increasing demand for data transmission over mobile networks. (Wesolowski and Wesolowski, 2001). It offers a reasonable data transfer speed and reduced call setup time (Arshad et al., 2010). It employs packet based transfer of data over the circuit switched GSM network. This allows it to run IP based network applications over the GSM network (Usman and Shami, 2013). It is often combined with short distance communication technologies such as ZigBee to form a remote sensor network. A remote automatic meter reading system based on ZigBee and GPRS has been proposed by (Quan-Xi and Gang, 2010). Also (Ahmad et al., 2013) developed a smart water meter based on GPRS to frequently record and transmit the water diversion data to a centralized server.

EDGE is a further major enhancement to the GSM data rates. Although GSM network have already offered advanced data services like GPRS, EDGE is specified in a way that provides higher levels of performance (Wesolowski and Wesolowski, 2001). 3G networks combine the strengths of two of the most successful communication technologies: cellular and internet technologies (Shaikh et al., 2013). These networks aim at offering their users ubiquitous access to a multitude of feature-rich, IP-based, multimedia services (El Barachi and Alfandi, 2013), making it ideal for applications that require higher data rates. However, its power consumption and coverage in remote areas is of great concern.

Because of resource limitations and processing requirements, decisions for storing sensor network data involve determining what data to be stored, where to store and for how long it should be stored. Several approaches for storing data generated by sensor networks have been proposed.

The first approach is the local storage where data is being stored within the node, for example, storing data on the SD card. This method is used in situations where sensor nodes are designed with no connectivity to other nodes or intended as a backup-logging in case sensor node is disconnected from the central storage (Bell, 2013). Nodes with this type of storage are often power efficient because sending of data consume a great deal of energy. Also sensor data for some long time can be stored since the capacity of storage devices such as SD card is no longer a challenge. However the main drawback of this method is that it requires manual visits to the sensor nodes to offload data and thus not suitable for places that visits to offload data are not possible, feasible or dangerous.

Another approach is the remote storage or base station storage where all data is collected and processed in a centralized manner. For example, storing data on a different node usually sink node or on a server connected to the Internet. This normally requires some form of communication or network connectivity to the remote storage (Ai et al., 2009; Bell, 2013). This approach has the benefit of allowing a friendly centralized access to data at any time and from anywhere provided internet connection is available. Nevertheless, sensor nodes will deplete energy rapidly for continually reporting and forwarding data to this central system.

The hybrid approach is another alternative for sensor network data storage whereby a combination of both local and remote storage is applied. Although this option consumes more resources, it is a more robust and reliable data storage design, both the local and remote storage can act as a backup for each other ensuring data is not lost in case of anything happening with either the storages or the communication system itself. Table 3 summarizes a comparison of data storage between sensing node, central database and at both locations while Table 4 sums up the comparison of data processing between sensing node processing and the central database processing.

Table 3: Comparison of storage locations for sensor data

Storage location	Advantage	Disadvantage
(Local storage only) i.e. at sensing node.	- Less complicated - More power efficient as /sending consumes more energy	- Require manual visits to site offload data. - High risk of losing data /no backup - Difficult to monitor data logging
(Remote storage only) i.e. at the centralized database	- Possible to remotely monitor data logging - Easy to notice failure - Friendly centralised data with real time access.	- Sensor nodes will deplete energy rapidly for continually sending of data. - High risk of losing/missing data during sending in case of failure
At both places	- Robust approach, both ends acts as backup to each other. Hence a more reliable option	- Consume more resources - More complicated

Table 4: Sensor data processing location comparison

Processing location	Advantage	Disadvantage
(Local processing only) i.e. at sensing node.	- Processing of single node data is less complicated.	- Possible only for lightweight processing requirements. - Require additional components at each node of which increases cost. - Loss of raw data which could be used for other purposes.
(Remote processing only) i.e. at the centralized database	- More organised and centralized processing. - Reduce cost (the centralized processing) - Easy to notice failure	- Require more sophisticated processing system capable of handling data for different sensor nodes separately and accordingly.

2.3 Factors to consider during design of WSN for water monitoring.

Energy supply has been the greatest limiting factor on sensor networks to date (Park and Chou, 2006). Although recent technological progress has helped to decrease the power consumption of electronic devices, the gap between the energy that can be stored in current energy storage devices and the power consumption of the electronic circuitry, limits the system's lifespan. Moreover, the lifespan of a WSN deployments depends on the type of events that are monitored. High data rate applications can have a lifetime of few days while environmental applications, like tracking animal movements, or flood detection require lower data rate and can therefore achieve longer lifetimes for an equivalent energy budget (Castagnetti et al., 2012).

The basic way for powering sensor node is a battery. Despite recent significant improvements, batteries still have limited life span and expensive to maintain and hence not a long-term viable source of energy for sensor networks and embedded systems (Nechibvute et al., 2012). Furthermore in some applications like structural health monitoring of critical infrastructures and buildings, it is difficult to replace or recharge batteries (Akbari, 2014). However there are number of works that have been able to utilize batteries as a source of power successfully including the work by (Ahmad et al., 2013) that uses Lithium Thionyl Chloride batteries with specifications of 3.6V and 14mAh to power their smart water discharges meter for a period of up to 5 years. This such an extra low power design is highly contributed by the development of own PCB (Printed Circuit Board) that uses products with Microchip's Nano Watt XLP (Extra Low Power) technology.

The second way that has lately attracted the attention of design engineers, are systems that are able to acquire energy from the environment(Ševcík and Kovár, 2013). Since sensor networks are mostly used in outdoor settings, energy can be harvested from environmental sources such as sunlight, wind, water flow, etc. This characteristics can be exploited to increase sensor network lifetime. However the use of energy from the environment instead of batteries is sometimes not possible due to the fact that environmental conditions are sometime variable and unreliable.

Therefore a combination of an energy harvesting scheme with rechargeable battery can be implemented for the WSN. Batteries can directly be recharged onsite by using energy from the environment. The hybrid energy sources increase the probability of having uninterruptible power supply because each source can compensate some fluctuation of energy on its counterpart transmitted to the powered device (Akbari, 2014). The work by (Semente et al., 2013) on an energy efficient sensor network system for limited power source environments is a good depiction of this technique.

Despite the fact that sensor networks are no longer expensive industrial constructs that can be built from easily procured and low-cost hardware (Bell, 2013), companies around the globe are still offering off-the-shelf solutions that are even more expensive. Low-cost sensor network for obtaining continuous and high quality data can be built in-house if sufficient skilled personnel are available. Yet the decision to build in-house or use of off-the-shelf solutions is a complex trade-off of various factors such as data sensitivity, time, cost and expertise (Watras et al., 2014). The use of low power and low-cost open source hardware and software platforms over the proprietary platforms offer more room for reducing costs, time and effort. They are the more reliable approach providing full control and flexibility of future maintenance with handful support of various learning facilities where people contribute and benefit from their collective efforts. The work presented by (Kinzli, 2012) for monitoring farmers irrigation practise is a low-cost solution for American small scale farmers but for the case of smallholder farmers in developing Sub-Saharan countries, the cost is still not affordable. This brings the fact that the cost of WSN as applied in different application environments is typically relative and should be kept in the mind of design engineers. Taking this fact into consideration could be the first step towards introduction of WSN solutions or products targeted and tailored for different user groups like in the case of other information technology (IT) related products such as mobile phones and computers. On the other hand, the low-cost of (Ahmad et al., 2013) smart meter for river water discharges is claimed to have been contributed by the use of annually replaceable batteries that have significantly reduced costs by replacing the use of solar panels, but the fact that costs for solar panels are only one time and nowadays can be procured cheaply and easily, it is therefore challenging to conclude which is the cheaper option. Therefore, it is important to conduct a systematic cost-benefit analysis between solar panel costs and the cost for periodic replacement of the batteries for a particular application context before making the final decision for the cheaper option. Therefore, while making design decisions, it is important to address the budget of sensor network in terms of both onetime initial costs as well as ongoing costs such as maintenance costs. It is always unrealistic that, the maintenance costs are far higher that the initial installation costs, thus during design decisions, it is very important that this factors are carefully analysed and addressed.

2.4 Conclusion

This chapter looked at the current developments in WSN for water monitoring building blocks. The main focus was on technological options available on each of the WSN subsystems. The paper also discussed factors to consider during design decisions such as costs and power sources. Although not discussed in this chapter, software and hardware security is also a key factor for consideration during the design of systems destined for real environment operations. Physically securing of sensing components is challenging and tend to significantly add to the costs. Issues of security and protection from environmental conditions tend to cost more than the actual cost of the components. Therefore, it is important to innovate low-cost components combinations as well as physical and weather protections that will significantly reduce the risk of financial losses, while keeping in mind that application of participatory approaches have been witnessed to have reduced risks of financial losses to some great extent. The next chapters present how the current technological developments have been exploited, together with the factors discussed in this chapter, in the design and development of sensing and communication subsystem of the water monitoring system in traditional irrigation canals.

CHAPTER THREE

Sensor Based Method for Water Monitoring: Design and Development of Sensing and Communication Subsystems.

Summary

In the previous chapter, we discussed current technological developments, options and factors for consideration available at our disposal for the design and development of sensor based systems. In this chapter we present how we have made use of such developments combined with locally engineered techniques and approaches compatible with the case study application environment – the developing Sub-Saharan countries, to build a low-cost sensing and communication subsystems which is an integral part of the water monitoring system. The chapter focuses on presenting the design, development and testing results of a low-cost ultrasonic sensor and Arduino based subsystem intended for real time discharge data acquisition and transportation to the centralized sever for storage, processing and reporting.

3.1 Introduction

Designing is a fundamental task when preparing for the development of any system, particularly systems destined for real environment implementation. While Costs, power consumptions, security, performance and remote flexibility are vital factors for consideration during design decisions, they are also compelling criteria for assessing their relevance to particular application context. Major goal is to achieve both the effectiveness (building the right system) and efficiency (building the system right). Low-cost sensor network for obtaining continuous and high quality data can be built in-house with the use of easily available low power and low-cost open source hardware and software platforms. The choice of open source platforms over the proprietary platforms has several benefits including offering room for reducing costs, time and effort. Furthermore, they are more reliable approach providing full control and flexibility of future maintenance with lot of support of active forums and other learning facilities where people contribute and benefit from their collective efforts.

3.2 The Building blocks literature survey

Sensors are electronic devices that generate a voltage based on the unique properties of their chemical and mechanical construction. They do not actually manipulate the phenomena they are designed to measure. Rather, sensors sample some physical variable and turn it into a proportional electric signal (voltage, current, digital, and so on) (Bell, 2013). WSN consists of various sensors nodes that are deployed in the application environment to monitor physical or environmental conditions, conditions such as temperature, pressure, etc. to collaboratively pass their data through the networked medium to a main location. The ultrasonic sensors selected in this work, can be affected by the changing coefficient of sound due to moisture, temperature or pressure and not suitable for highly pressurised, high turbulence or applications with steam or foam (Process Industry Forum, 2013). However they are the most commonly used sensors and suitable for wide range of liquids and non-liquids products. The fact that measurements are taken without physical contact with the product, sensing components can be packaged into small, portable and lightweight sensor nodes, and this can facilitate easy securing of the sensing components from physical and weather threats. Making ultrasonic sensors an appropriate sensing mechanism for remote water monitoring in open channels irrigation canals. A wireless sensor node is not only equipped with a sensing component, but also on-board processing, communication, and storage capabilities. With these enhancements, a sensor node is often not only responsible for data collection, but also communicate with other nodes and with a base station by using their wireless radios to allowing them to disseminate their sensor data to remote processing, visualization, analysis, and storage systems (Dargie and Poellabauer, 2010). Structure of a WSN includes different topologies for radio communications networks such as star network (single point-to-multipoint) where a single base station can send and/or receive messages to a number of remote nodes. Mesh network that allows transmitting data from one node to another in the network and within its radio transmission range. This allows for multi-hop communications whereby a node can use an intermediate node to forward the message to the desired node. While a hybrid star - mesh network provides a robust and versatile communications network, yet maintaining the ability to keep the wireless sensor nodes power consumption to a minimum (Matin and Islam, 2012). The WSN communication unit is highly dominated by the ZigBee wireless technology developed as a global open standard to address the unique needs of low-cost, low-power wireless M2M networks. The ZigBee standard operates on the IEEE 802.15.4 physical radio specification and operates in unlicensed bands including 2.4 GHz, 900 MHz and 868 MHz. The ZigBee protocol was designed to provide an easy-to-use wireless data solution characterized by secure, reliable wireless network architecture. Its features include, support for multiple network topologies, low duty cycle that provides long battery life, low latency, direct sequence spread spectrum (DSSS) with up to 65,000 nodes per network, 128-bit AES encryption for secure data connections, collision avoidance, retries and acknowledgements(Digi, 2015). The ZigBee based, XBee and XBee-PRO modules and other XBee-enabled devices provide an easy-to-implement solution that provides functionality to connect to a wide variety of devices WSN data can be uploaded to the cloud/web server and be accessed and manipulated from anywhere at any time with internet access. ZigBee based sensor network can integrate with wide area networks such as GSM, GPRS, EDGE or 3G technologies to offer remote coverage. The BRCK, a portable GSM based router designed to work with SIM card loaded with data subscriptions from mobile operators to bring 2G/3G internet connectivity is one of the suitable source of internet for WSN intended to work in rural and harsh environments. This router is very compatible with such environments with dust and weather resistance capabilities. It has a smart power feature equipped with a built in rechargeable battery and supporting various powering options such as solar, USB and wall sockets making the router even more attractive option as it can serve for both internet and power requirements. The mobility feature of the router, (portability) has made possible for use as source of internet in remote areas and thus suitable in many area of applications including WSN for remote monitoring systems. The processing unit is in charge of all the functionalities that make the sensor node to collaborate with the other nodes. Usually the microcontroller where instructions (small programs) are loaded to operate and monitor hardware devices used in sensor networks. Microcontrollers are little computers that do a specific job such as taking input from switches and sensors and then deciding whether to turn on a light, ring a bell (Faludi, 2010) or forward to another microcontroller. The Arduino is an open source microcontroller supported by an open source software environment. It provides an integrated development environment called the Arduino IDE. The IDE runs on the computer, where can write and compile sketches and then upload them to the Arduino via USB connections. Sketches are written in a special format consisting of only two required methods, one that executes when the Arduino is reset or powered on and another that executes continuously. The language is C-like, and can define own variables and functions (Bell, 2013). The next section presents the application of technological options discussed here to design water discharge monitoring system for use in farmer-led irrigation canals.

3.3 Material and Methods

3.3.1 Requirements

In coming up with the system, requirements for such a system were first established. The requirements were gathered through our interactions with the farmers, interviews, field studies and literature review. Table 5 below summarizes the requirements.

Table 5: Functional and Non-functional requirements

Functional Requirements	Non-functional requirements
1. Automatically, estimate canal water discharge. 2. Transfer data to a central database system in a robust manner. 3. Monitor canal water discharge using Web-based interface. 4. Register river-canal network for monitoring using Web-based interface. 5. Generate hourly, weekly, monthly and annual monitoring reports. 6. Monitor canal discharge using a mobile application.	1. Easily customizable and low cost solution. 2. Quickly deployable solution. 3. GSM/3G-based connectivity. 4. Secured housing 5. One security level for farmers, the canal network administrator and the system administrator

3.3.2 System Architecture design.

The proposed system has four major parts as shown in Fig. 3. Sensing: This part consists of sensing nodes and is responsible for sensing water level from the canals. These nodes are located at canals distribution points to monitor water level and submits data to the sink node in the data transfer part. A group of 2 to N sensing nodes are managed by a single sink node. Data transfer: This part consists of sink nodes which manages the sensing nodes. The sink nodes collect data from all the sensing nodes and store on SD card as a backup temporarily before transferring to the central database through a 2G/3G internet. Data stored on the SD card as a backup could be deleted manually when no longer needed.

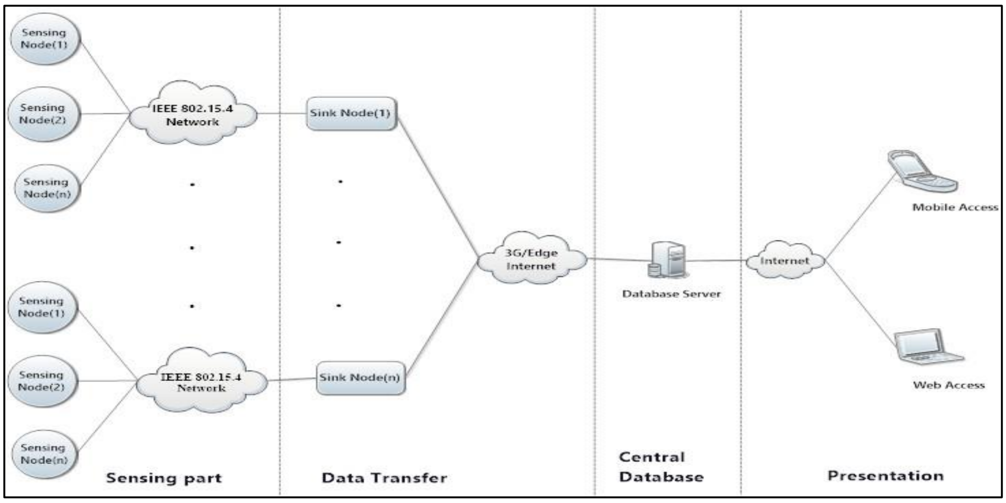


Figure 3: System high level architecture.

Fig. 4 depicts the components involved at each node. Sensing node comprise of microcontroller Arduino boards and ultrasonic based sensor (LV- MaxSonar EZ) to monitor water level at a regular but defined intervals. Real time clock (RTC) for maintaining track of when the sample was taken and XBee-PRO 802.15.4 module with a wired antenna of 60mW power output for providing the wireless medium for data exchange.

