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A Wireless M-Bus based smart water meter model: a case of Nairobi City Water & Sewerage Company

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Declaration

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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Abstract

Water in the many aspects of our lives is used, and therefore it is very critical to humanity's survival. Unfortunately, in Kenya, water industry has been facing myriad meter reading challenges. Notably, as the population of the meters increase, companies have employed more staff to read meters manually. These has subsequently triggered a blotted work force hence increased operational costs. Security and privacy concerns arise due to the frequency of water company's staffs visiting the customer's premises to perform various duties. Customer complaints relating to wrong billing that are occasioned by erroneous meter reads and wrong meter matching consequently leading to misstated bills to the customers, have been on the rise. It is also not possible in almost all households to estimate the quantity of water in the storage without manually checking the water tank level.

On the other hand, various phone-based applications in the water that are developed are not able to eradicate fully the challenges experienced in the water sector.

This paper adopts applied research methodology to provide a practical solution to the challenges affecting meter reading in the water companies using the Wireless M-Bus technology. The study delivers a wireless meter-bus smart water meter model integrated with other smart metering devices to enable remote meter reading. It further discusses technologies used in the smart water meters, various smart meter implementations and the driving factors to adopting smart metering while exploring the advantages with smart meters over the mechanical meters and their economic value.

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List of Abbreviations/Acronyms

AMI	Automatic Metering Infrastructure
ERD:	Entity Relation Diagram
GPRS:	General Packet Radio Service
GSM:	Global System for Mobile Communications
HTML:	HyperText Markup Language
HTTP:	Hypertext Transfer Protocol
IWSN:	Industrial Wireless Sensor Networks
M-BUS:	Meter Bus
MFA:	Mobile Field Assistant
MNO:	Mobile Network Operators
NWSC:	Nairobi Water and Sewerage Company
PHP:	Hypertext Preprocessor
SDLC:	Software Development Life Cycle.
SIM:	Subscriber Identity Module
SMS:	Short Message Service.
UML:	Unified Modelling Language
WASREB	Water Services Regulatory Board

ACKNOWLEDGEMENTS

I would wish to thank God the almighty for giving strength and seeing me through the project. Secondly, I thank the supervisor who has not only instructed but has also made me work and learn. Thirdly is to my parents, brother, sisters, wife and the larger family who have relentlessly cheered me on while doing this study.

Chapter 1: Introduction

1.1 Background study

According to (Philipe et al., 2011), the aquatic sector embodies a major challenge for the 21st century. The dynamic situation in the environment coupled with the ever-increasing population has generated significant constraints on the limited resource. There is therefore need to have continuous flow of data relating to natural and build in environment hence moving towards “data rich world” which will potentially improve water management. The improvement can be realized through real mobilization of all actors in the water sector i.e. Regulating bodies, public services, water utilities and IT producers. The actors can therefore analyse the data and thereafter coin concreate strategies that positively influence decisions made pertaining to management of the resource including changes in business processes.

Moraa et.al, (2012), noted the myriad efforts intended to reorganize the water industry in Kenya. The efforts include changes in the 2002 Water Act in Kenya that initiated restructuring in the water industry through enabling access to clean water and sewerage services to all. The creation of Regional Water Boards provided an oversite role in the asset development and in the operations of water and sewerage services within their jurisdiction. According to (Nwsc Strategic Plan, 2014), in embracing the reforms within the water sector industry, it projected increase to 4.5 million by 2018/19 based on the estimated population of 3.8 million in 2014.

According to (Champanis, Rivett, Gool and Nyemba-Mudenda, 2013) water service providers are using mobile phone, SMS messages and unique identification of meters to bill water utility services. However, there are innovative applications developed to solve water sector problems in Kenya such as Majivoice, Watex System and M-Maji.

According to (Champanis et al, 2013), MajiVoice as a bilateral podium, which affords the citizenry and the water utilities with communication through technologies that are affordable, accessible and user-friendly. MajiVoice an application that uses mobile phone and websites platforms enables the water consumers raise complaints relating to the water service delivery and receives timely feedback. Further, they noted that the application that is being steered in Kenyan towns and cities through the Water Services Regulatory Board (WASREB) has strengthened timely and transparent communication interchange between the citizens and water utilities. It has also reinforced efficiency, accountability, responsiveness and transparency of water services that have led to improved service delivery.

According to (Philipe et al., 2011), data acquisition process through sensors in the water cycle as critical. They point out that with the proliferation of wireless technologies, transmission of data is made faster. This is achieved mainly because the sensors are not only able to transmit data to remote locations but even while in motion. The sensors also been embedded in the meter reading technology devices and subsequently made it possible to automate meter reading through Automated Meter Readers (AMR) which have greatly impacted the various business processes. The same technology has advanced leading to abandonment of mechanical meters to adoption of smart meters in the smart metering concept.

According to (Butler, 2008), a smart meter is a typical water meter that is linked to a data logger and affords a user to continuously monitor water in use. Mead and Arayinthan (2009), notes that the smart meters are able to offer real time water consumption patterns through a software that captures water events and assigns them based on predefined parameters such as flow rate, volume and time.