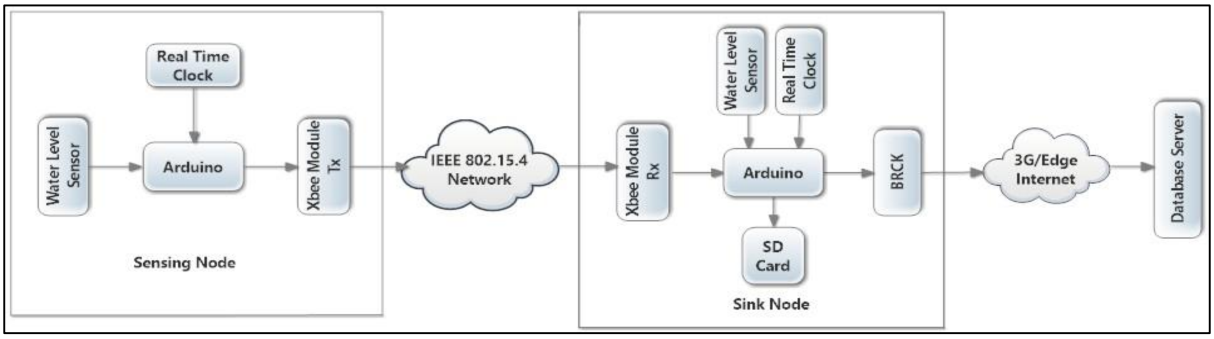


Figure 4: System's components level architecture

Because the sink node is also a sensing node, it has additional components for data aggregate functionality; an Ethernet shield for interfacing the node to internet connection for enabling communication with the remote Server. SD card for local storage of sensor data and the BRCK, a portable GSM modem cum router designed to work with a SIM card for internet provision. Central database: The remotely collected water level data are submitted to a centralized database server for processing to transform the level data into discharge information by using the developed discharge-level relationship called the rating relation. Thereafter a web application presents the discharge information in various forms such as canal hourly, daily and monthly discharge reports.

3.3.3 The System operating principle

The overall operations of the entire system are summarized in Fig. 5 which is essentially a representation of our system general operating principle showing the building blocks involved.

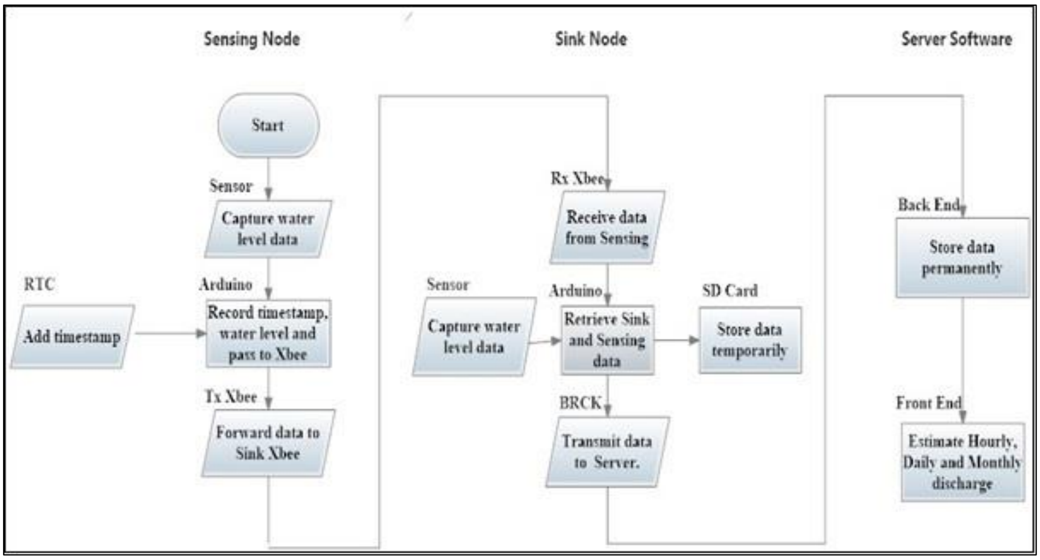


Figure 5: System flow chart

3.4 The prototype development, testing and results

The sensing nodes are required to monitor level of water crossing a particular distribution point (intake) and report the readings to the sink node in a defined interval. Fig. 6 shows the hardware configuration of the elements needed to carry out the functionalities of the sensing node.

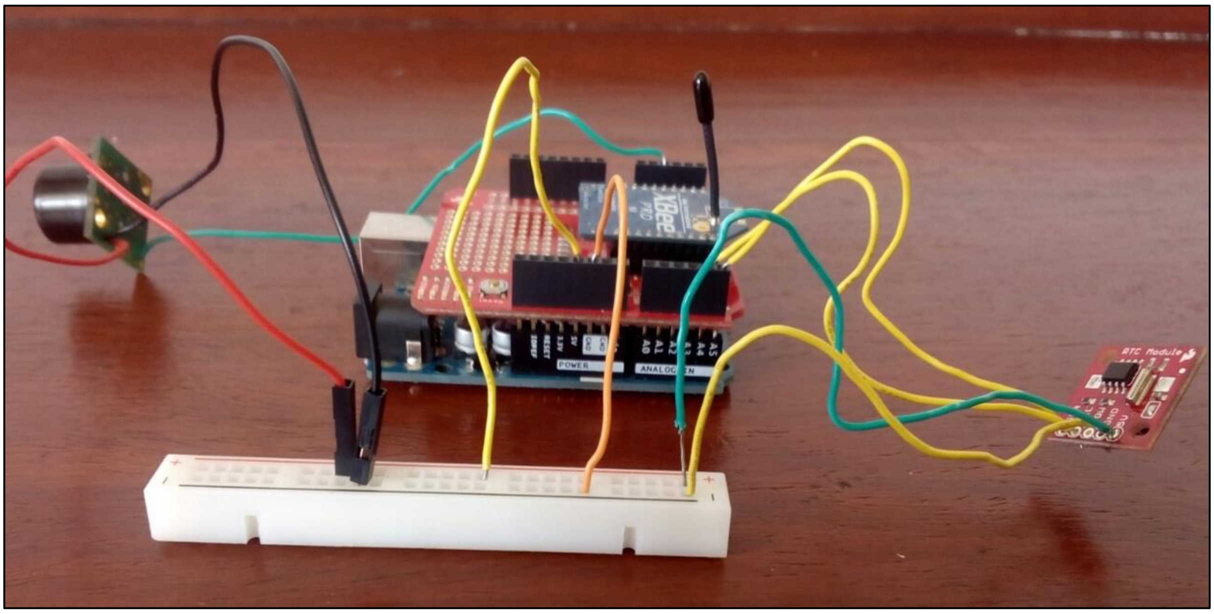


Figure 6: Sensing node components configuration

The Sink node is responsible for reporting all the node's data to the database server, it has additional hardware components for delivering such functionality. Fig. 7 shows the node hardware configuration for the sensing and communication functionalities. Fig. 9 shows components responsible for internet and power provisions, the solar panel and the BRCK.

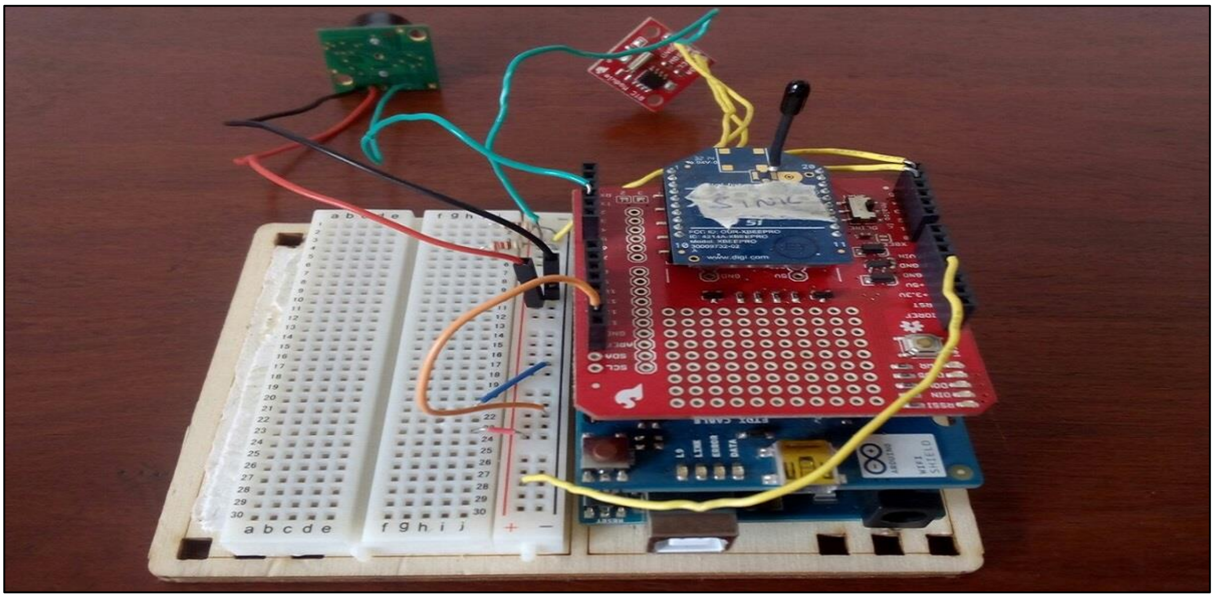


Figure 7: Sink node components configuration

The node components are controlled by the Arduino sketches (programs) written and uploaded into the Arduino board, the brain of the node. To control and coordinate all the components operations systematically. The program instructions were composed and uploaded into the Arduino through the Arduino IDE as shown in Fig 8. The IDE is installed in the computer and uses the serial ports to communicate with the Arduino. Appendix 3 and 4 present the code for the sensing node and sink node respectively.

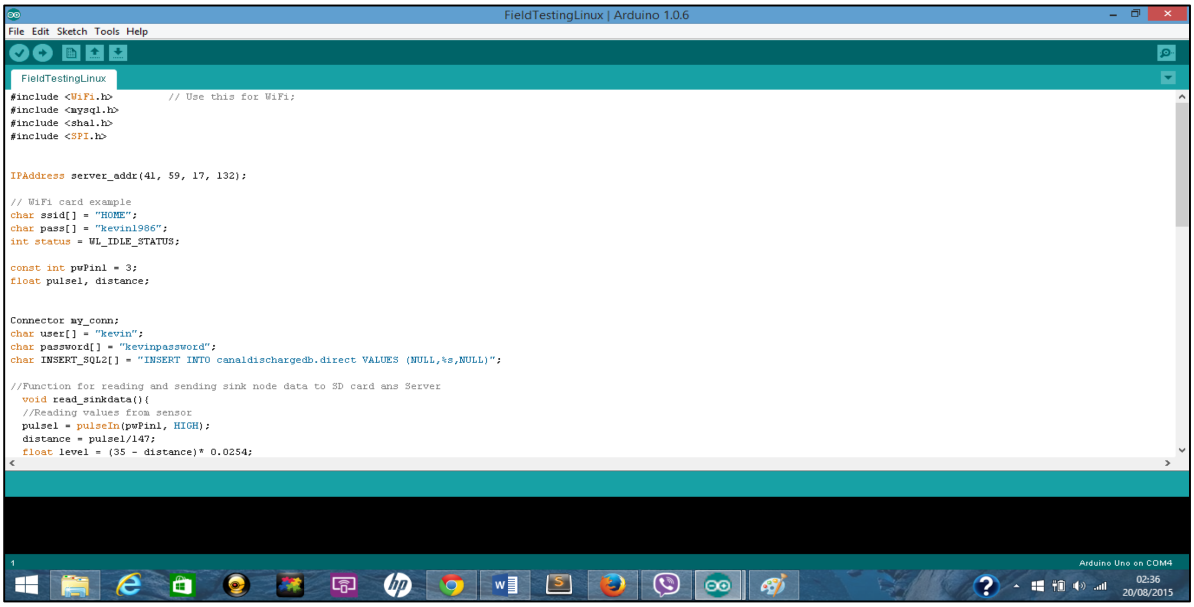


Figure 8: The Arduino IDE environment

Power requirements for sensing nodes are handled by low-cost solar panels and rechargeable motorcycle batteries are used as backup for periods of low solar charging. Sink node is powered by solar panels and a rechargeable battery built-in within the BRCK as shown in Fig 9.

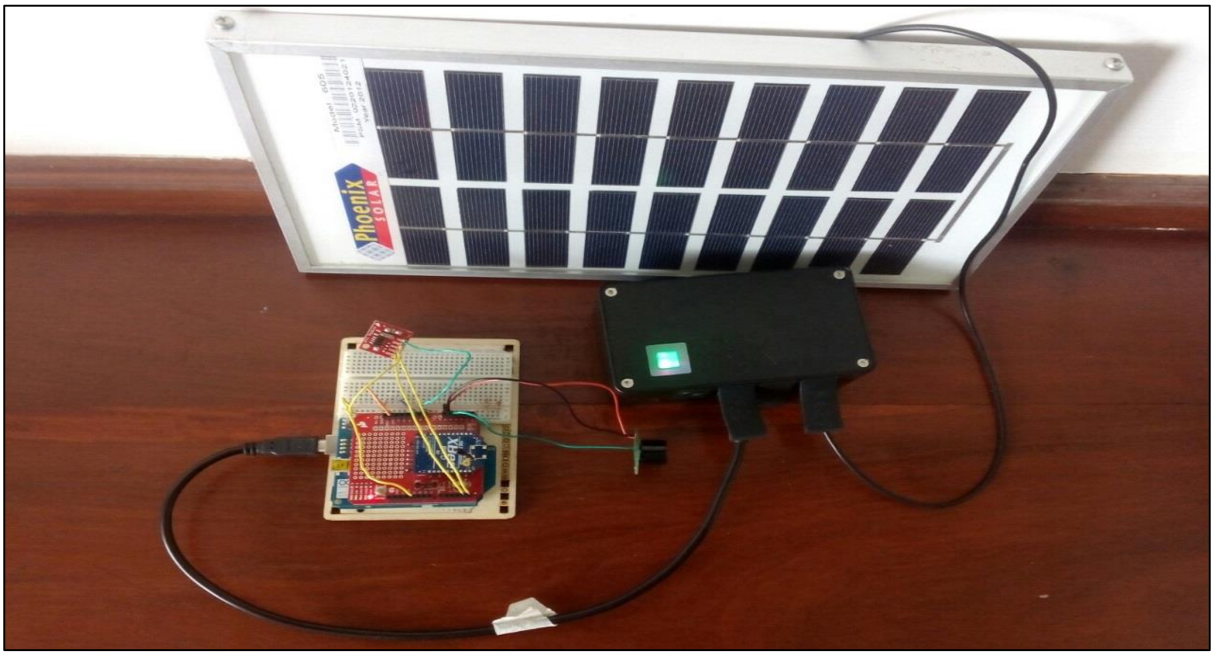


Figure 9: Power source setup for the Sink node

Node components are securely placed in a small plastic box similar to lunch box, container as Fig. 10 and Fig. 11 represent the enclosures for the sink node and sensing node respectively. The container is then kept in a node house built right on top of the canal for real time water monitoring.

Figure 10: The Sink node

Figure 11: The Sensing node

Thereafter the system was tested and validated in the lab environment as shown in Fig 12. The configuration for the system testing was thought in such a way that it best simulates the irrigation canals. The buckets represents the distribution/diversion points also known as intakes, the locations where sensing nodes are commonly deployed to conduct water discharge measurements.

Figure 12: Lab test configuration

To determine the system accuracy, ultrasonic measurements were taken and compared with their corresponding manual measurements. Results indicated a very close agreement of an average difference of 0.5cm and correlation coefficient of 0.999 as Fig 13 details.

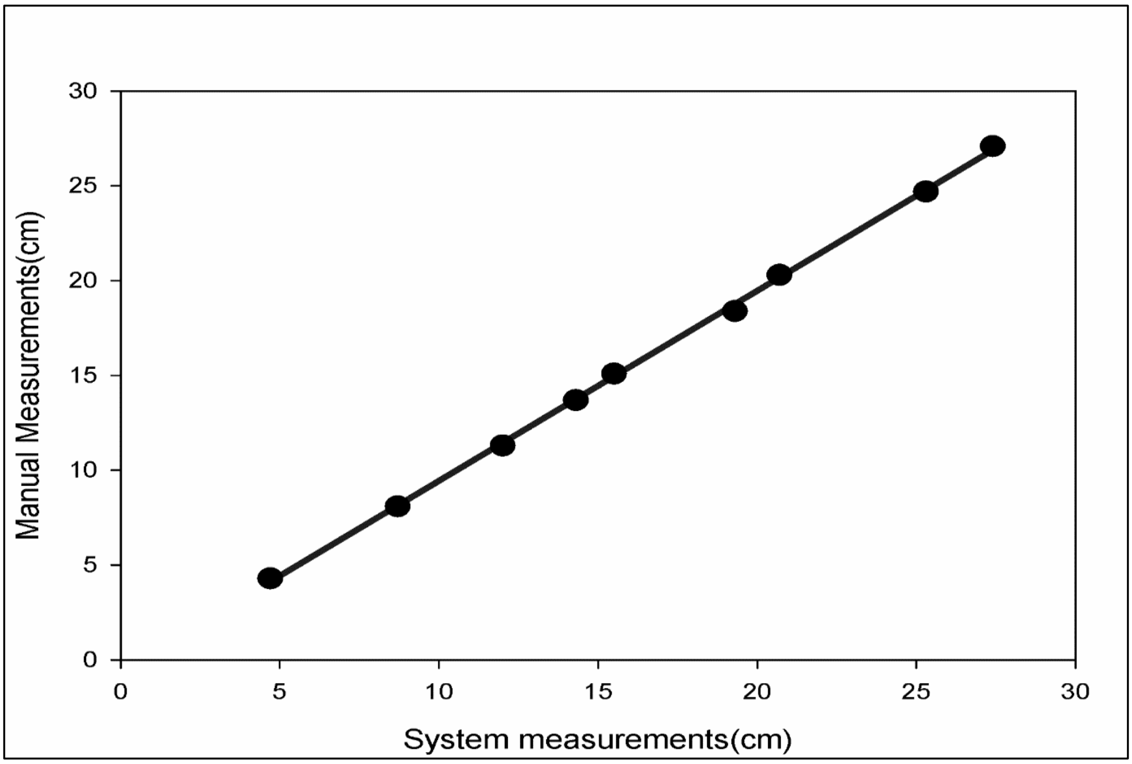


Figure 13: Comparison of ultrasonic and manual measurements.

Another test was performed to determine the sensitivity of the ultrasonic measurements. Two systems were configured as shown in Figure 12. Water level in system B was allowed to decrease which in turn increased the level in system A. Level changes in both systems were recorded in real time basis at an interval of 30 seconds as graphed in Fig. 14 and correlation analysis produced a coefficient of -0.957. The negative sign indicates that one system tends to decrease while the other increases and the magnitude indicates a strong relationship between the two systems. A good depiction of the situation where water in one canal has been diverted to allow water to flow in another canal, as a result the level of water in the primary canal will decrease while in the secondary canal will increase.