Use of smart meters has numerous benefits which include effectiveness occasioned by direct feedback leading to customer satisfaction, ability to transmit real time information, cost effective especially in eliminating use of computer portals among others. However, the main attribute that the study will focus on is that they are not easy to tamper with in comparison to the mechanical meters. This study is therefore aimed at developing a mobile model that will help in capturing meter reads from a smart meter and other relevant information relating to the meter and customer data of importance to the water sector and other stakeholders. This data will therefore be stored in a central database which can be accessed by all the water stakeholders but of priority is the customers and the water service provider who can access it using a unique identification number that every customer and users of the system will have.

1.2 Problem Statement

Water utilities records water consumption manually on a monthly, quarterly or half-year basis (Giurco et al, 2008). This not only brings forth infrequent data that is not sufficient for billing purposes but also gives limited information on actual water use behaviour, leakage and seasonal variation.

According to (Butler, 2008), he defines a smart meter is a normal water meter connected to a data logger that allows for the continuous monitoring of water consumption. The smart metering system can provide real-time water consumption or sufficient data points to determine usage patterns through use of a special purpose software that can disaggregate the water events and assign them to various water uses according to a number of user-defined parameters such as flow rate, volume and time (Mead and Aravinthan, 2009).

It is noted by (Giurco et al, 2010) that in spite of the gains offered by smart meters water companies still use the mechanical meters due to the cost of procuring the smart meters coupled with the lack of readily affordable infrastructure that support the smart meters. They acknowledge that since there are drawbacks associated with use of traditional meters over use of smart meters, timely collection and analysis of water use data, and the timely relaying of these data to the water user, can result in significant changes in water use behaviour.

This thesis therefore sorts to understand the information necessary in meter reading application, analyse the drawbacks of mechanical meters, investigate advantages of smart meters and with this knowledge propose a smart water meter prototype that will remotely read smart water meter, capture information relating to status of the meter, quantity of water supplied, water consumed and quantity of water stored in the customer's premises at any one time.

1.3 Objectives of the Study

1.3.1 General objectives

The aim of this study is to develop a smart water meter model that will allow customers to read their water smart meters and to update other information necessary to the water companies.

1.3.2 Specific objectives

i. To determine type of information requirements needed for meter reading application

ii. To investigate the problem with the current water meters.

iii. To propose a mobile application to be integrated with smart meter reading.

iv. To test the proposed model

1.4 Research questions

i. What kind of information requirements is needed for a meter reading application?

ii. What are the problems with the current meters?

iii. How is the proposed application integrated with smart meter reading?

iv. Will the proposed application help in meter reading?

1.5 Scope of the Study

The study was conducted in the county of Nairobi, Kenya and focused on the water service providers in Nairobi County. The target group were the respondents living in Nairobi County specifically residents in westlands and buruburu estates.

1.6 Significance of the Study

The smart meter model aims at making the water companies more efficient in their service delivery through constant interactions with the customers. This has been achieved through the immediate feedback to the customers through the mobile application model proposed once they query or request for a service. The implementation of the model resulted to operation efficiency and cost reduction to the water companies. This has been realized through reduction of the frequent transportation cost and time taken to visit the customer premises to read meters or obtain any necessary data by the water company staffs.

The model has lead to a faster problem resolving process by clustering similar problems hence leading to optimization of resources.

An increase of customer satisfaction is attained through personalized attention enabled by the smart water meter model application.

Chapter 2: Literature Review

2.1 Introduction

This chapter covers the literature about how the water meters have evolved and draws a comparison between the mechanical water meters and the smart water meters. The chapter discusses the penetration of mobile phones in Kenya and the mobile applications developed that focus on the water management and supply.

2.2 Water Meter Reading

According to (Crainic et al., 2012), water meters can measure water while in use through two technologies. The displacement technology is used by water meters with oscillating pistons and nutating disks while velocity technology is found in water jet and turbine meters. The displacement water meters measures water as it flows by holding it a little while in chambers and lets it out back to the flow stream. The number of times water is held in chambers and the size of chambers are used to aggregate the amount of water used. Crainic et al, (2012) further notes that the cylinders used in the oscillating piston meters which have inlets and outlets controlled by the pistons, lack accuracy because the meter counted the number of pistons strokes whose lengths varied with the flow.

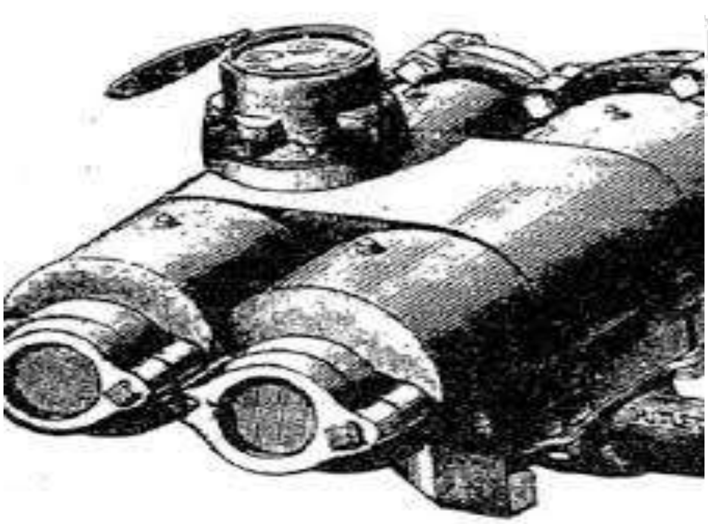

Figure 2. 1: Picture demonstrating original duplex piston meter (Crainic et al., 2012)

According to (Crainic et al., 2012), they state that the second technology the water meters can measure water in use is velocity. These water meters using this technology are mainly turbine and jet meters. They further note that, the velocity meter contained very light water wheels which were operated by the water current and on its axis they contained a worm for actuating gearing and totalizers. The measuring of the water used is made possible when a meter of known internal capacity is used and the speed of the flow is converted into volume used. The rate of the flow is computed from rotations obtained during a given period.

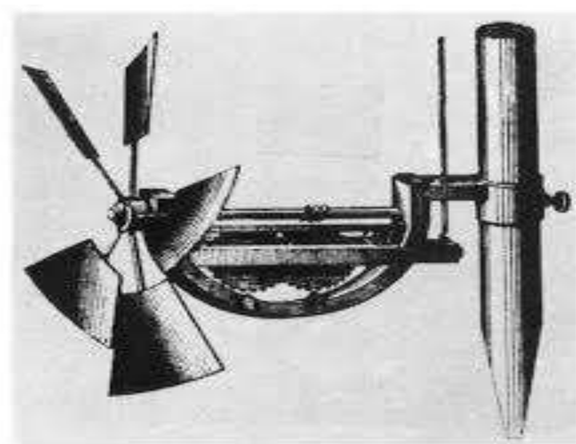

Figure 2. 2: Picture demonstrating woltman velocity water meter (Crainic et al., 2012)

According to (Crainic et al., 2012), earlier meters before World War 1 were mainly used at the Northern part of the world, and they were greatly affected by extreme cold temperatures that would affect the meter gears. They used to be blown apart as pipes crystallized due to frost. Figure 2.2 in the next page demonstrates how water meters are damaged by frost while figure 2.3 shows the conical disc meters.

Crainic et al., (2012) notes that the nutating conical disc meters were preferred at the time than the flat disc meter as they were easier to drain water from the meter.

Figure 2. 3: Picture demonstrating water meter damaged from frost (Crainic et al., 2012)

Figure 2. 4: Picture demonstrating the conical meter (Crainic et al., 2012)

Cranic et al., (2012) noted that, in efforts to curb their inefficiency at the time, a breakable frost bottom was developed. It was meant to be blown out during the expansive action of freezing. In 1904 more development was done on the meter by introducing a cover that would use of bolts that would "break, strip or yield resiliently" while under pressure greater than normal but yet within the strength of the casings. After the World War 1, meter gears that had oil-enclosed chambers were used as they would protect the wear and tear of the meter gears. These were used until 1950 to 1960 paving way for magnetic driven meters which used small, four-pole and usually round ceramic magnets. Before 1970 most meters parts used to be metallic after which a number of utilities were using meters with plastic parts.

2.3 Mechanical Water meters

According to (Betty M, 2016) the mechanical meters have plastic parts that wear out thus leading to increased cost of possession and loss of revenue. Accuracy tends to be compromised with the aging water meters because the movable parts are rendered inefficient, once particles get deposited on the inside of the flow chamber of the meter and consequently causing over-registration at high flow rates and under-registration at low flow rates. This challenge however is eradicated through use of the solid state non-mechanical and electronic metering which have fascinating finance and ecological gains. The absence of moving parts which get clogged by particles thus compromising accuracy, makes them easy to maintain because the small matter can pass right though.

Betty M, (2016) further notes that as the metering technology advances to Automatic Metering Infrastructure (AMI) it complements the non-mechanical and electronic metering. It further reduces the apparent losses from meters allowing utilities to bill for more of the water actually consumed. Water leaks are eradicated with the use of the solid state technology and more information necessary to both the customer and water utilities is made available.

2.3.1 Physics of the Ultrasonic Meter

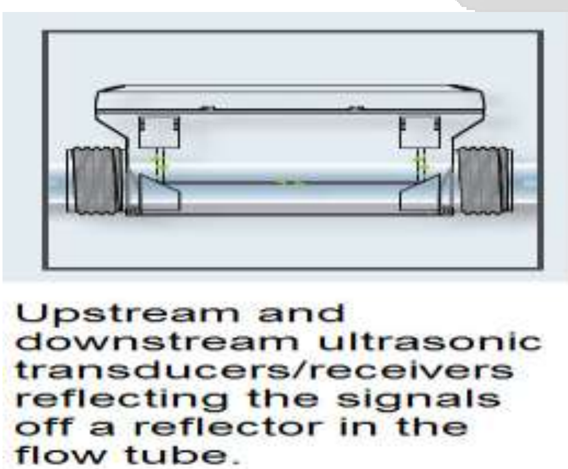

Figure 2. 5: Picture demonstrating movement of the signals in a smart meter (Betty M, 2016)

The diagram above depicts the water movement through the Ultrasonic meter. Signals are sent upstream and downstream. The time the signal takes to move upstream is slower than when moving downstream in direct proportion to the speed of the water flow. The time dissimilarity is therefore used to calculate the flow rate and total amount of water flowing. It is accurate at measuring and detecting flow in either direction. The water generally takes a straight path through the meter without any moving mechanical parts.

Unlike the mechanical meters that use mechanical parts these Ultrasonic meters use batteries which therefore makes them to have a longer useful life.