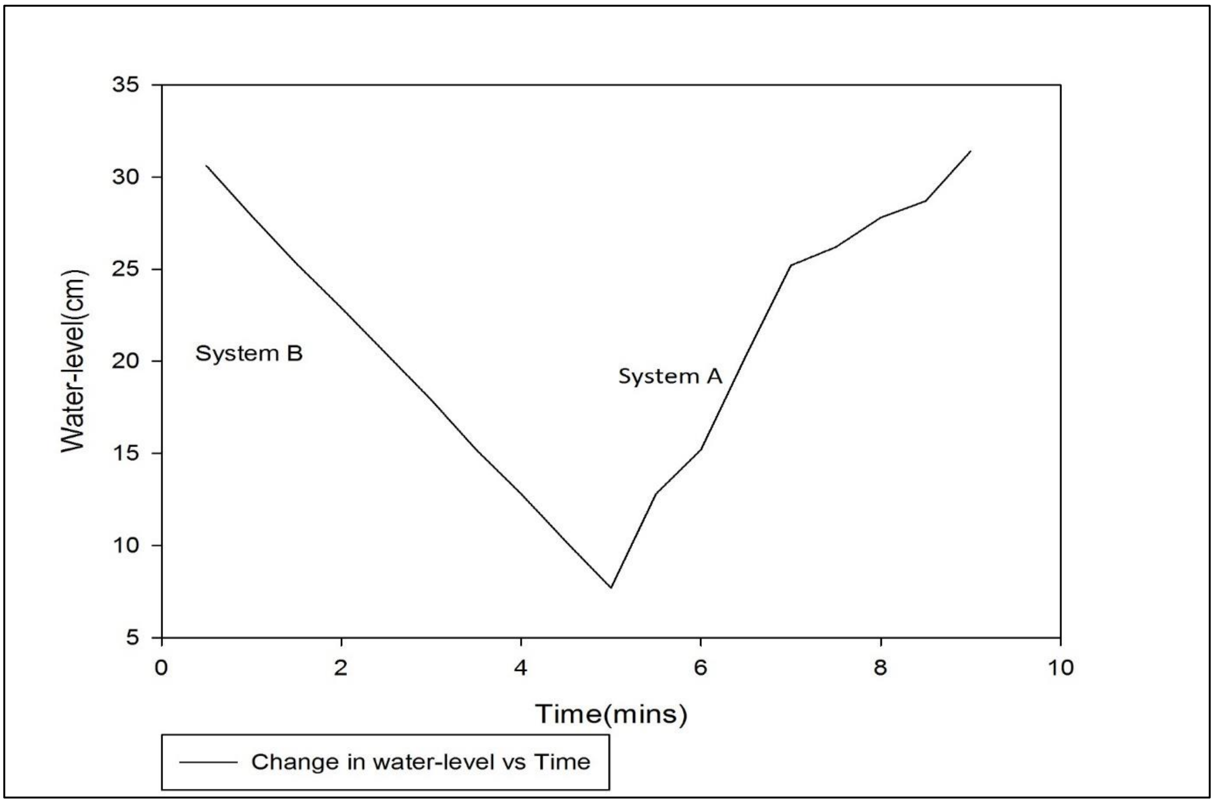


Figure 14: Sensitivity graph

3.5 Conclusion

This chapter presented the electronics and communication aspects of the irrigation water monitoring system. The chapter focused on the system architecture design and prototype development to prove the concept of sensing nodes and sink node working together unattended to form the internet of things (IoT) for the remote irrigation canals discharge data acquisition. The underlying prototype tests indicated the system potential applicability in suiting the requirement for an affordable water monitoring solution tailored for cost prohibitive traditional irrigation canals. The resulted low-cost design is friendly to smallholder irrigators and was inspired by the prevalence of cheap and easily available open source hardware platforms, the Arduino platform and ZigBee open standard technology. The main purpose of this chapter was to demonstrate the design, development and testing of the sensing and communication subsystem. An integral part of the water monitoring system responsible for data acquisition and transportation to the main severs for permanent storage. In the following chapter, a detailed exploration of the web based application development for data storage, processing to extract useful information and information sharing among various stakeholders is presented.

CHAPTER FOUR

Sensor Based Method for Water Monitoring: Design and Development of Web Based Application for Data Processing and Presentation.

Summary

Access to low-cost web based application for data storage, processing and sharing is key for improving water management in farmer-led irrigation systems in Tanzania. In this chapter, we report the design and development of a web based application for traditional irrigation canals data storage processing and presentation using MySQL and ATK framework as core technologies. The remotely collected water level data are submitted to a centralized database server where the web application is hosted to extract useful information such as canal hourly, daily and monthly discharge reports. The application allows dynamic canals registration to a system categorized into primary, secondary and tertiary canals belonging to a particular network which is also dynamically registered. The reports are generated for each canal in a network and for each network. The application also allows previewing of the water level data for verification if they are smoothly received from all the sensing nodes. A web based application then permit information sharing among stakeholders with various credentials.

4.1 Introduction

Web-Based Applications (WBA) are fast becoming more widespread, larger, more interactive, and more essential to the international use of computers(Nabil et al., 2011). A web-based application unlikely traditional desktop based applications (DBA) is any software system that can be accessed from anywhere using any computer connected to the internet or any other capable devices like PDAs and mobile phones through standard browsers such as Mozilla Firefox, Google chrome, Internet Explorer just to mention a few.

In WBA, software and database are hosted on a centralized server whereby in DBA, the software and the database are set up on each computer locally. The use of WBA over DBA has great potential for enhancing the efficiency and efficacy of any application environment such as this one for irrigation canals water monitoring. The first benefit is the possibility for developing a platform independent application. Since users are going to interact with the system through a common environment, web browsers, the only requirement is develop the application once and make sure it works with all the browsers if not with the commons browsers. While for the case of DBA, it is necessary to develop or produce different version of the application for different operating systems. Thus making the web based development cost effective in terms of development itself. Maintenance and support has also been massively simplified in WBA, new software or a version only needs to be installed on a dedicated server which in turn centralises all system administration operations. This is a more effective approach than dealing with many individual computers. Central administration also reduces security risks and it is technically and economically easier to monitor all activities on the application from a single point. Furthermore, web-based architecture makes it possible to rapidly integrate enterprise systems, improving work-flow and other business processes. Thus uplifting possibility of achieving higher level of interoperability between applications than with standalone desktop systems (Magic, 2015). Portable and flexible accessibility is yet another benefit over the traditional desktop applications, since it is possible to access the application from anywhere, anytime with a wide range of capable devices. This feature is increasingly putting users in control of their applications whenever, wherever and in real time basis without having to move with their computers or without having to install the application in different computers. There exist proprietary and open source technologies for building web based applications. Proprietary technologies include the Sun Microsystem Java-based (J2EE) platform and the Microsoft .NET platform. The J2EE uses JSP and Servlet while the .NET platform uses Active Server Pages, SQL Server and .NET scripting languages. The open source platform dominated by the PHP scripting language and the MySQL database management system is more cost effective and more attractive option for smaller and low-cost applications such as the web application for irrigation canals data acquisition, processing and sharing.

4.2 Software systems development methods.

A software development cycle or system development cycle is a framework that is used to structure, plan, and control the process of developing software systems. It is a way of describing the planning, designing, coding, and testing of a software system, as well as the method in which these steps are implemented. A variety of life cycle models exist, but they all include the common constituent parts. All life cycle models take a project through several phases such as requirements gathering phase, design phase, development or implementation phase, and a testing phase (Oadu). The series of phases that a software project passes through from its initiation to its closure (the software life cycle) can well be used to describe the methodologies available.

Predictive life cycles (also known as fully plan-driven) are ones in which the project scope, time and cost required to deliver that scope, are determined as early in the project life cycle as practically possible. Generally preferred when the product to be delivered is well understood, or when the product to be delivered is required in full to have value to stakeholder groups (Rose, 2013).The waterfall and V-models methodologies belong to predictive life cycle. The waterfall model also called the classic or sequential model is the oldest and the most widely used methodology for software development. In this mode, a particular phase has to be completed before moving to the next phase and once the phase is completed it is difficult to move back to the previous phase. This sequential fashion of dealing with phases pose some challenges like if clients are not certain with their own requirements and frequently change requirements then it becomes difficult to make changes in the previous phase once moved to the following phase. As a result the produced software is neither adaptable nor realistic (Shukla and Saxena, 2013). However, the model is simple and easy to use, appropriate for small development projects in which the requirements are well understood (Oadu). The V model (Validation & Verification model) is a modified version of the Waterfall methodology. It was not designed in a linear axis, instead the stages turn back upwards after the coding phase is done. This developmental process is balanced and relies on the verification from the previous steps before proceeding forward. The product from every phase needs to be checked and approved before moving forward, developer and tester works parallel. The biggest disadvantage of V-model is that it is very rigid and the least flexible model (Balaji and Murugaiyan, 2012). However the model is relatively simple and easy to use. Specific goals are defined for each phase. The focus on preparing test plans early in the process gives the V-Shaped model a higher chance for success. Like the Waterfall model, the V-Shaped model is appropriate for small development projects in which requirements are well understood (Oadu).

Iterative and incremental life cycles are ones in which project phases intentionally repeat one or more project activities as the project team's understanding of the product increases. Iterations develop the product through a series of repeated cycles, while the increments successively add up to the functionality of the product. Generally preferred when an organization needs to manage changing objectives and scope, to reduce the complexity of a project, or when the partial delivery of a product is beneficial and provides value for one or more stakeholder groups without impact to the final deliverable or set of deliverables (Rose, 2013). Spiral and Rapid application development (RAD) are examples of iterative and incremental methods. Spiral model consist four phases; the planning, risk analysis, development and Evaluation. These phases are involved in iterations of any software project in a spiral like fashion. In the first phase, requirements analysis and planning is conducted from the gathered information and thereafter risk is estimated in the second phase. Alternative solutions are also identified within this phase as well as prototype development. The Software is developed in the third phase along with performance checking by conducting software testing. Finally customers are engaged to evaluate the output of the project in the evaluation phase before the project continues to the next spiral (Shukla and Saxena, 2013).The Spiral model can cost considerably more than other models. The risk analysis phase requires highly specific expertise, and the project's success depends on the output of this phase. The Spiral model is inappropriate for use in small and medium-scale projects that are not mission-critical. However the focus on risk avoidance makes the Spiral model ideal for large-scale and mission critical products (Oadu). Rapid application uses minimal planning in favour of rapid prototyping. The functional modules are developed in parallel as prototypes and are integrated to make the complete product for faster product delivery. Since there is no detailed preplanning, it makes it easier to incorporate the changes within the development process. RAD projects have small teams comprising of developers, domain experts, customer representatives and other IT resources working progressively on their component or prototype. It distributes the analysis, design, build, and test phases into a series of short, iterative development cycles. RAD accommodates frequently changing requirements and reduces development time with few people while increases reusability of components and encourages customer feedback. However it requires highly skilled developers and designers, inapplicable to cheaper projects and suitable for systems that are component based, scalable and require shorter development times (Point, 2015).

Adaptive life cycles (also known as *change-driven* or *agile* methods) are intended to respond to high levels of change and ongoing stakeholder involvement. Adaptive methods are also iterative and incremental, but differ in the sense that iterations are very rapid and are fixed in time and cost. Generally preferred when dealing with a rapidly changing environment, when requirements and scope are difficult to define in advance, and when it is possible to define small incremental improvements that will deliver value to stakeholders (Rose, 2013). Extreme programing (XP), Scrum, Dynamic system development methodology (DSDM) are examples of agile methods. Extreme programming focuses on adaptability rather than predictability and capable to adapt to the changing requirements. XP proposes four basic activities; coding which is considered the only important product of the system development process, testing to check if the product is in line with the requirements, listening to enable developers to understand what customers want, and designing that organizes the logics in the system. Although XP methodology can result in an improved process which is more efficient more predictable more flexible and more fun, it also has weaknesses such as difficulty coordinating larger teams and can result in a never-ending project if not managed properly. XP works best if applied on projects which have certain characteristics such as frequent and small releases are possible. Suitable for research projects or small projects that are more easier to managed through informal methods (Hutagalung, 2006). Scrum consists of five phases, the requirement analysis, design, implementation, testing and release. The main concept of scrum is sprint, which last between one week and one month, and are restricted to a specific duration. Each sprint is preceded by a planning meeting, where the tasks for the sprint are identified and an estimated commitment is made, followed by a review or retrospective meeting, where the progress is evaluated. During each sprint, the team creates finished portions of a product. Scrum enables the creation of self-organizing teams by encouraging co-location and verbal communication between team members. Scrum is applicable in software projects with aggressive deadlines, a high degree of complexity and novelty. (Cohn, 2005). The fundamental idea behind DSDM is that instead of fixing the amount of functionality in a product, and then adjusting time and resources to reach that functionality, it is preferred to fix time and resources and then adjust the amount of functionality accordingly. DSDM consists of five phases, the feasibility study and business study are sequential and done only once. The functional model, design and build, and implementation are iterative and incremental (Abrahamsson, 2002). DSDM employs time boxing, facilitated workshops and MoSCoW prioritisation (The Must have, Should have, Could have and Want to have) techniques. However this methodology is costly to implement, as it requires both developers and users to be trained to employ it effectively, therefore it may not be suitable for small organisations (DSDM, 2015).

4.3 Materials and Methods

Systems analysis consists of activities that enable a person to understand and specify what the new system should accomplish while systems design consists of those activities that enable a person to describe in detail the system that solves the need (Satzinger et al., 2011). Because agile software development techniques are tailored to respond high levels of change and continuous stakeholder participation, have become one of the most widely used methodology preferred when dealing with frequently changing requirements. Perhaps the best-known and most widely used agile method, the extreme programing (XP) that takes an ‘extreme’ approach to iterative development was employed in the whole process of developing the subsystem for storage and processing of the irrigation canals water data. A more efficient, flexible and fun approach suitable for research projects where frequent and small releases are of interest and easy to manage through application of informal methods. The MoSCoW technique of the DSDM methodology were borrowed that helped in prioritizing the system functionalities i.e into the must have, should have, could have and want to have categories. Because of the fixed time and resources, the MoSCoW technique has significantly helped in the process of adjusting the amount of functionality to match the available resource while making sure the necessary requirements are met. The hybrid approach of employing the extreme programing methodology while borrowing techniques from the DSDM methodology resulted into the reducing of overheads in the software development process by limiting documentation and be able to respond quickly to high level of change and ongoing stakeholder involvement without excessive work. Although focus was on the code rather than the design, in understanding data inputs and data flows, the data flow diagram (DFD) has been used, particularly Fig. 15 depicts the context diagram for the system. In investigating user requirements (system analysis) and specifying how the system will work (system design), UML diagrams have been used for describing major elements of the software, particularly the use case and class diagrams for the modelling and realization of requirements.

4.3.1 Data flow model

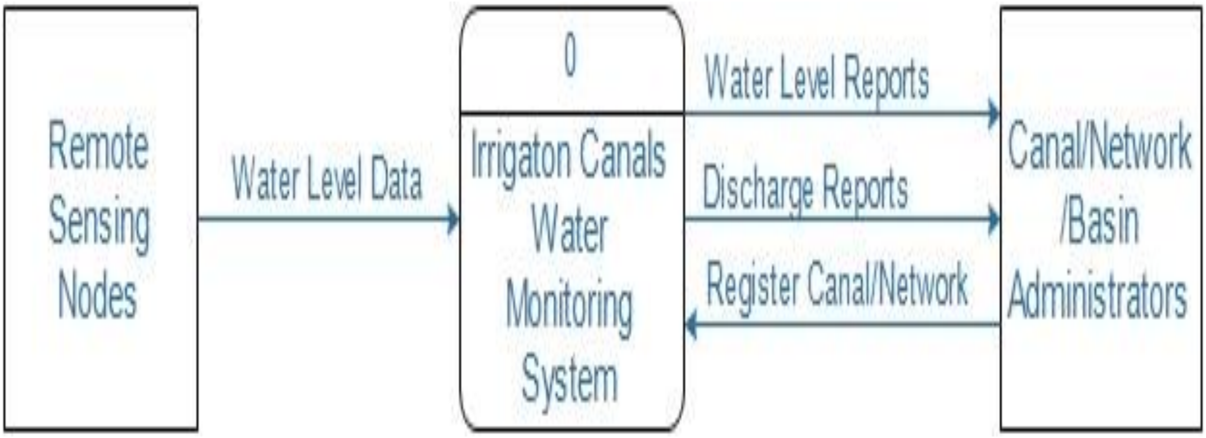


Figure 15: DFD context diagram

4.3.2 Requirements model

4.3.2.1 Requirements list

Table 6: Requirements list

SN	Requirement	Use case
1	Administrator should be able to register and manage basin administrator and perform any action in the system	Manage basin administrator
2	Basin administrator should be able to register and manage network administrators	Manage network administrator
3	Network administrator should be able to register and manage canal administrator	Manage canal administrator
4	All users should be able to login to use the system	Login
5	The system should be able to register and administer (update, delete, search) irrigation networks.	Manage network
6	The system should be able to register and administer irrigation (update, delete, search) canals within a specified network	Manage canal
7	Users should be able to view water level data of the canals they belong to.	View water level data
8	Users should be able to generate and print hourly, daily and monthly reports of the canals they belong to.	Generate and print reports

4.3.2.2 System actors

The system comprises of two groups of actors and their underlying roles, the primary actors and secondary actors. Primary actors are the direct and important users of the system because they represent interests of various groups of stakeholders in water resources usage and management. The secondary actor (also called supporting actor) provides technical support to help keeping the system up and running all the time and offering other services such as technical advice and opinion. Table 3 shows the primary and secondary actors of the system

Table 7: System actors

Sn	Primary actors	Secondary actors
1	Basin Administrator	System Administrator
2	Network Administrator	
3	Canal Administrator	

4.3.2.3 Use case diagram

Use case diagram, Fig. 16 is the representation of system main functionalities and actors involved from user's viewpoint. A valuable but simple platform providing a common language for both end users (customers) and technical people (developers) to collaboratively understand system requirements.