2.4 Mobile Phones Penetration

According to (Zah (2015), she notes that one of the countries rated to be fast growing in mobile and internet penetration in Africa is Kenya. It is also rated third in the world as fastest growing in its economy. She states that its mobile and internet penetration is among the highest at 83% and 58% respectively. The Kenyan mobile internet and phone penetration are as shown in figure 2.6 in the next page. As at September 2014, the total number of mobile subscribers increased to 32.8 million. She further notes that the estimated number of internet users across all Mobile Network Operators (MNOs) stands at 26.1 million where 99.9% access the internet through mobile data. She also noted that 58% of all phones sold in the country were smartphones with the remaining 42% as feature phones.

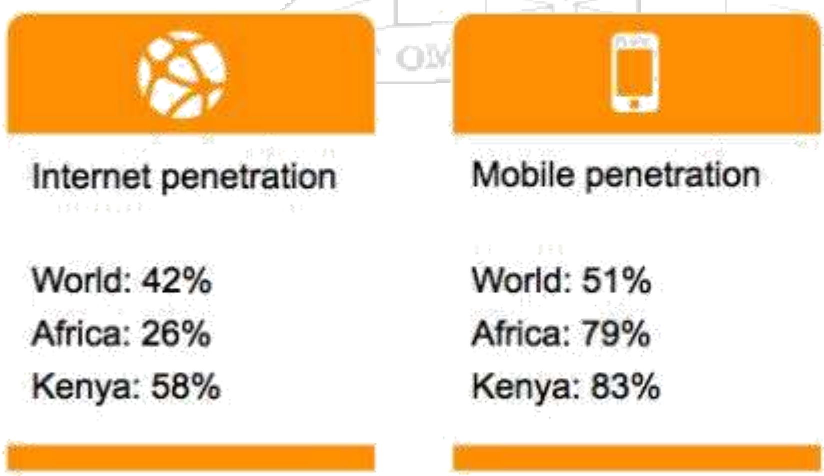

Figure 2. 6: Internet, mobile and social media infiltration figures in Kenya to convey smart meter data from the field to a computer near you. (Zah, 2015)

According to (Zah, 2015), the County of Nairobi in Kenya in comparison with other counties, registers the highest sales generating over 42% of the smart phones. Internet and mobile as greatly infiltrated in Kenya based on the statistics above, is therefore an ideal environment for reaching out to the population. According to (Strategic plan of Nairobi city water and Sewerage Company, 2014), the city of Nairobi has got an estimated population of 3.8 million and projected to grow to 4.5 million by 2018/19. This fact has necessitated need to review the management of water resources and innovating ways of how to improve service delivery to the residents.

2.5 Related Mobile Phones Applications

The following are some of the mobile applications developed and already being used by water companies in Kenya.

2.5.1 Mobile Field Assistant

Mobile field Assistant (MFA) is a meter reading application used to read water meters. A smart phone is deployed with a camera and can read. According to (Martey R.B, 2016), it is an android based application that can be installed on the simplest of smart phones. Mobile meter reader takes three functionalities GPS location, meter readings input (verification with variance) and sending readings real time. The SIM card sends readings via SMS to the head office. The mobile application offers high integrity with data being entered successfully by the reader when within the location of the meter. This is controlled by use of the GPS details of the meter that is already preloaded to the system. Once data is entered and sent to the office, one can validate the readings before posting them to the billing system. This gives the management the control to authenticate the readings. The readings of the meters are done on a sequence similar to the data loggers. The application also offers reports of meters read and the ones not read.

The researched proposed have ushered the customer to a better service but has not yet addressed the inefficiencies which exist in the industry especially where the staffs on the water utility companies have to visit all the customer’s premises in Nairobi.

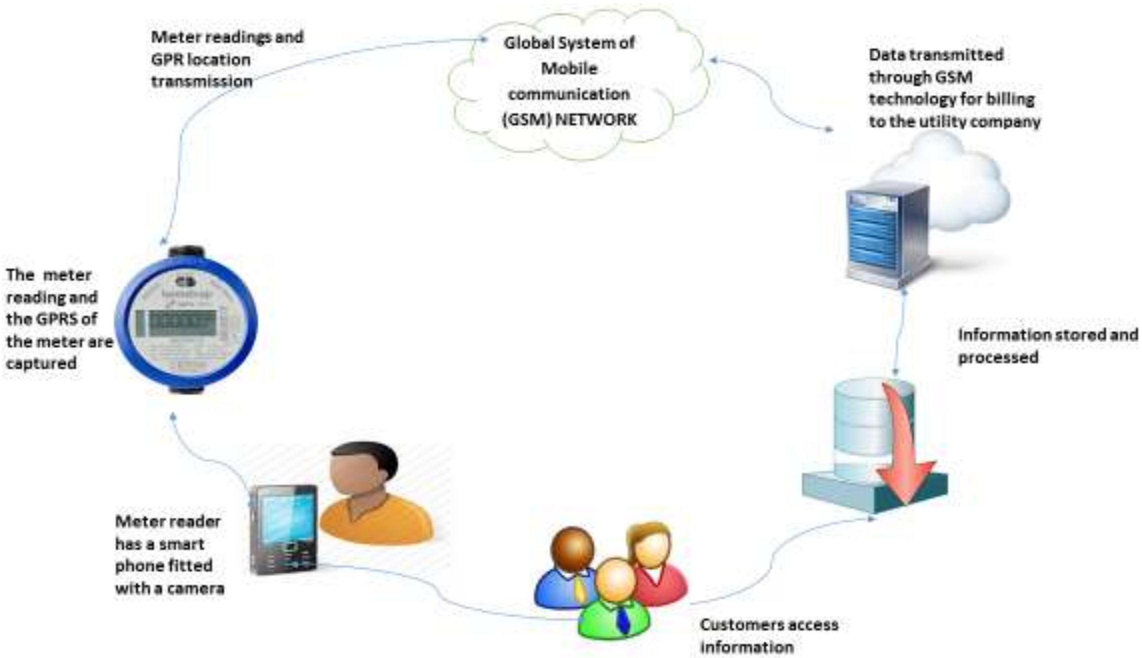

Figure 2. 7: Diagram demonstrating the Mobile Field Assistant implementation

2.5.2 mWater

mWater is a mobile application which is enables the users to be monitoring water quality. According to (Salim A, 2014), she states the application has been used extensively in West Africa countries by the water schemes in testing piped water schemes. The application has modules which enable the user to capture information through a mobile phone and indicates the type of infrastructure and the water points. Another modules enables the operators to navigate the operations of the network and therefore giving the customer a better experience in how they are handled. The third module is used by the regulators who are able to review the performance of the water schemes.

mWater has been piloted in areas like Benin, Niger and Senegal and according to (Salim A, 2014), the mobile application has been successful at monitoring water quality that flows in the system. However, this mobile application has not been able to address the water storage issue especially in informing the customers the quantity of the commodity stored at any given time to determine the next best cause of action be it to seek an alternative water supply other than the piped water or to scale down the water use.

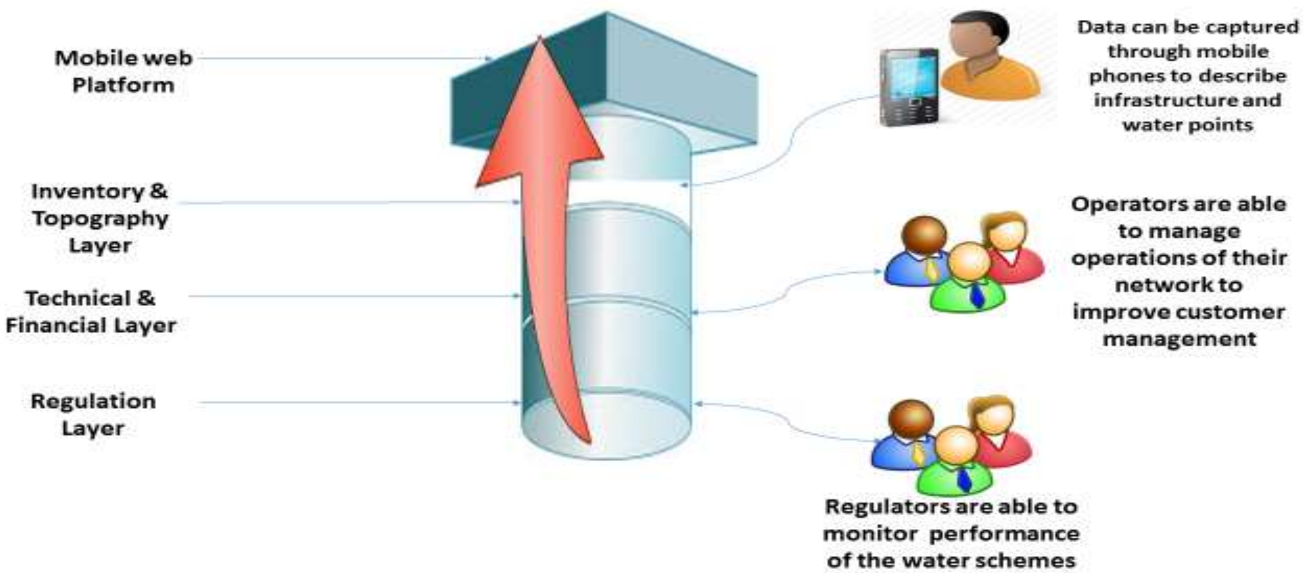

Figure 2. 8: Diagram explaining the mWater mobile web platform implementation

2.5.3 Maji Voice

According to (Salim A et.al, 2014) Maji voice is a mobile application that leverages use of Short messaging service, unstructured supplementary service data and web to capture data on matters relating to water that affect the citizens. Upon receipt of the complaints from the customer, it is subjected to the work flow processes within the water utilities.

Moraa et.al, (2012) also states that, the deployment of Majivoice involves a communication platform that allows water consumers and water service providers communicate through affordable, accessible and user-friendly technologies which include mobile phone and internet. The citizens are able to raise concerns with the water utility providers and are also able to appraise the progress of the complaints. Feedback on the resolution of complaints is sent to the customer at their convenient location hence convenient.

According to (Salim A et.al, 2014) escalation of the complaints which are not resolved on time are automatically escalated to the water regulators who then take appropriate action on the water utility companies. Figure 2.9 below summarizes the structure of majivoice implementation which involves the various actors in the water sector.

The mobile application therefore being a web based application, it provides a good point of reference when auditing the issues raised and it also guarantees action on the complaint to the satisfaction of the customer. However, it does not assist in dealing with the rising costs of operations in the water utilities due to blotted work forces. There therefore need to remotely read the smart water meter, capture information relating to status of the meter, quantity of water supplied, water consumed and quantity of water stored in the customer's premises at any one time.