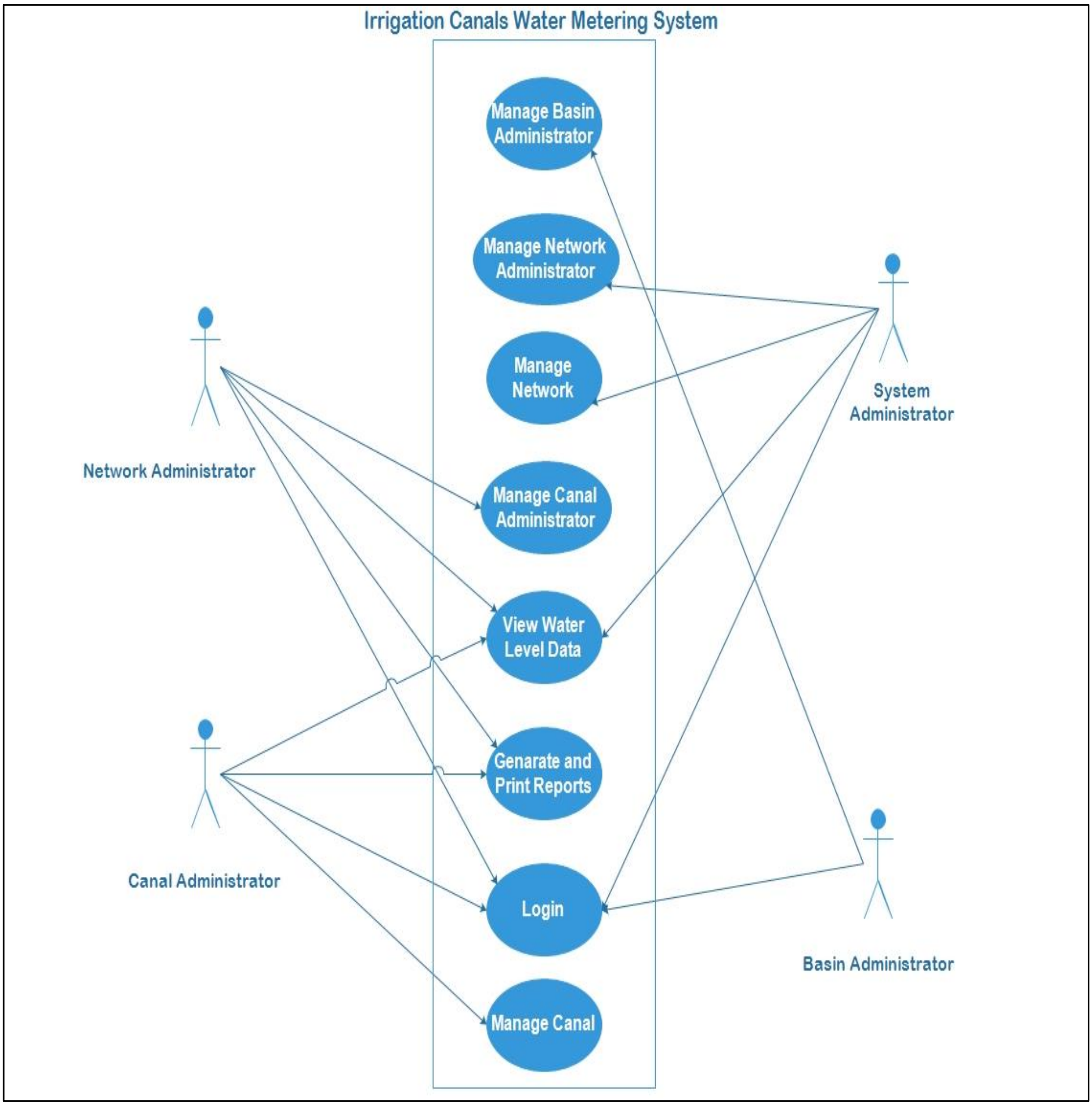


Figure 16: System use case diagram

4.3.3 Conceptual Model

The conceptual model consists of entities to represent the real system objects, attributes to represent characteristics of the entities and relationships to represent association between entities from the user perspective of the system concepts. Conceptual model in combination with use case forms powerful tool for requirement realisation at the analysis stage. Class diagram shown on Fig. 17 is an essential aspect of object oriented software development approach used to depict the conceptual model that is useful at analysis and design phases.

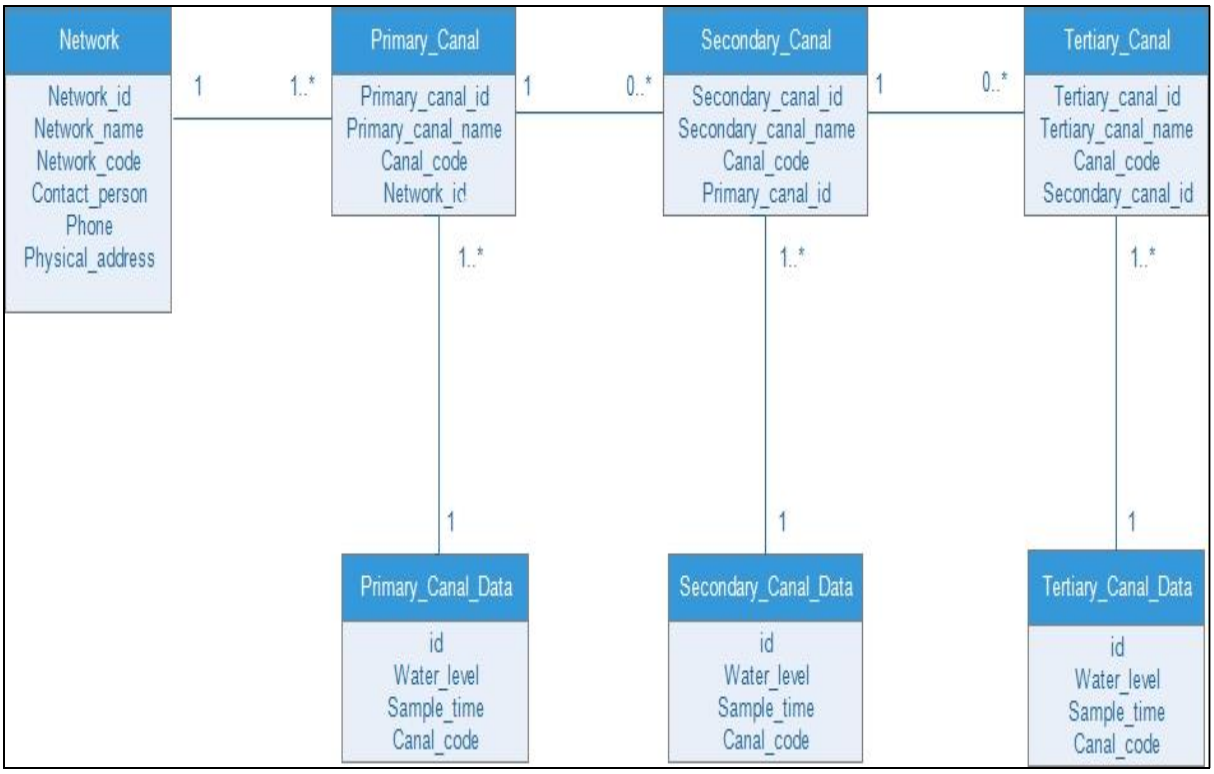


Figure 17. System class diagram

4.4 The development, testing and results.

Frameworks facilitate development of applications through provision of standard functionalities to reduce amount of code. This system which is basically a web application was developed using MySQL database at the back-end and ATK, an open source PHP framework for the front-end. The system requires users to login before being able to use as shown in Fig.18.

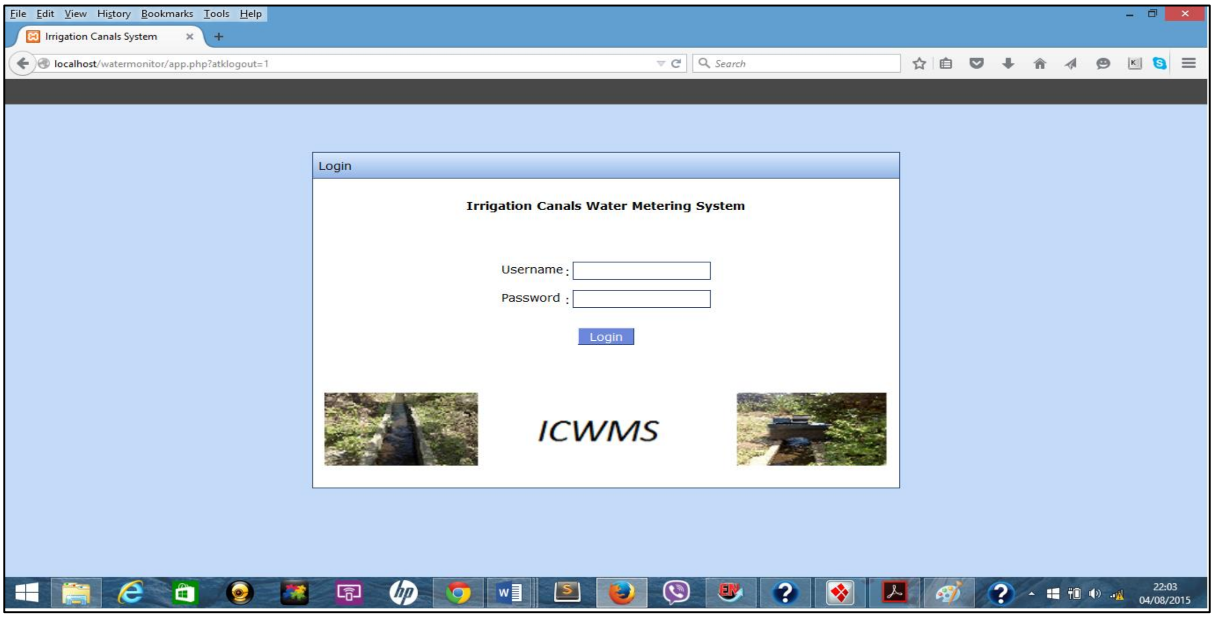


Figure 18: Login page

Once a user has successfully logged in, a main menu comprising of system modules as shown in Fig. 19 is presented on the system home page.

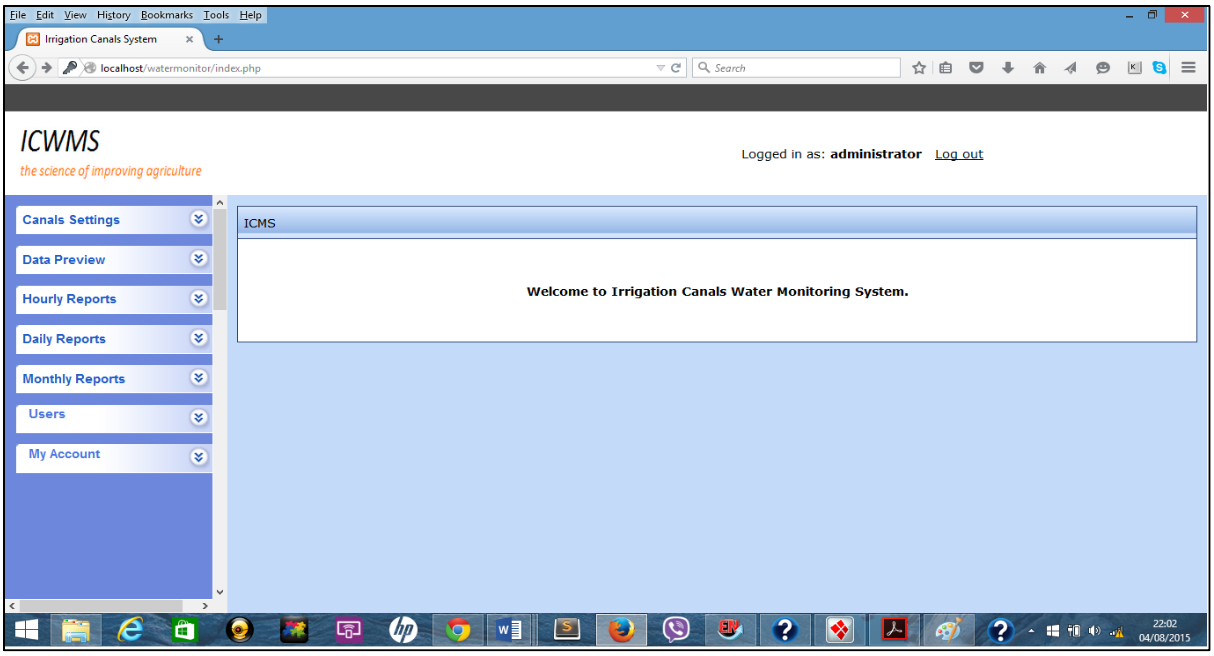


Figure 19: System main menu

The canal settings module allows canal registration to the system shown in Fig. 20 and 21 below based on category, such as primary, secondary and tertiary canals that are belonging to a certain network which is also registered as shown in Fig. 22.

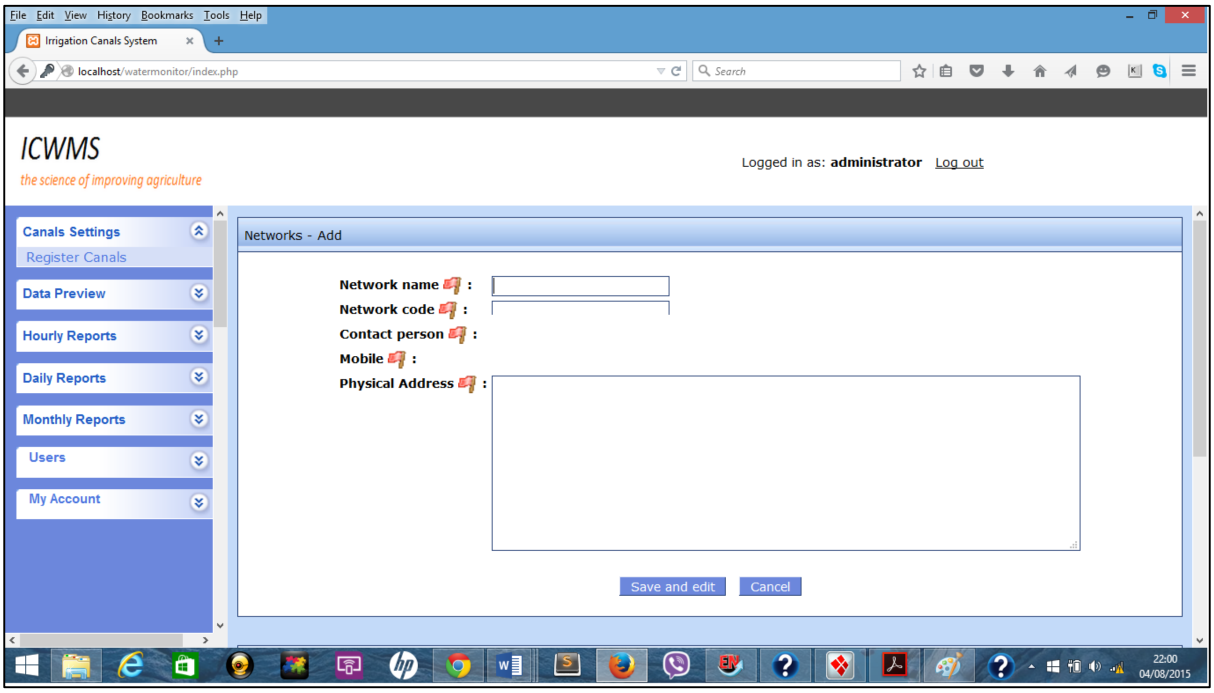


Figure 20: Network registration page

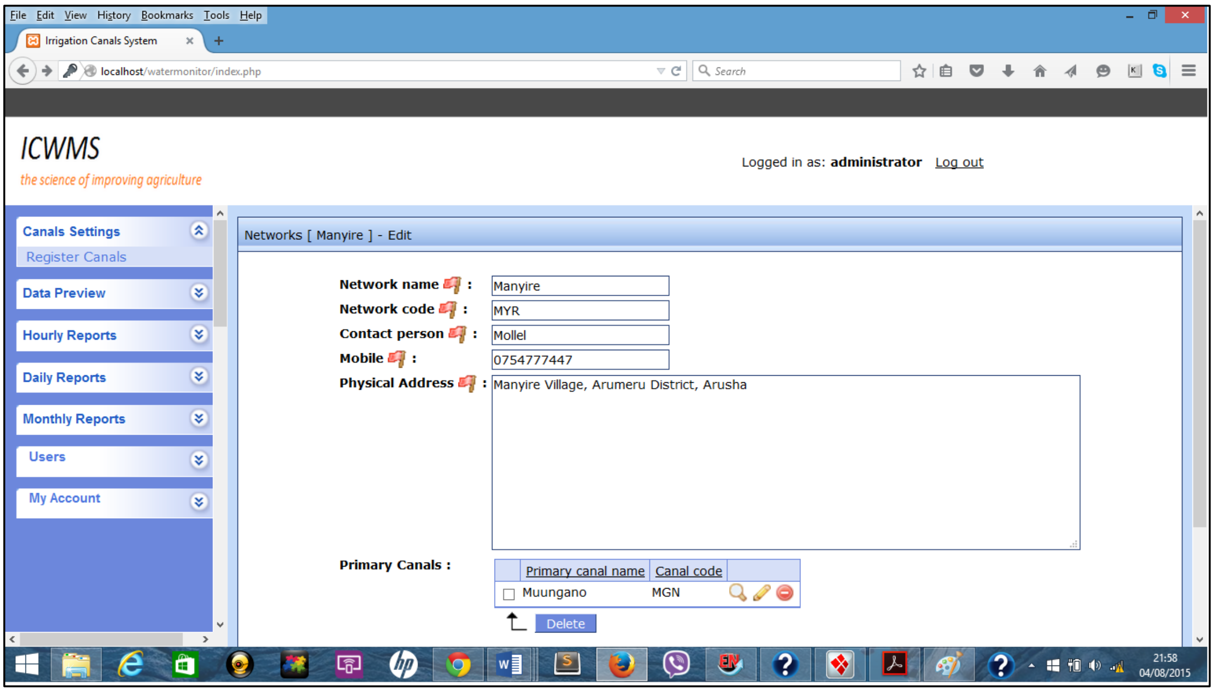


Figure 21: Primary canals registration page

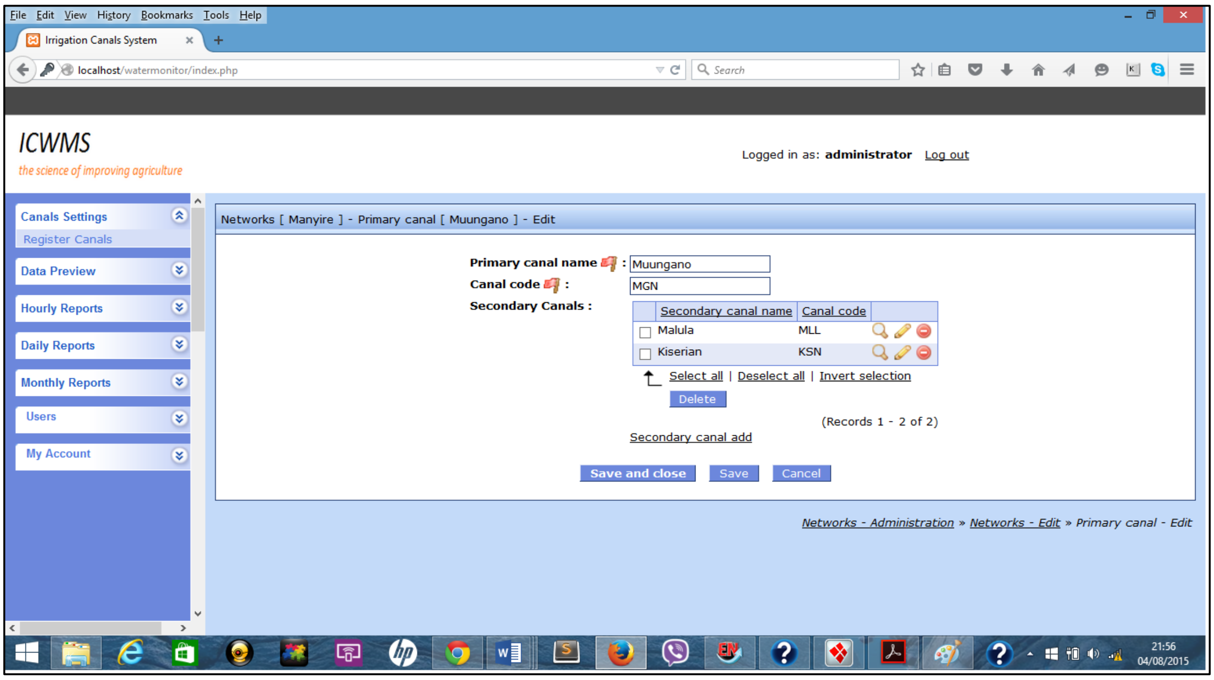


Figure 22: Secondary canals registration

Data for each canal category are stored on a separate table and uses the canal code that is transported together with the data for identifying a canal within a particular category. Data preview module allow previewing of data and verification if they are smoothly received from all the nodes as portrayed in Fig 23. The water level data are organised by canal type and name and normal users are able to search for particular canal to view its data, however editing and deleting of such data is only enabled to super users, such as system administrator.