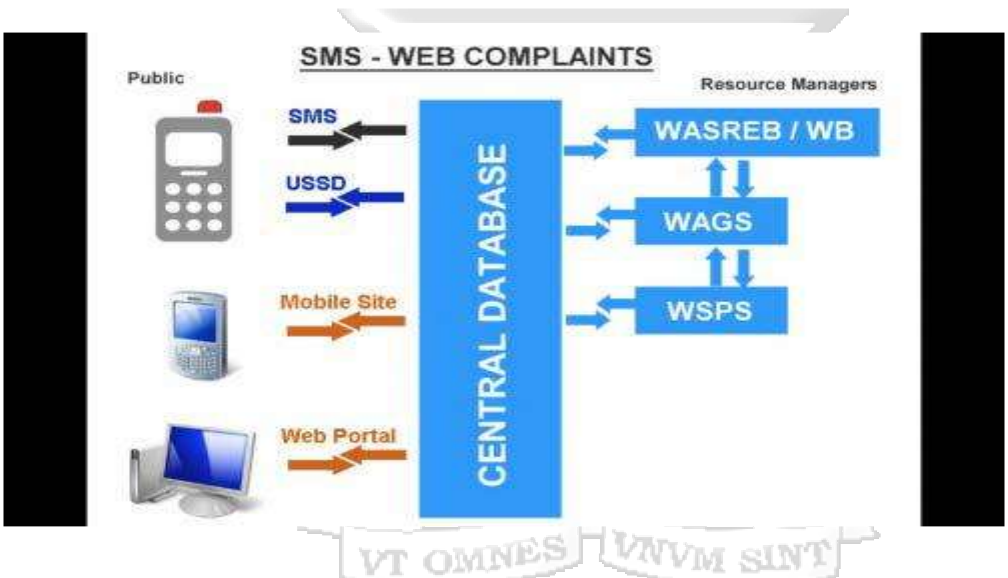

Figure 2. 9: Diagram explaining the proposed structure of Majivoice. (Salim et al., 2014)

2.5.4 MMaji

According to (Moraa et. al, 2013), Mmaji is a mobile application that contains information relating to water availability, price, and quality. The vendors use the USSD- (Unstructured Supplementary Service Data) to create the advertisements that consists of the location, price and purification method, which are stored in a central database. The buyers then obtain this information by sending an (SMS)-Short Message Service with the name of the village they are looking for water, at which point they receive back an SMS listing all available water vendors in that village or the nearest location. The system does guarantee correct information because once a customer retrieves false information, they are able to log the complaint in the system and the database will keep track of complaints and alert future buyers of such negative histories through the use of vendor ratings.

The system has therefore been able to assist the vendors advertise their product, prices and location. It has also assisted the customer's access water at an affordable cost and at the most convenient location. However, this mobile application is not widely used as it is only used in informal settlement.

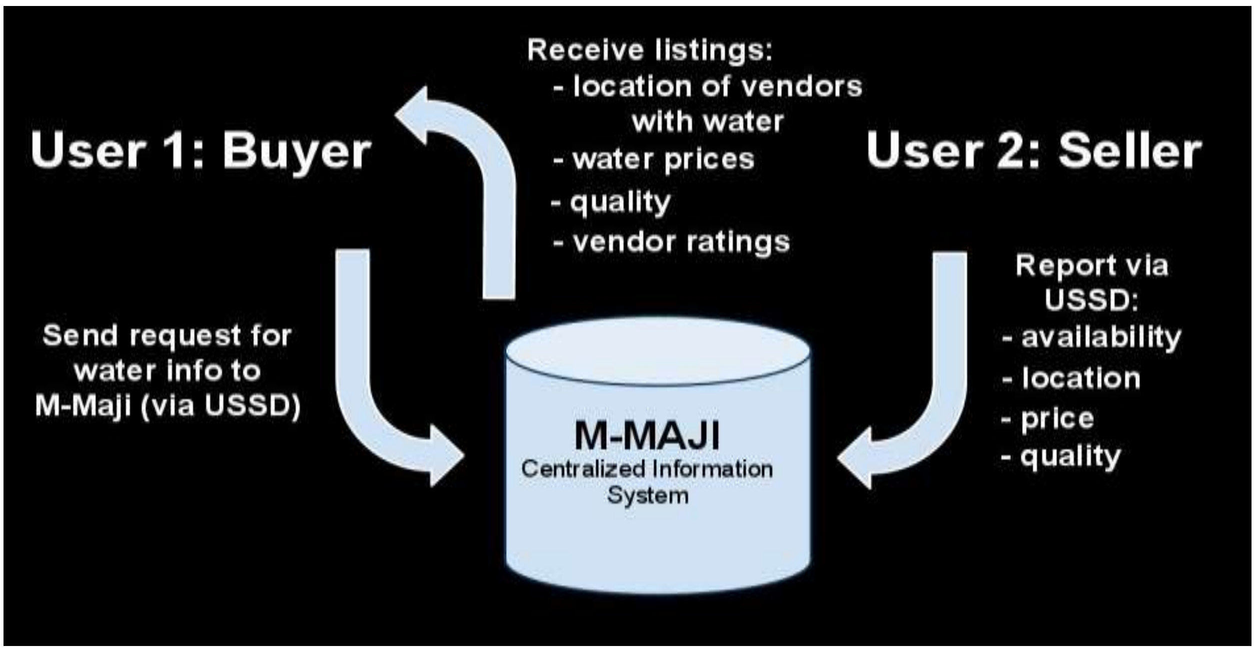

Figure 2. 10: Diagram explaining how mmaji works (Moraa et al., 2013)