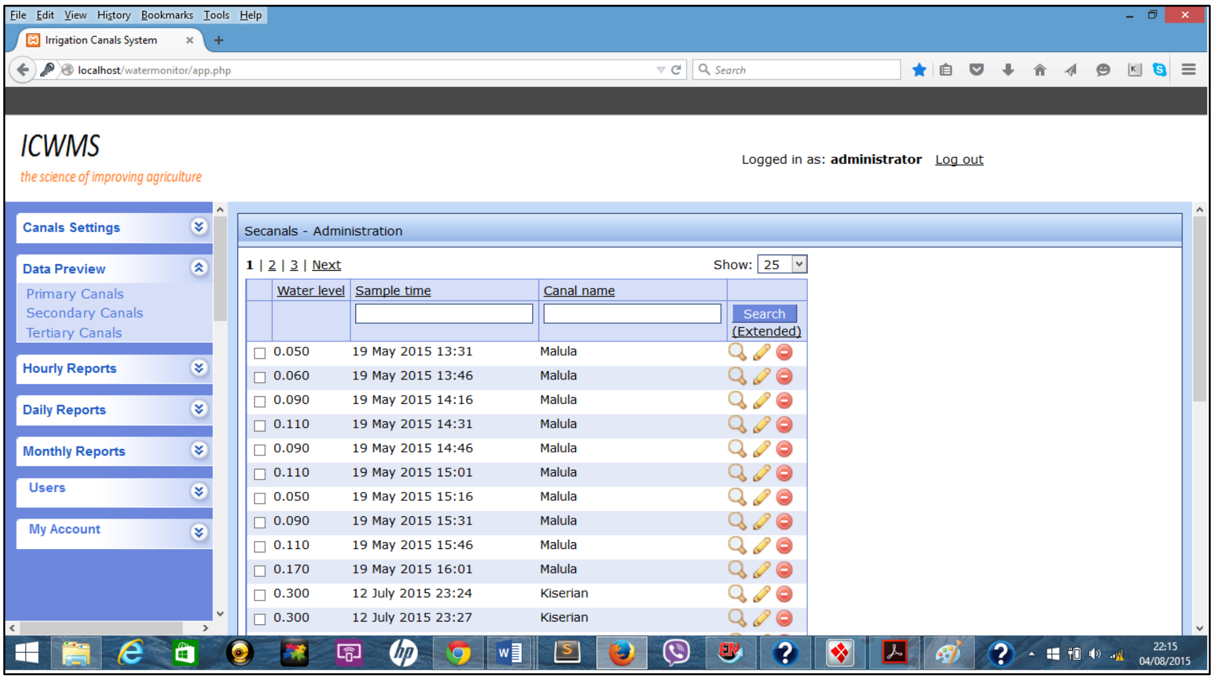


Figure 23: Water level preview page

The water level data are then processed in order to transform them into corresponding discharge information using the developed level - discharge relationship called the rating relation. The discharge information are then presented in tables and graphs showing water utilizations for canals over periods of time reported on hourly, daily and monthly shown in Fig 24 - 26.

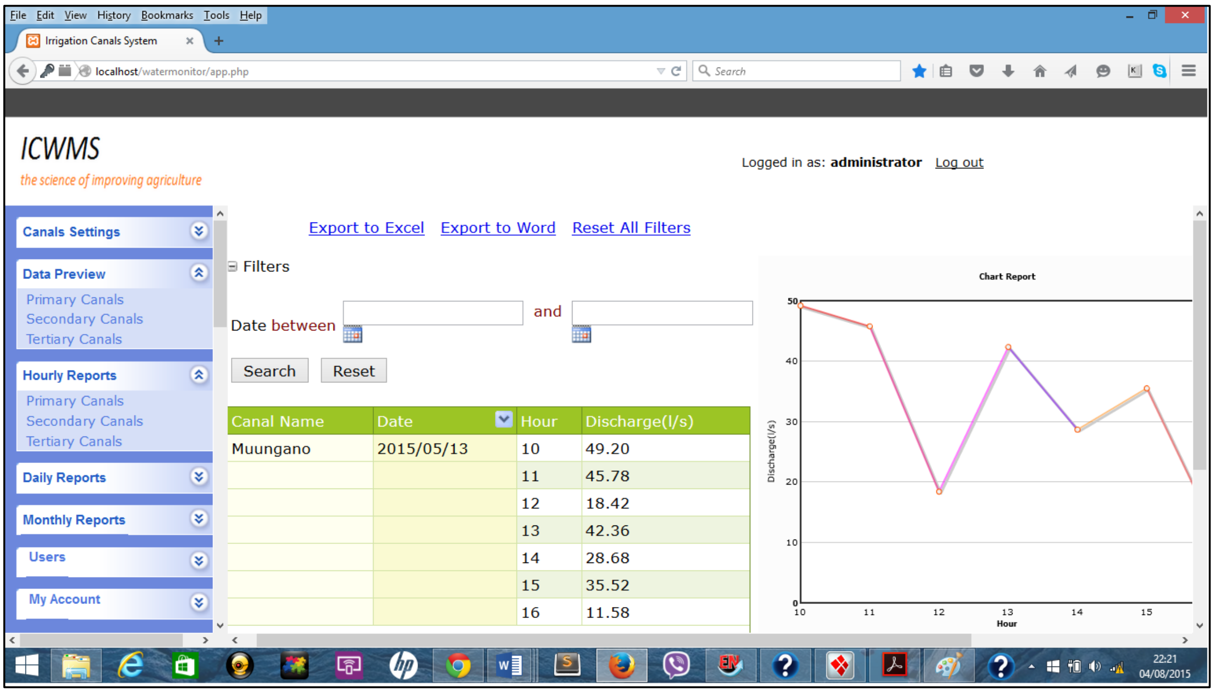


Figure 24: Hourly discharge report page

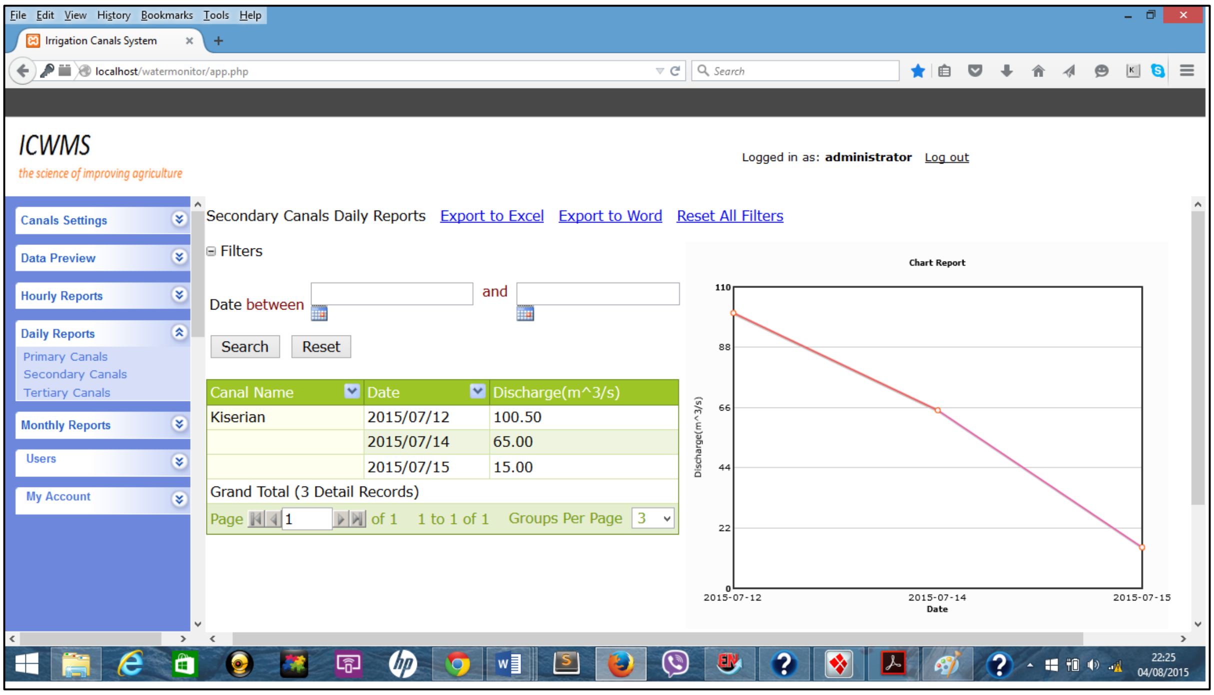


Figure 25: Daily discharge report page

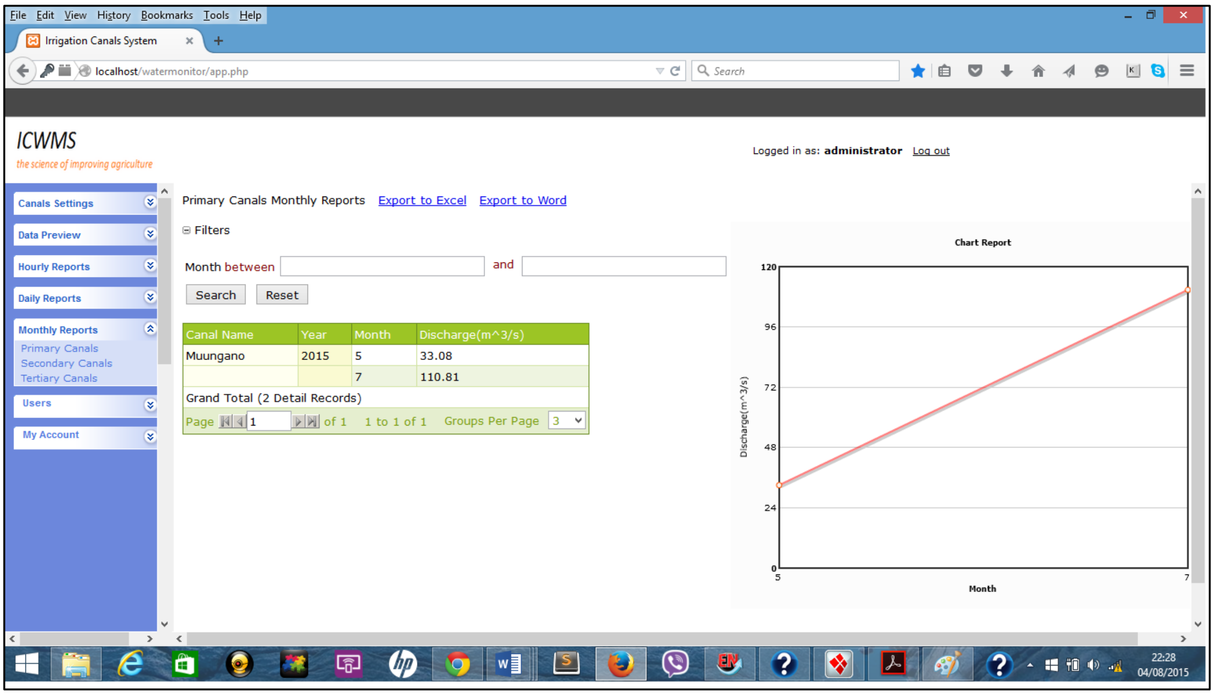


Figure 26: Monthly discharge report page

User actions on the modules are controlled by the access rights (user profile) granted during user registration to the system as shown in Fig 27.

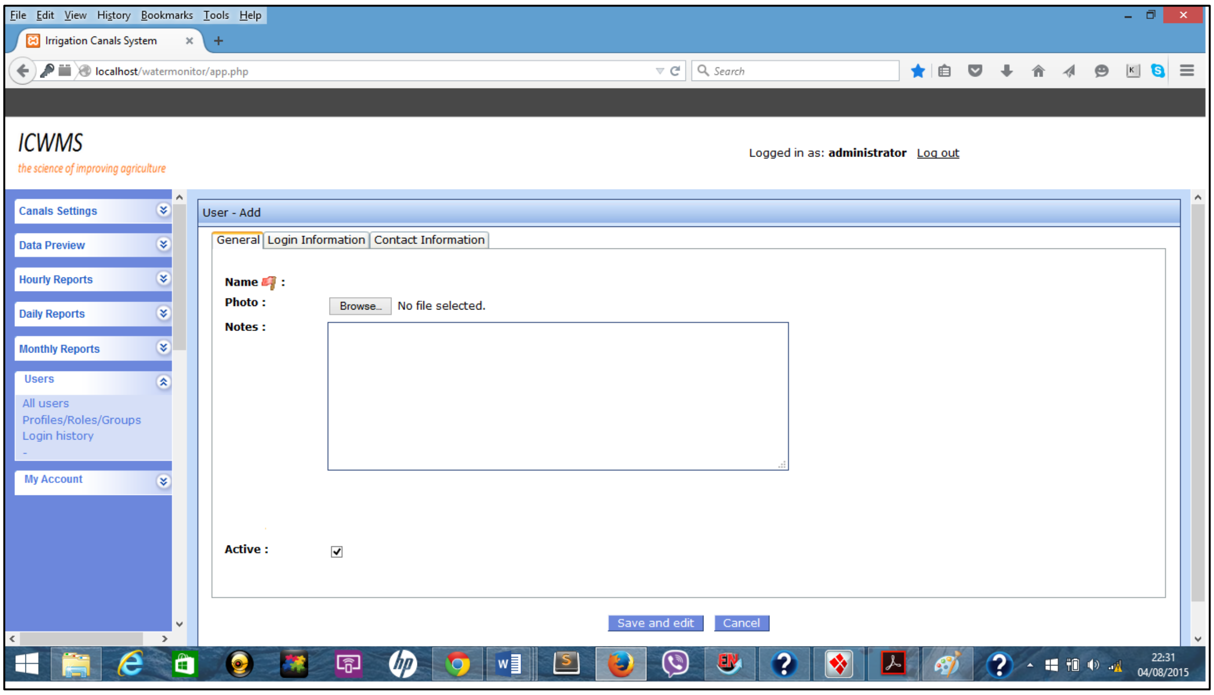


Figure 27: User registration page

4.5 Conclusion

This chapter presented the data processing and information presentation aspects of the irrigation water monitoring system. The primary focus was on the WBA developed by using extreme approaches of software development that borrowed the MoSCoW technique from the fellow agile methodology, the DSDM. The "Must have" and "Should have" requirements were successfully implemented, in particular, the permanent data storage, data processing to estimate hourly, daily and monthly discharges and dissemination of information among stakeholders. These hourly, daily and monthly discharge reports generated are the primary data processing, which could be used to derive other higher level reports such as seasonal and yearly discharge reports, the "Could have" requirements. However, due to time constraints the system requirements could not include the google maps of the canals monitored, that were categorized as the "Want have" requirements. The water level data that are stored in the system permanently, are very valuable and multipurpose, discharge estimations presented in this chapter are merely one of the many potential usages of such data. The data could also be employed to gain other useful instruments for improving irrigation water management, such as water allocation models, and can even be used to predict other various future trends. The chapter also proved the concept of Internet of Things (IoT), whereby the sensing nodes communicated successfully with the WBA to submit data captured in real time basis without human interaction. Next chapter presents the operation of the developed water monitoring system in the actual application environment. The presentation that is intended to demonstrate integration of the system units in operation, the sensing and communication subsystem and the storage and processing subsystem to prove the concept of IoT, one of the main theories that the sensor based water monitoring system relies.

CHAPTER FIVE

System Deployment in Manyire Farmer-led Irrigation Canals for Testing and Evaluation in Real Environment Operations.

Summary

Testing is a fundamental stage in any system development project. Its main purpose is to ensure the system was built right according to users' requirements and specification and that the system meets the expected use when placed in its expected environment. The main objective of constructing the water monitoring system was to know the amount of water allocated to a particular canal from the river and even knowing how much water a particular farmer has actually used for irrigating during a specified period of time is important information for enhancing the effective utilization of the diminishing resource, in usage fee charging and in ensuring equity and transparency in the distribution of water in farmer-led irrigation canals. This chapter presents the implementation of the entire water monitoring system to test and evaluate the system in real environment operations. To accomplish the objective, the system was deployed in Manyire traditional irrigation canals to monitor water discharge at regular and defined interval then submit data to a centralised server for storage and processing to extract usefully information such as hourly, daily and monthly discharges reports.

5.1 Introduction

The concept of the automating of monitoring irrigation water delivery in traditional irrigation canals during dry and rainy season is necessary and has become quite possible with the availability of low cost monitoring methods tailored for cost prohibitive smallholders. Particularly the sensor based system for water monitoring in traditional irrigation canals developed and presented in earlier chapters. With these advancements and innovations compatible with developing countries, remote monitoring systems are progressively becoming an attractive option because they are portable and affordable. Their benefits should therefore penetrate to rural areas and realized by smallholder farmers to assist irrigated agriculture to become more efficient and effective. Through automating collection of data on canal water discharges and access to decision support tool to give reports in real time basis for supporting decisions making and planning to ensure transparency and equity amongst users. To prove the concept, we have deployed the system in Manyire irrigation canals in Arusha, Tanzania where smallholder farmers are mainly involved in growing of vegetables for food and business. The vegetables such Cabbages, Tomatoes, Onions, Cucumbers and Green pepper are raised by irrigating using the Muungano primary canal which allocates water from the river Nduruma and later split into secondary and tertiary canals, Kiserian, Malula and Kazamoyo as shown in Fig. 28 to distribute water direct into the farms.

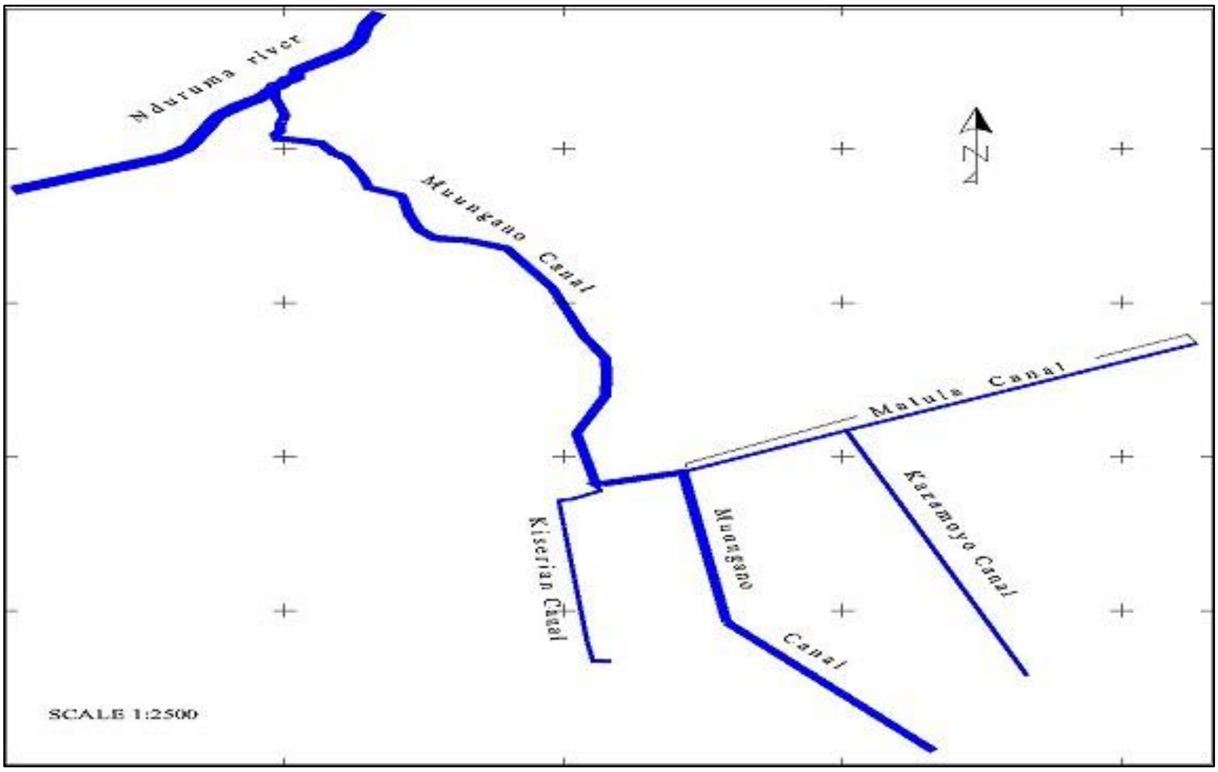


Figure 28: Map of Muungano irrigation canal used by Manyire village

Currently water monitoring activities in the Manyire irrigation canals and along the Nduruma river are purely manual in terms of both monitoring and regulating. This situation has perhaps resulted due to the cost of off-the-shelf monitoring methods. Usually, users are given either hourly or daily turns of using water regardless of the exact amount that have been employed by a particular user or group of users. These traditional monitoring methods are indeed less precise, not timely and not consider amounts in distribution has caused lots of challenges and difficulties in enhancing the effective utilization of the diminishing resources, usage fee charging as currently use is being calculated with no justification of how much water has been applied by a particular user and also in ensuring equity and transparency which sometimes has led into conflicts. This chapter represents an initial execution of a low cost, water discharge monitoring method to collect water delivery data in Manyire irrigation canals to improve fairness and transparency in water distribution, raise water use efficiency and generally empower water management practices. Two nodes were installed in the area to test and evaluate the system, one is monitoring the amount of water allocated to the main Muungano canal and the other is monitoring the amount of water allocated to Kiseriani canal.

5.2 Materials, methods and results

The house for accommodating a sensing node is designed as shown in the Fig. 29 and constructed by the fabrication of Expanded Polystyrene (EPS) technology shown in Fig. 30.

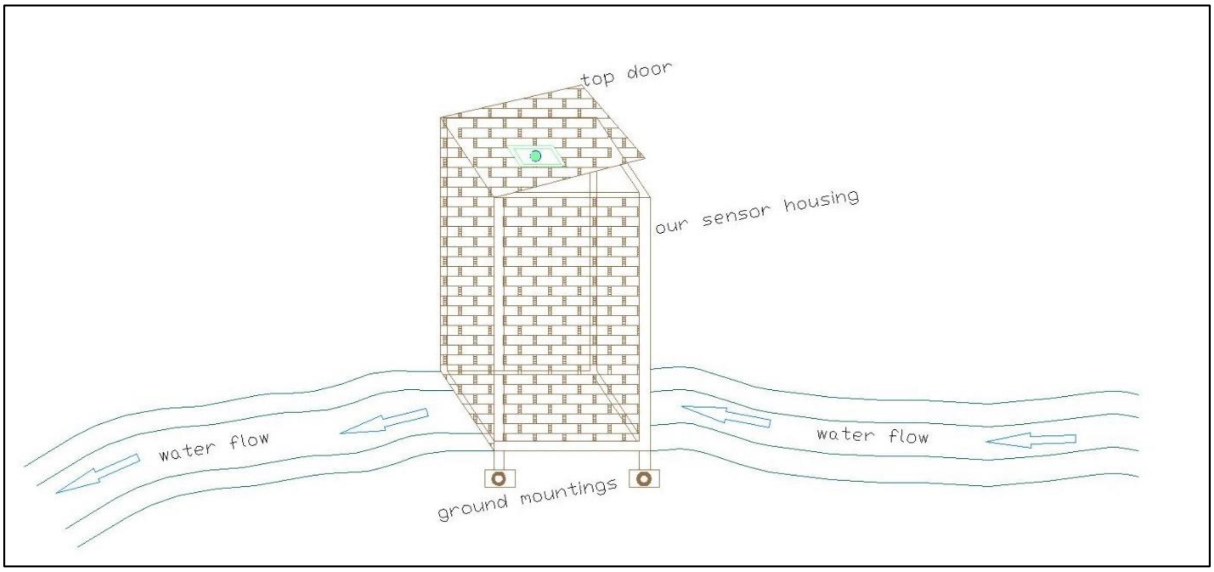


Figure 29: Node house design

The use of polystyrene materials was purposely for heat insulation to protect parts from overheating during sunny conditions and for cost reduction because they can be acquired for free from the packaging material.

Figure 30: Node House

The outer part of the house is strengthened up by concrete plaster and a metal top for physical and weather protections. A technique that contributed to further cost reduction by allowing the use of indoor sensors in the outdoor settings. The house is generally designed in a manner that it allows communication signals to go through and constructed right over the canal as portrayed in Fig. 31 for enabling real time water discharge monitoring. The system is deployed in the irrigation canals and initial results indicate a promising step towards total automation of the entire network.

Figure 31: Node House

The existing theoretical relationship between water level and discharge in open channels called the rating relation was developed as captured in Fig. 32 for all of the irrigation canals in the Manyire network. The relation was developed by recording discharge at wide range of levels, since for each measurement of water level there is a corresponding measurement of discharge.

Figure 32: Rating relation development

The level measurements were done by using the developed water monitoring system deployed in the irrigation canals at the distribution points while the discharge measurements were conducted by using salt dilution method. A cheap, portable, readily available and suitable for relatively small streams method. The method is done by injecting known amount of salt at an upstream location in the canal and tracking variation in electrical conductivity of water at defined time intervals using a multi-parameter at a downstream location in the canal (at the canal distribution points) where the sensor system is monitoring water level. Appendix 1 shows how Equation 1 was used to estimate discharge from the recorded data of conductivity changing over time for the irrigation canals.

$$Q = M / \int (C - C0)\, dt$$

Equation 1: Stream discharge equation (Rantz, 1982).

Where Q is discharge, M is the mass of salt injected, C is current concentration and C0 is the background concentration of the canal. The corresponding measurements of water level and discharge were obtained. Table 8 shows sample level-discharge data for one of the canals.

Table 8: Water level and discharge data

Water level (m)	Discharge (m^3/s)
0.025	10.00
0.050	15.35
0.060	19.00
0.075	23.00
0.090	25.00
0.110	43.29
0.135	44.39
0.150	49.44
0.170	53.00
0.200	67.00

The graph plotted (Fig. 33) by using the data above gave a straight line of the form y = 330.21x - 0.2209 which is essentially the resulting rating relation where y is discharge, x is water-level.

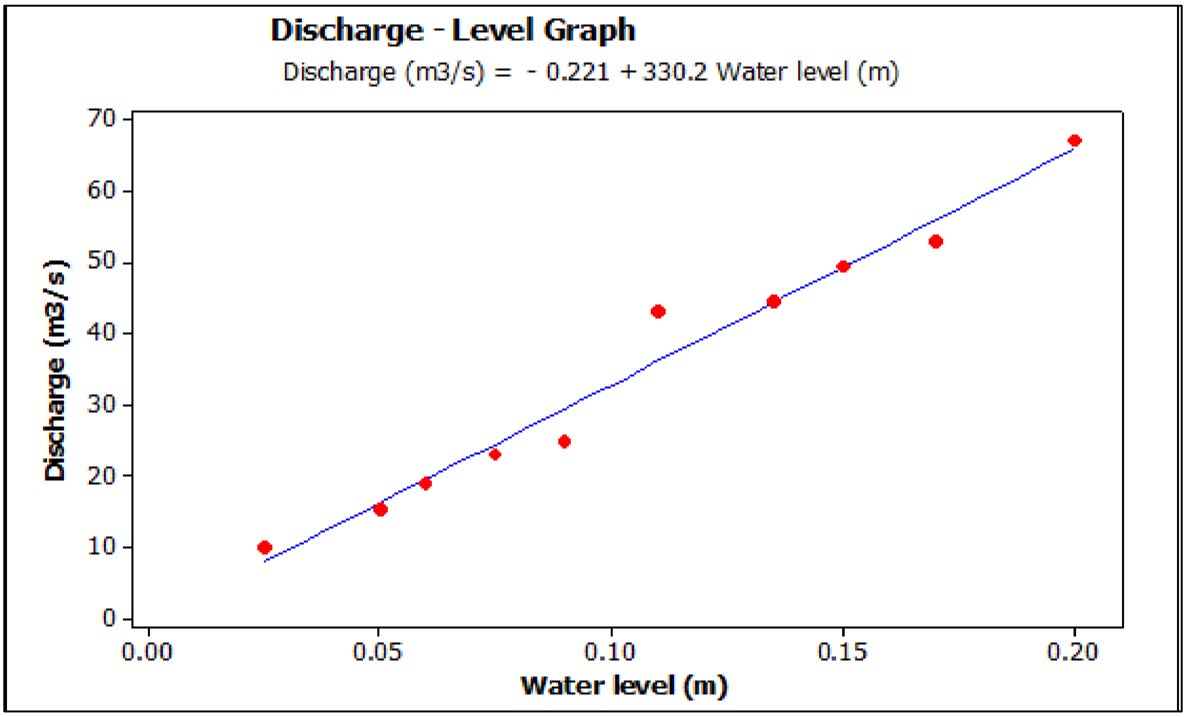


Figure 33: The rating relation

Thereafter, the developed discharge - level relation was used to continuously estimate canal discharge for each of the water levels recorded by the system in a defined time interval e.g. 15 minutes interval. The web application hosts water level data received from the nodes and allow previewing of data for verification if they are smoothly recorded from all the nodes as portrayed in Fig. 34.

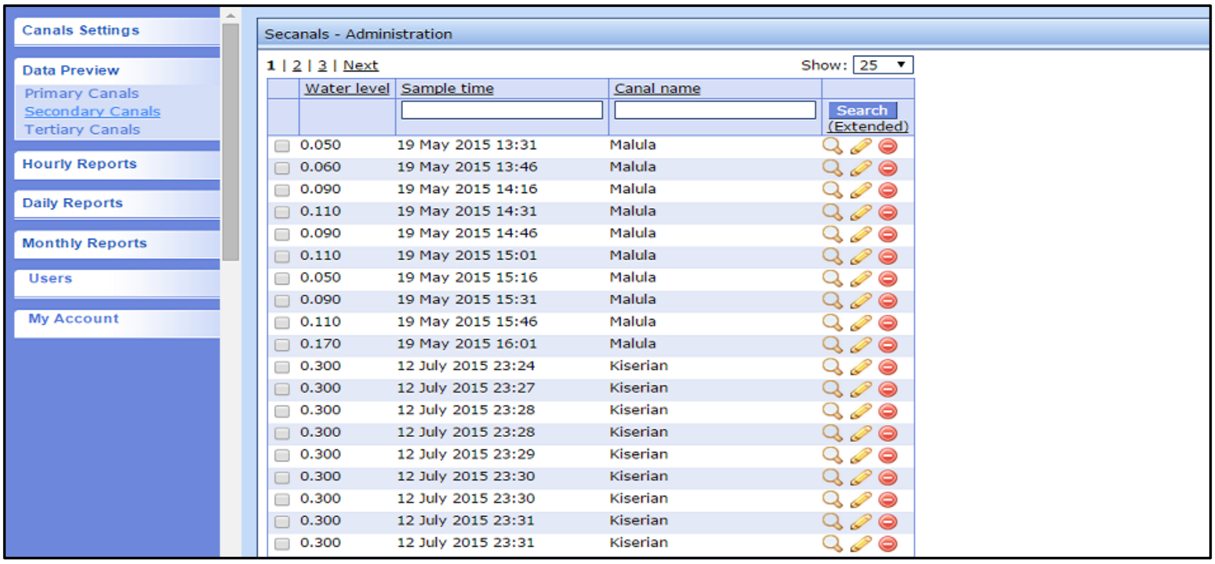


Figure 34: Water level data preview

The discharge information is then presented in text and graph showing water utilizations for each of the canals over periods of time. Usually reported on hourly, daily and monthly basis as depicted in Fig. 35 showing an hourly discharge report for the Kiserian canal.

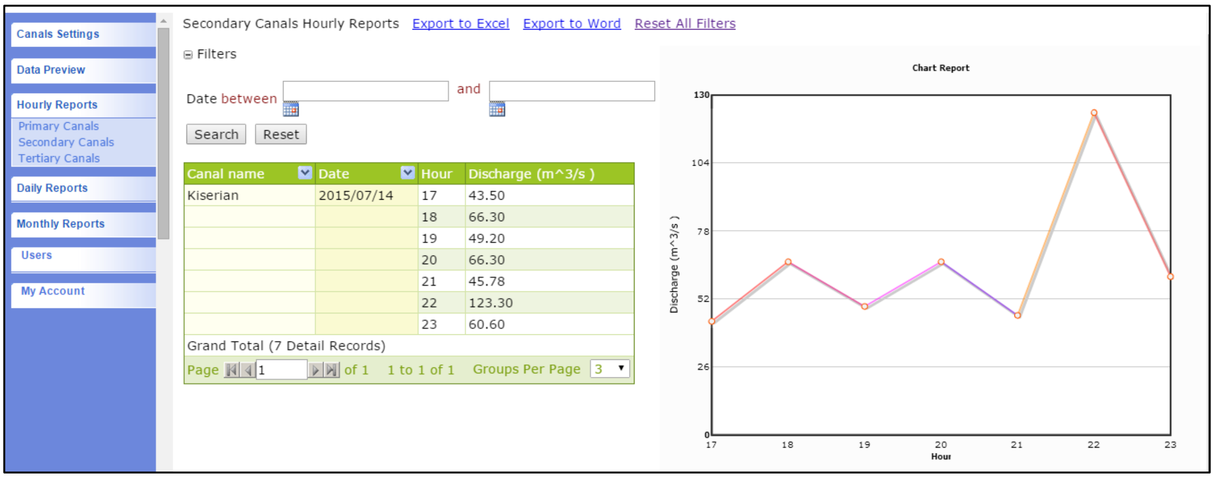


Figure 35: Hourly discharge report

5.3 Conclusion

To confirm that the developed system works in accordance to the requirements specifications it was important to conduct a system testing and evaluation. To fulfil the objective, testing and evaluation was conducted by deploying the system in actual environment application, the Manyire farmer-led irrigation canals. This final phase of system testing and evaluation (also called the beta phase) was preceded by the alpha testing (first phase of testing in the lab environment) that included the subsystem testing and entire system testing. The testing results indicated low-cost possibility of getting real time canal discharge data remotely which could be adopted to improve irrigation water management.

CHAPTER SIX

6.1 General discussion

This segment discusses each of the subsystems in the system development that are essentially inspired by the prevalence of low-cost components and open-source platforms. The subsystems are sensing, communication, and storage, processing and power sources subsystems. There exist several techniques for liquid level sensing. The ultrasonic based level measurement, we used have become one of the most commonly employed methods. It works by giving off high frequency acoustic signals that are reflected back and detected. The transit time of the signal, from the sensor to the target and back again, is correlated to the level. Measurements are taken without physical contact with the product and suitable for a broad range of liquids and bulk products. However, ultrasonic can be affected by the changing coefficient of sound due to moisture, temperature or pressure. Therefore, not desirable for highly pressurised, high turbulence or applications with steam or foam (Process Industry Forum, 2013). The LV-MaxSonar-EZ1 selected is a very affordable, low power and easy to interface sensor for reliable and stable range measurements with a skillful balance between sensitivity and interference margin. The minimum reported distance is 15.2cm, targets closer than 15.2cm will typically range as 15.2cm (Maxbotix, 2015). This challenge being addressed by mounting the sensor unit in such a way that the highest level of water will be detected at a distance that is always greater than 15.2cm as shown in the Fig. 36. Works by (Ahmad et al., 2013) and (Rowe et al., 2009) have clearly presented the use of ultrasonic sensors for monitoring river and stream flows.