2.5.5 Banki ya Maji

Banki ya Maji is a mobile application that allows users to take cognisance of their consumption pattern on a monthly basis. According to (Moraa et al, 2012), the user usually obtains automatically monthly reports of water used. Points are awarded to the users after consumption consumed per month reduces. It is also noted that the applications exist in various forms which can be either be Unstructured Supplementary Service Data-based version or Android version.

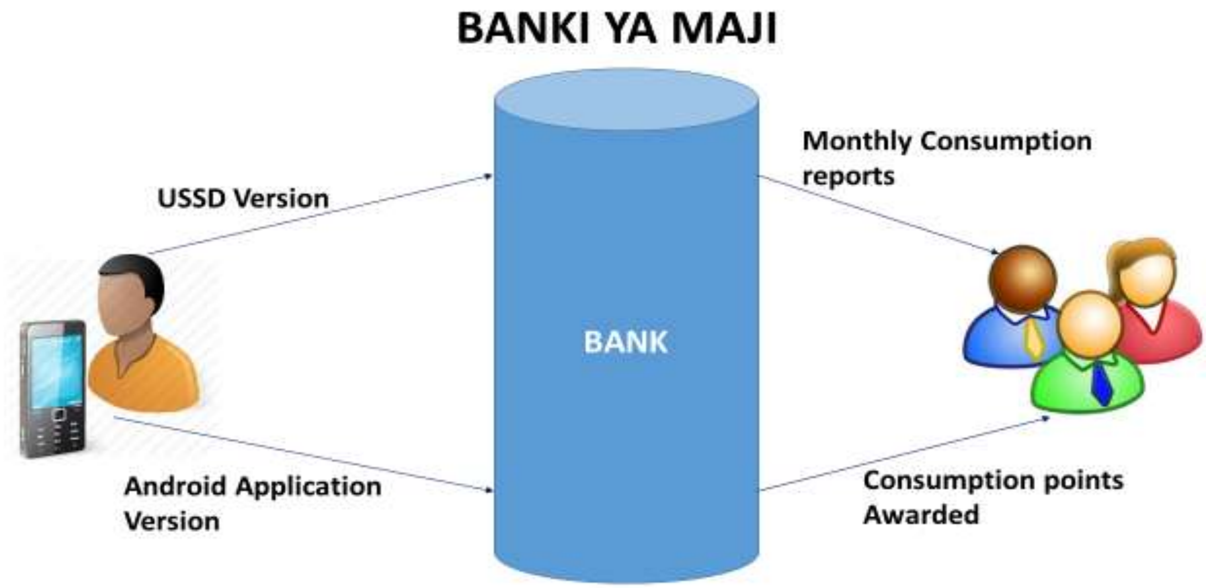

Figure 2. 11: Diagram explaining how Banki ya Maji works

2.5.6 Mobile Water Metering System Based on Hall Effect Sensor

According to (Mwangi C.K , 2016), mobile water metering system based on a hall effect sensor is an application which allows the customers to raise issues pertaining water supply mainly water leakages, vandalism and illegal connections. It also ensures that the users are well informed on matters pertaining water and by actively raising issues, they advise decision makers in water management, monitoring and assessment which in turn culminates to heightened levels of effectiveness, advocacy and transparency. The system makes use of a Hall Effect sensor for automatic water metering and subsequent real time data overload to a cloud server for storage and subsequent analysis.

According to (Mwangi C.K , 2016), the automated meter consists of 3 apparatuses, which are Hall Effect sensor, Arduino board and GSM shield. The sensor will detect the water flow and then pass on the message to Arduino board, which has a program that is able to convert signals into data. The GSM shield will then submit the data to the cloud using the GSM network. The main apparatuses used in the automated water meter are as shown in figure 2.13