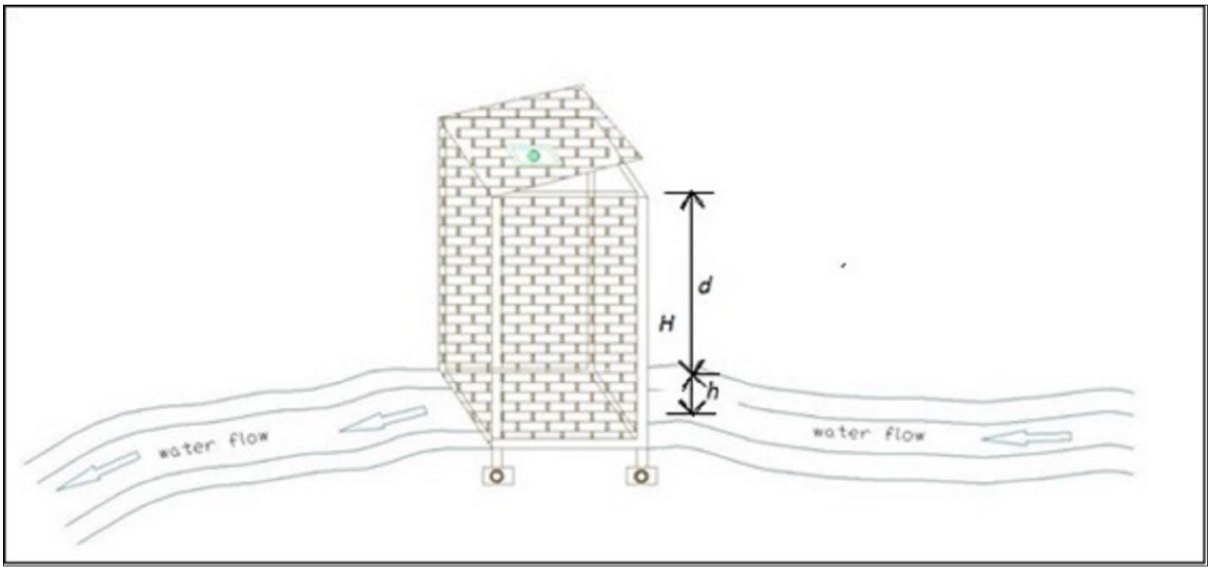


Figure 36: Sensor unit configuration

H: Distance from the sensor face to canal floor = 89cm

h: Canal depth, the highest possible water level = 31cm

d: Distance from the sensor face to the maximum level = H-h = 58cm

The ZigBee (IEEE 802.15.4) communication technology, we opted for, is a low power and low cost wireless networking protocol useful option for obtaining continuous and quality data. It also supports various topologies such as star, cluster and mesh. The star topology selected is the one that single sink node can send and/or receive message to a number of remote nodes. The remote nodes are not permitted to send messages to each other. The advantage includes simplicity and ability to keep the remote node's power consumption to minimum. It also allows low latency between the communicating nodes. Disadvantage is that, the sink must be within radio transmission range of all the individual sensing nodes and is not as robust as other topologies due to its dependency on a single node to manage the network (Matin and Islam, 2012). Although we have implemented a star topology in our logical mappings, we even have room for altering data flow design making our implementation flexible and indeed scalable. Because of resource limitations at the sensing nodes and the processing requirements, decision for storing our system data involved determining what to be stored, where to store and for how long it should be stored. Several approaches for storing data generated by sensor systems have been suggested. The hybrid approach is chosen in our design, we store data locally on the nodes before sending them to the server for permanent storage and processing. Although this option may seem to consume more resources, it is rather robust and more reliable data storage design, both local and remote storage can act as a backup for each other ensuring data is not lost in case of something happening with either storages or communication subsystems. Although there are works that have been able to utilize batteries as a source of power successfully such as (Ahmad et al., 2013) for their smart water discharge meter. There is another means of powering sensor systems by taking energy from the surroundings. Because our system is used in outdoor settings, energy can be harvested from sunlight. However use of energy from the environment is sometimes not possible because environmental conditions are variable and unreliable, this is the cause that we have implemented a combination of environmental energy harvesting and rechargeable battery for powering our system. The backup power at the sink node is supplied by the internet generating device equipped with solar reachable batteries and a cloud facility for outside access and management. Thus possible for monitoring battery status remotely as shown in Fig. 37, making sink node power source configuration even smarter.

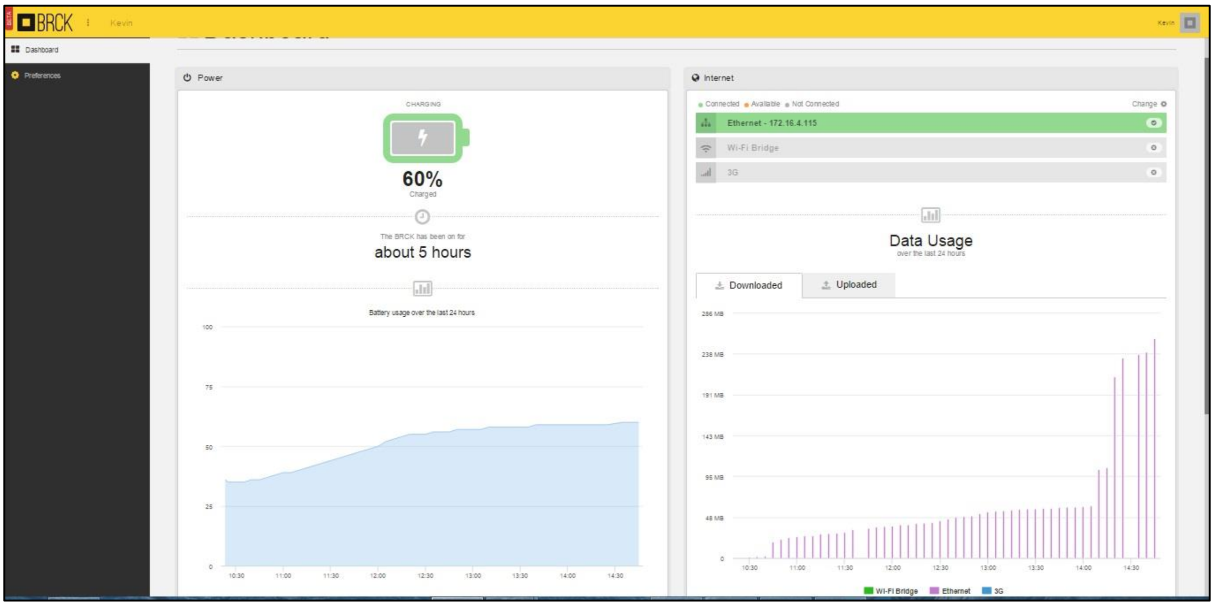


Figure 37: BRCK dashboard for battery status monitoring

The low-cost components and techniques used in each of the subsystems development have collectively played a big part in letting down the budget for our water monitoring system significantly as shown in table1 and table 2 for the sensing and sink node respectively. More sensible and low-cost option for smallholder irrigators in developing rural areas as compared to the cost of off-the-shelf systems which may run from 700 to 900 Euros.

Table 9: Sensing node budget

S/N	ITEM	COST(EURO)
1.	Sensor	28
2.	Arduino	23
3.	Real time clock	14
4.	Xbee Module	34
5.	Solal panel and battery	23
6.	Packaging and housing	100
	Total	222

Table 10: Sink node budget

S/N	ITEM	COST(EURO)
1.	Sensor	28
2.	Arduino	23
3.	Real time clock	14
4.	Xbee Module	34

5.	Solal panel	14
6.	Packaging and housing	100
7.	Ethernet Shield	64
8.	BRCK (for internet and backup battery)	184
9.	SD Card	5
	Total	466

6.2.1 Answers to research questions

Table 9 summarizes the research questions and their brief answers of the main research questions that this study had intended to provide during its completion.

Table 11: Research questions and brief answers

Sn	Research question	Answers
1	What are the strengths and weaknesses of the current technological developments in the building blocks for water monitoring methods?	Chapter two discusses in detail the current technological developments in WSN for water monitoring subsystems including their strengths and weaknesses. In brief, the subsystem discussed are, -Sensing subsystem (The liquid level sensing techniques; ultrasonic, radar, pressure and capacitive methods). -Communication subsystem (Wireless standards for WSN; Wi-Fi, Bluetooth and ZigBee). -Storage and processing subsystem (storage locations for WSN data includes; SD card at the sensing node, database at the central database, or at both locations).
2	What are the factors for consideration during design decisions when developing WSN for water monitoring methods?	Chapter two also discusses in detail issues of costs, power sources and management (the power sources could either be batteries, energy harvesting from the environment (e.g solar and wind), security issues were also pointed out that implied the packaging and

		housing of sensing components as important factors for consideration during design decisions of WSN for water monitoring
3	How water delivery data for traditional irrigation canals can effectively be gathered and communicated in real time?	Chapter three discusses in detail the use of open source hardware technology such as Arduino based platform, ZigBee open access technology and low-cost ultrasonic sensors to develop low-cost sensing and communication subsystem.
4	How real time water delivery data can effectively be aggregated, processed and presented to give meaningful information?	Chapter three discusses the storage of sensor data temporarily particularly at the sensing nodes, while chapter four discusses in detail the development of web based application for water delivery data permanent storage and processing to extract useful information such as hourly, daily and monthly discharge reports. Chapter five presents the testing of the underlying system in the actual environment.

6.2.2 Research contributions

This research has laid the ground works that could be used to provide both theoretical and practical insight for future works particularly for the implementation of large projects towards total automation of canal discharge data acquisition, processing and sharing. The contribution has been attained through

i. The low-cost design suitable for cost prohibitive small holder irrigators facilitated by
   - Use of open source software and hardware components combination
   - Securely packaging of sensor node components in a lunch box like container instead of off-the-shelf costly enclosures.
   - Fabrication of EPS technology for the node house construction, a low-cost technique for providing physical and weather protections that also made possible use of low-cost indoor sensors in the outdoor settings a technique that contributed to further cost reduction.

ii. Successfully demonstration of the use of BRCK (A device designed in Africa (Kenya) for Africa) to provide 3G/2G internet and backup power for monitoring systems.
iii. Development of an open source, dynamic and user friend web based application for discharge data storage and processing to extract useful information such as hourly daily and monthly discharge reports presented in tables and graphs formats.

6.2 Conclusion

In order to enhance the effective utilization of the diminishing water resource, levying of usage fees and equity and transparency in water distribution, access to low-cost decision support system for data acquisition, analysis and presentation is important for improving water management in farmer-led irrigation systems in Tanzania. Keeping in mind irrigated agriculture is the largest water user dominated by smallholder irrigators, the objective of this work was to develop a low-cost sensor based method for water discharge monitoring. A cost effective system for smallholder farmers to collect irrigation canals water delivery data in real time basis.

Thus the study focused on low-cost solution by exploiting the affordable and more attractive open source hardware and software techniques. In particular the Arduino platform, low cost ultrasonic sensors and ZigBee open standard technology were employed for the sensing and communications subsystems. Locally engineered enclosure, the modification of lunchbox containers and fabrication of the EPS technology were used for the packaging and housing of the sensing components. Solar panels were used for powering of sensing node and rechargeable motorcycle batteries provided backup power. For the case of storage and processing subsystem, the MySQL database and ATK (an open source PHP framework) were the technologies used for the back end and front end respectively.

Tests in the lab environment and initial results from the irrigation canals deployment depicted low-cost possibility of getting real time canal discharge data remotely which could be adopted to improve irrigation water management.

6.3 Recommendations

Before complete adoption of the proposed method, system scaling up by introducing more nodes to build up a larger network and able to monitor data on catchment wide water diversions is recommended and is the crucial next stage of this study. The process of upscaling to a larger network is currently being undertaken in Usa-river catchment one of the catchment of the Pangani basin as Fig. 38 depicts the ongoing activities.

Figure 38: System scaling up in Usa-River catchment

Development of the mobile application is also important for easier sharing of information among stakeholders as depicted in our system architecture. The intention here is to have in place online system that users can access data from and also upload other relevant materials.

REFERENCES

Abrahamsson, P., 2002. Agile Software Development Methods: Review and Analysis (VTT publications).

Ahmad, Z., Asad, E.U., Muhammad, A., Ahmad, W., Anwar, A., 2013. Development of a low-power smart water meter for discharges in indus basin irrigation networks, Wireless Sensor Networks for Developing Countries. Springer, pp. 1-13.

Ai, C., Du, R., Zhang, M., Li, Y., 2009. In-network historical data storage and query processing based on distributed indexing techniques in wireless sensor networks, Wireless Algorithms, Systems, and Applications. Springer, pp. 264-273.

Akbari, S., 2014. Energy harvesting for wireless sensor networks review, Computer Science and Information Systems (FedCSIS), 2014 Federated Conference on. IEEE, pp. 987-992.

Arshad, M.J., Farooq, A., Shah, A., 2010. Evolution and development towards 4th generation (4G) mobile communication systems. Journal of American Science 6, 63-68.

Balaji, R., Ganesan, R., 2012. Remote Water Pollution Monitoring System Using GSM. International Journal of Computer Science and its Applications.

Balaji, S., Murugaiyan, M.S., 2012. Waterfall vs. V-Model vs. Agile: A comparative study on SDLC. International Journal of Information Technology and Business Management 2, 26-30.

Bell, C., 2013. Beginning Sensor Networks with Arduino and Raspberry Pi. Apress.

Boyes, W., 2009. Instrumentation reference book. Butterworth-Heinemann.

Castagnetti, A., Pegatoquet, A., Belleudy, C., Auguin, M., 2012. A framework for modeling and simulating energy harvesting wsn nodes with efficient power management policies. EURASIP Journal on Embedded Systems 2012, 1-20.

Cohn, M., 2005. Scrum Overview for Agile Software Development.

Dargie, W.W., Poellabauer, C., 2010. Fundamentals of wireless sensor networks: theory and practice. John Wiley & Sons.

Digi, 2015. ZigBee: Low-cost,low-power, wireless networking for deveice monitoring and control.

DSDM, 2015. What is DSDM?

Eddabbah, M., Moussaoui, M., Laaziz, Y., 2015. A flexible 3G WebService Based Gateway for Wireless Sensor Networks in support of Remote Patient Monitoring Systems.

El Barachi, M., Alfandi, O., 2013. The design and implementation of a wireless healthcare application for WSN-enabled IMS environments, Consumer Communications and Networking Conference (CCNC), 2013 IEEE. IEEE, pp. 892-897.

Faludi, R., 2010. Building wireless sensor networks: with ZigBee, XBee, arduino, and processing. " O'Reilly Media, Inc.".

Fourty, N., Val, T., Fraisse, P., Mercier, J.-J., 2005. Comparative analysis of new high data rate wireless communication technologies" From Wi-Fi to WiMAX", Autonomic and Autonomous Systems and International Conference on Networking and Services, 2005. ICAS-ICNS 2005. Joint International Conference on. IEEE, pp. 66-66.

Garg, V., 2010. Wireless Communications & Networking. Morgan Kaufmann.

Hutagalung, W., 2006. Extreme Programming.

Instrumentation toolbox, 2015. Ultrasonic level sensors- Operating principles.

Kinzli, K.-D., 2012. A low cost remote monitoring method for determining farmer irrigation practices and water use. INTECH Open Access Publisher.

Komakech, H., van Koppen, B., Mahoo, H., van der Zaag, P., 2011. Pangani river basin over time and space: on the interface of local and basin level responses. Agricultural Water Management 98, 1740-1751.

Kooker, J., 2008. Bluetooth, zigbee, and wibree: A comparison of wpan technologies. CSE 237A, November 20.

Magic, 2015. Benefits of web-based applications.

Mathews, S.C., Thattai, K., Ramanathan, P.K., 2013. Design and Development of a Simple and Efficient Low Cost Embedded Liquid Level Measurement System.

Matin, M., Islam, M., 2012. Overview of wireless sensor network. INTECH Open Access Publisher.

Maxbotix, 2015. LV-MaxSonar -EZ Series High Performance Sonar Range Finder.

Nabil, D., Mosad, A., Hefny, H.A., 2011. Web-Based Applications quality factors: A survey and a proposed conceptual model. Egyptian Informatics Journal 12, 211-217.

Nechibvute, A., Chawanda, A., Luhanga, P., 2012. Piezoelectric energy harvesting devices: an alternative energy source for wireless sensors. Smart Materials Research 2012.

Nikolov, G., Nikolova, B., 2008. Virtual techniques for liquid level monitoring using differential pressure sensors. RCENT 9, 2.

Oadu, ood_with_java_c++_and_uml.

Park, C., Chou, P.H., 2006. Ambimax: Autonomous energy harvesting platform for multi-supply wireless sensor nodes, Sensor and Ad Hoc Communications and Networks, 2006. SECON'06. 2006 3rd Annual IEEE Communications Society on. IEEE, pp. 168-177.

Point, T., 2015. SDLC- RAD Model.

Process Industry Forum, 2013. Tutorial on level measuring techniques for liquids and fluids.

Quan-Xi, L., Gang, L., 2010. Design of remote automatic meter reading system based on ZigBee and GPRS, Proceedings of the Third International Symposium on Computer Science and Computational Technology (ISCSCT’10), pp. 14-15.

Rantz, S., 1982. Measurement and computation of stream flow. Volume 1: Measurement of stage and discharge; Volume 2: Computation of discharge. US Geological Survey water-supply paper 2175, 631.

Reverter, F., Li, X., Meijer, G.C., 2007. Liquid-level measurement system based on a remote grounded capacitive sensor. Sensors and Actuators A: Physical 138, 1-8.

Rose, K.H., 2013. A Guide to the Project Management Body of Knowledge (PMBOK® Guide)—Fifth Edition. Project Management Journal 44, e1-e1.

Rowe, M., Fry, L., Mihelcic, J., 2009. Low-Cost Sensor Network for Stream Flow Monitoring in the Alto Beni Region of Bolivia, AGU Fall Meeting Abstracts, p. 0896.

Ruiz-Garcia, L., Lunadei, L., Barreiro, P., Robla, I., 2009. A review of wireless sensor technologies and applications in agriculture and food industry: state of the art and current trends. Sensors 9, 4728-4750.

Satzinger, J., Jackson, R., Burd, S.D., 2011. Systems analysis and design in a changing world. Cengage Learning.

Semente, R.S., Silva, A., Salazar, A.O., Oliveira, F.D., Lock, A.S., 2013. A energy efficient WSN system for limited power source environments, Proceedings of 7th International Conference on Sensing Technology (ICST), pp. 193-197.

Ševcík, P., Kovár, O., 2013. Alternative energy sources for WSN node power supply. ITS.

Shaikh, F.K., Chowdhry, B.S., Ammari, H., Uqaili, M.A., Shah, A., 2013. Wireless Sensor Networks for Developing Countries, First International Conference, WSN4DC. Springer.

Shuaib, K., Boulmalf, M., Sallabi, F., Lakas, A., 2006. Co-existence of Zigbee and WLAN, a performance study, Wireless Telecommunications Symposium, 2006. WTS'06. IEEE, pp. 1-6.

Shukla, A.K., Saxena, A., 2013. Which model is best for the Software Project?"A Comparative Analysis of Software Engineering Models". International Journal of Computer Applications 76.

URT, T.U.R.o.T., 2009. The water resources management act.

Usman, A., Shami, S.H., 2013. Evolution of communication technologies for smart grid applications. Renewable and Sustainable Energy Reviews 19, 191-199.

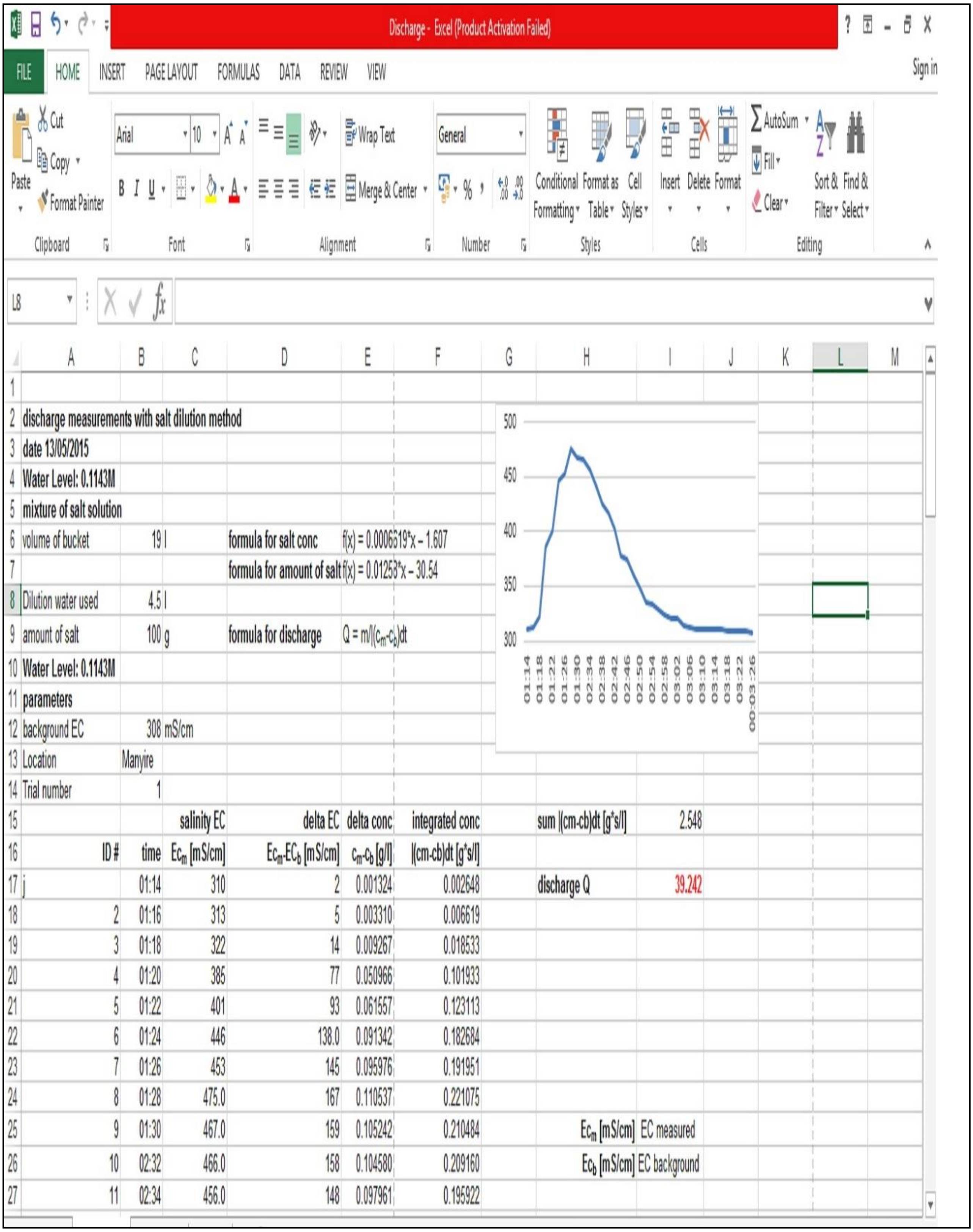
Wang, N., Zhang, N., Wang, M., 2006. Wireless sensors in agriculture and food industry—Recent development and future perspective. Computers and electronics in agriculture 50, 1-14.

Watras, C.J., Morrow, M., Morrison, K., Scannell, S., Yaziciaglu, S., Read, J.S., Hu, Y.-H., Hanson, P.C., Kratz, T., 2014. Evaluation of wireless sensor networks (WSNs) for remote wetland monitoring: design and initial results. Environmental monitoring and assessment 186, 919-934.

Wesolowski, H., Wesolowski, K., 2001. Mobile communication systems. John Wiley & Sons, Inc.

APPENDICES

Appendix 1: Discharge sheet



	A	B	C	D	E	F	G	H	I
1									
2	discharge measurements with salt dilution method								
3	date 13/05/2015								
4	Water Level: 0.1143M								
5	mixture of salt solution								
6	volume of bucket	19	l	formula for salt conc	f(x) = 0.0006619*x – 1.607				
7				formula for amount of salt	f(x) = 0.01253*x – 30.54				
8	Dilution water used	4.5	l						
9	amount of salt	100	g	formula for discharge	$Q = m/\int(c_m-c_b)dt$				
10	Water Level: 0.1143M								
11	parameters								
12	background EC	308	mS/cm						
13	Location	Manyire							
14	Trial number	1							
15			salinity EC	delta EC	delta conc	integrated conc		sum ∫(cm-cb)dt [g*s/l]	2.548
16	ID #	time	Ec_m [mS/cm]	Ec_m-EC_b [mS/cm]	c_m-c_b [g/l]	∫(cm-cb)dt [g*s/l]			
17	j	01:14	310	2	0.001324	0.002648		discharge Q	39.242
18	2	01:16	313	5	0.003310	0.006619			
19	3	01:18	322	14	0.009267	0.018533			
20	4	01:20	385	77	0.050966	0.101933			
21	5	01:22	401	93	0.061557	0.123113			
22	6	01:24	446	138.0	0.091342	0.182684			
23	7	01:26	453	145	0.095976	0.191951			
24	8	01:28	475.0	167	0.110537	0.221075			
25	9	01:30	467.0	159	0.105242	0.210484		Ec_m [mS/cm]	EC measured
26	10	02:32	466.0	158	0.104580	0.209160		Ec_b [mS/cm]	EC background
27	11	02:34	456.0	148	0.097961	0.195922			

Appendix 2: Sample Sql codes for database creation

Network and Canal registration tables

```
CREATE TABLE `tbl_set_network` (
  `network_id` int (5) NOT NULL,
  `network_name` varchar (50) NOT NULL,
  `Network_code` varchar (10) NOT NULL,
  `Contact_Person` varchar (50) NOT NULL,
  `Mobile` varchar (12) NOT NULL,
  `Physical_Address` varchar (50) NOT NULL,
  PRIMARY KEY (`network_id`)
 UNIQUE KEY `Network_code` (`Network_code`)
);

CREATE TABLE `tbl_set_pricanal` (
  `Primary_canal_id` int (5) NOT NULL,
  `Primary_canal_name` varchar (50) NOT NULL,
  `Canal_code` varchar (10) NOT NULL,
  `Network_id` int (5) NOT NULL,
  PRIMARY KEY (`Primary_canal_id`),
  UNIQUE KEY `Canal_code` (`Canal_code`)
);

CREATE TABLE `tbl_set_secanal` (
  `secondary_canal_id` int (5) NOT NULL,
  `Secondary_canal_name` varchar (50) NOT NULL,
  `Canal_code` varchar (50) NOT NULL,
```

```
  `primary_canal_id` int (5) NOT NULL,
  PRIMARY KEY (`secondary_canal_id`),
  UNIQUE KEY `Canal_code` (`Canal_code`)
);
CREATE TABLE `tbl_set_terticanal` (
  `tertiary_canal_id` int (5) NOT NULL,
  `Tertiary_canal_name` varchar (50) NOT NULL,
  `Canal_code` varchar (10) NOT NULL,
  `secondary_canal_id` int (5) NOT NULL,
  PRIMARY KEY (`tertiary_canal_id`),
  UNIQUE KEY `Canal_code` (`Canal_code`)
);
```

Data tables

```
CREATE TABLE `tbl_data_pricanals` (
  `id` int(10) NOT NULL AUTO_INCREMENT,
  `Water_level` float (10, 2) NOT NULL,
  `Sample_time` datetime NOT NULL,
  `Canal_code` varchar (10) COLLATE latin1_general_ci NOT NULL,
  PRIMARY KEY (`id`),
  UNIQUE KEY `id` (`id`)
);

CREATE TABLE `tbl_data_secanals` (
  `id` int(10) NOT NULL AUTO_INCREMENT,
  `Water_level` float (10,2) NOT NULL,
```

```
  `Sample_time` datetime NOT NULL,
  `Canal_code` varchar (10) NOT NULL,
  PRIMARY KEY (`id`),
  UNIQUE KEY `id` (`id`)
) ;

CREATE TABLE `tbl_data_terticanals` (
  `id` int(10) NOT NULL AUTO_INCREMENT,
  `Water_level` float NOT NULL,
  `Sample_time` datetime NOT NULL,
  `Canal_code` varchar (10) NOT NULL,
  PRIMARY KEY (`id`),
  UNIQUE KEY `id` (`id`)
);
```

Data processing views

```
CREATE VIEW `view_terti_hourly` AS
SELECT tbl_set_terticanal.tertiary_canal_name, DATE (Sample_time) AS date, HOUR (Sample_time) AS hour, AVG (Water_level) AS level
FROM tbl_data_terticanals,tbl_set_terticanal
WHERE tbl_data_terticanals.Canal_code = tbl_set_terticanal.Canal_code
GROUP BY Terticanal_name, date, hour;

CREATE VIEW `view_terti_daily` AS
SELECT tertiary_canal_name, date, AVG (level) AS level
FROM view_terti_hourly;
```

```
GROUP by Tertiary_canal_name, month;

CREATE VIEW `view_terti_monthly` AS
SELECT Tertiary_canal_name, YEAR (date) AS year, MONTH (date) AS month, AVG
(level) AS level
FROM view_terti_daily
GROUP by Tertiary_canal_name, year, month;

CREATE VIEW `Tertiary_Canals_Hourly_Report` AS
SELECT Tertiary_canal_name, date,hour, FORMAT ((342*level-2.1), 2) AS Quantity
FROM view_terti_hourly
GROUP BY Tertiary_canal_name, date, hour;

CREATE VIEW `Primary_Canals_Daily_Report` AS
SELECT Primary_canal_name, date, FORMAT ((342*level-2.1), 2) AS Quantity
FROM view_pri_daily
GROUP BY Primary_canal_name, date;

CREATE VIEW `Primary_Canals_Monthly Report` AS
SELECT Primary_canal_name, year, month, FORMAT ((342*level-2.1), 2) AS Quantity
FROM view_pri_monthly
GROUP BY Primary_canal_name, year, month;
```

Appendix 3: Sample Arduino code for Sensing nodes

```
#include <SPI.h>

#include <Wire.h>


const int pwPin1 = 3;

float pulse1, distance;


#define DS1307_ADDRESS 0x68

byte zero = 0x00;


// Function for converting binary coded decimal to normal decimal numbers

byte bcdToDec(byte val)  {

return ( (val/16*10) + (val%16) );

}


//Function for sensing values and sending to sink node

void read_sensor(){

  pulse1 = pulseIn(pwPin1, HIGH);

  distance = pulse1/147;

  float level = (35 - distance)* 0.0254;


  // RTC section

  Wire.beginTransmission(DS1307_ADDRESS);

  Wire.write(zero);

  Wire.endTransmission();

  Wire.requestFrom(DS1307_ADDRESS, 7);
```

```
int second = bcdToDec(Wire.read());
int minute = bcdToDec(Wire.read());
int hour = bcdToDec(Wire.read() & 0b111111); //24 hour time
int weekDay = bcdToDec(Wire.read()); //0-6 -> sunday - Saturday
int monthDay = bcdToDec(Wire.read());
int month = bcdToDec(Wire.read());
int year = bcdToDec(Wire.read());

//printing date into the format 3/1/11 23:59:59
String timestamp = month + ("/");
timestamp += month;
timestamp += ("/");
timestamp += monthDay;
timestamp += ("/");
timestamp += year;
timestamp += (" ");
timestamp += hour;
timestamp += (":");
timestamp += minute;
timestamp += (":");
timestamp += second;

//Sending values to Sink node(Canal_code, timestamp and level)
Serial.println(KSN);
Serial.println(timestamp);
Serial.println(level);
```

```
 }

void setup() {
  Serial.begin(9600);
  pinMode(pwPin1, INPUT);
  }

void loop() {
  //Execution of the sensing function after every 15 minutes
  read_sensor();
  delay(900000);
}
```

Appendix 4: Sample Arduino code for Sink node

```
#include <WiFi.h>

#include <mysql.h>

#include <sha1.h>

#include <SPI.h>

#include <SD.h>


IPAddress server_addr (192, 168, 43, 188);


// Wi-Fi credentials

char ssid[] = "KILIWIFI";

char pass[] = "Arduino_2015";

int status = WL_IDLE_STATUS;


File dataFile;

const int pwPin1 = 3;

float pulse1, distance;


Connector my_conn;        // Arduino Connection to MySQL

char user[] = "kevin";

char password[] = "tree";

char INSERT_SQL1[] = "INSERT INTO water_monitor.tbl_data_secanals(Water_level, Sample_time, Canal_code) VALUES (%s,%s, %s)";

char INSERT_SQL2[] = "INSERT INTO water_monitor.tbl_data_pricanals(Water_level, Sample_time,Canal_code) VALUES (%s,%s,%s)";


//Function for reading and sending sink node data to Server
```

```
 void read_sinkdata(){
//Reading values from sensor
 pulse1 = pulseIn(pwPin1, HIGH);
 distance = pulse1/147;
 float level = (35 - distance )* 0.0254;
 char canal_code1[5] = "MGN";

 // RTC section
 Wire.beginTransmission(DS1307_ADDRESS);
 Wire.write(zero);
 Wire.endTransmission();
 Wire.requestFrom(DS1307_ADDRESS, 7);
 int second = bcdToDec(Wire.read());
 int minute = bcdToDec(Wire.read());
 int hour = bcdToDec(Wire.read() & 0b111111); //24 hour time
 int weekDay = bcdToDec(Wire.read()); //0-6 -> sunday - Saturday
 int monthDay = bcdToDec(Wire.read());
 int month = bcdToDec(Wire.read());
 int year = bcdToDec(Wire.read());

 //printing date into the format 3/1/11 23:59:59
 String timestamp = month + ("/");
 timestamp += month;
 timestamp += ("/");
 timestamp += monthDay;
 timestamp += ("/");
```

```
  timestamp += year;
  timestamp += (" ");
  timestamp += hour;
  timestamp += (":");
  timestamp += minute;
  timestamp += (":");
  timestamp += second;

//Saving read values to SD Card
  dataFile = SD.open("sinklog.txt", FILE_WRITE);
  if (dataFile) {
   dataFile.print(canal_code);
    dataFile.print("  ");
    dataFile.print(level);
    dataFile.print("  ");
    dataFile.println(timestamp);
    dataFile.close();
    Serial.println("Sink data written to SD card succssessfully");
  }
  else {
    // if the file didn't open, print an error:
    Serial.println("error opening sinklog.txt");

  //Sending read values to server
  char query2[64];
  char sensor_reading2[10];
```

```
  char canal_reading2[10];
  char sample_time2[10];
  dtostrf (level, 1, 1, sensor_reading2);
  dtostrf (canal_code1, 1, 1, canal_reading2);
  dtostrf (timestamp, 1, 1, sample_time2);
  sprintf (query2, INSERT_SQL2,sensor_reading2,canal_reading2,sample_time2);
  my_conn.cmd_query(query2);
  Serial.println (" Sink Query Succsess");
  }
```

Function for reading and sending sensing node data to Server

```
  void read_sensingdata(){
  //Reading values from sensor
  float getLevel = Serial.parseFloat();
  date getTime = Serial.parseDate();
  char getCanal_code = Serial.parseChar();

//Saving read values to SD Card
  dataFile = SD.open("sensinglog.txt", FILE_WRITE);
  if (dataFile) {
dataFile.print (getCanal_code);
    dataFile.print ("  ");
    dataFile.print (getLevel);
    dataFile.print ("  ");
    dataFile.println (timestamp);
    dataFile.close();
```

```
    Serial.println("Sink data written to SD card succssessfully");
  }
  else {
    // if the file didn't open, print an error:
    Serial.println("error opening sinklog.txt");

  //Sending read values to server
  char sensor_reading1[10];
  char canal_reading1[10];
  char sample_time1[10];
  char query1[64];
  dtostrf (getLevel, 1, 1, sensor_reading1);
  sprintf (query1, INSERT_SQL1,sensor_reading);
  my_conn.cmd_query(query1);
  getLevel = ' ';
  Serial.println(" Sensing Query Succsess");

 }
void setup() {
  Serial.begin(9600);

  // WiFi section
  int status = WiFi.begin(ssid,pass);
  // if you're not connected, stop here:
  if ( status != WL_CONNECTED) {
    Serial.println("Couldn't get a WiFi connection!");
```

```
    while(true);
  }
  // printing connection details
  else {
    Serial.println ("Connected to network");
    IPAddress ip = WiFi.localIP();
    Serial.prin t("My IP address is: ");
    Serial.println (ip);
  }
  delay (1000);
  //Server connection section
  if (my_conn.mysql_connect(server_addr, 3306, user, password)) {
    delay (1000);
    Serial.println("Connected to Server");
  }
  else
    Serial.println("Connection failed.")
   void loop() {
   read_sinkdata ();
   //Check for serial data the read
   if (Serial.available())
  {
    read_sensingdata ();
  }
    delay (900000);
}
```