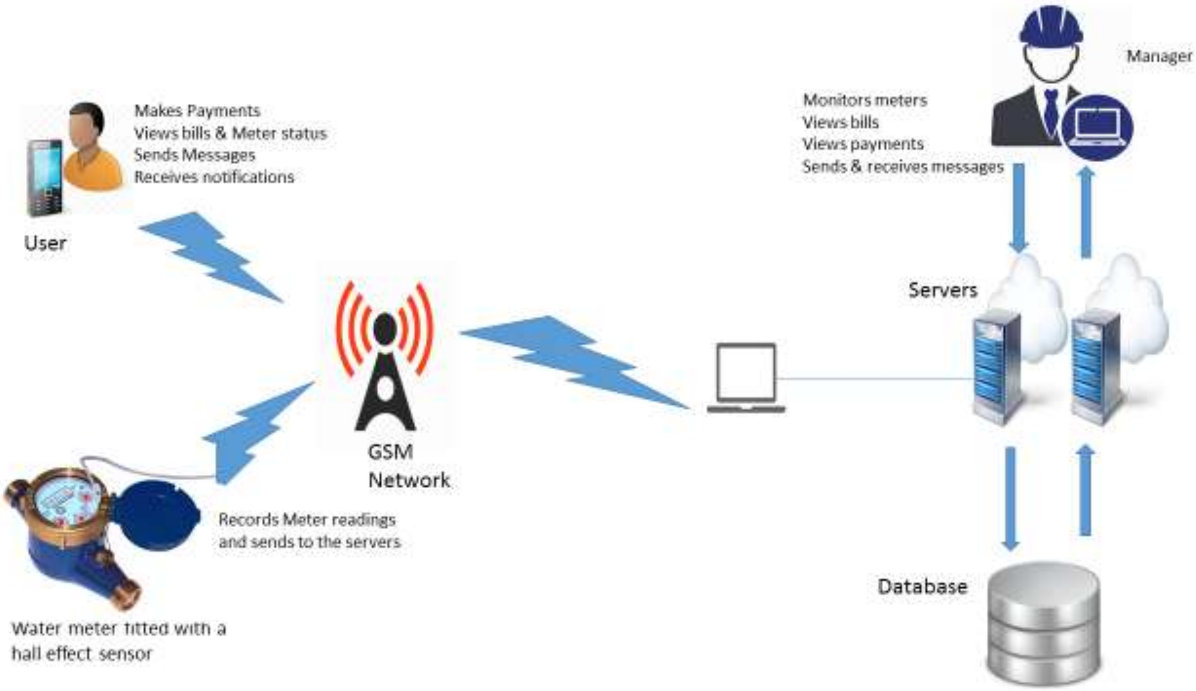

Figure 2. 12: Diagram demonstrating the implementation of mobile water metering system based on a Hall Effect sensor (Mwangi C.K, 2016)

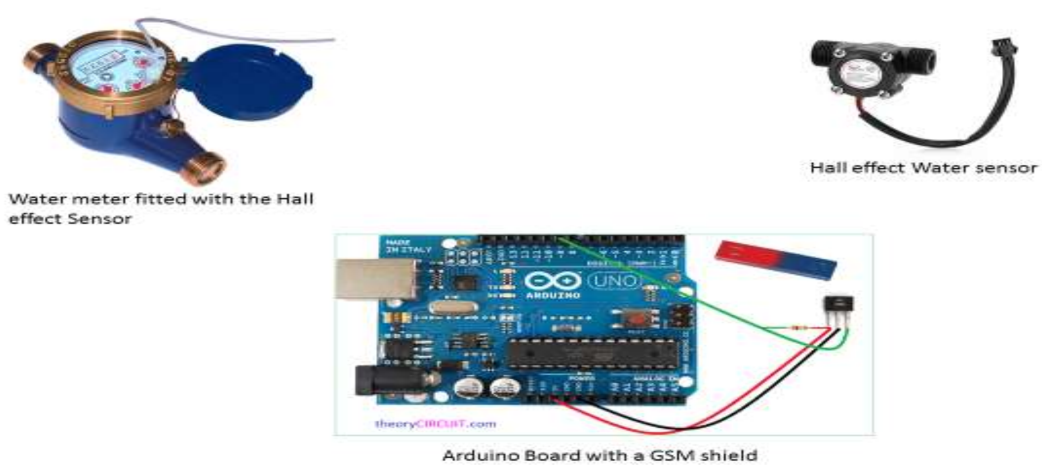

Figure 2. 13: Diagram demonstrating the apparatuses used in the water metering system that uses the Hall Effect sensor

2.6 Smart Meters

According to (Barmet et. al, 2012), smart metering implementations structures are determined by various factors. Commercial loss reduction is a factor which led to smart meter implementation in Italy as it would reduce theft and fraud notes (Barmet et.al, 2012). They further note that in Sweden, the smart meters were implemented out of a requirement by law which advocated for change in invoicing from annual to monthly while in Europe the change was initiated by the change in climatic policy which advocated for increase of energy efficiency that would lead to reduction in the final energy consumption. Barmet et al (2012) further stated that the smart metering implementation was propelled following a shortage in capacity. Demand side management and need for improved security of supply also catapulted smart meter implementation in the United States of America

However, prior to understanding the various implementations of the smart meters it is vital to understand the basic set up.

Figure 2. 14: Typical smart meter water set up (Davidson et al., 2016)

The diagram above shows normal set up of a Smart Water Meter linked to a device that allows continuous electronic reading and display of the water consumption. It negates manually reading of the meter. Once this information is available as an electronic signal, it can be captured, logged and processed like any other signal. Mobile phone technology, wireless modems, the internet and other data distribution technologies make it possible to bring this signal readily to a computer. Readings are captured every 15 min, even though most systems allow for far more frequent readings. Yet, in most cases this is found unnecessary, simply leading to an unnecessary flood of data rather than additional information.

According to (Davidson el al, 2016), data distribution model in a smart meter set up is dictated by the location, the application to be used and how easily it is to install the meter. The tenancy of the installation also plays a role in deciding the set up. They note that after the pulses are generated, recorded and time imprinted, consumption data can then be collected by either someone physically downloading it or by having the information relayed directly to the web, or at least to a central server using wireless modems, dial up links, secure connections via a company's LAN or ripple technology via electrical wires. The diagram in figure 2.15, shows the various ways in which data is transferred form the meter to the users and some of the determining factors that play a role while choosing a set up.

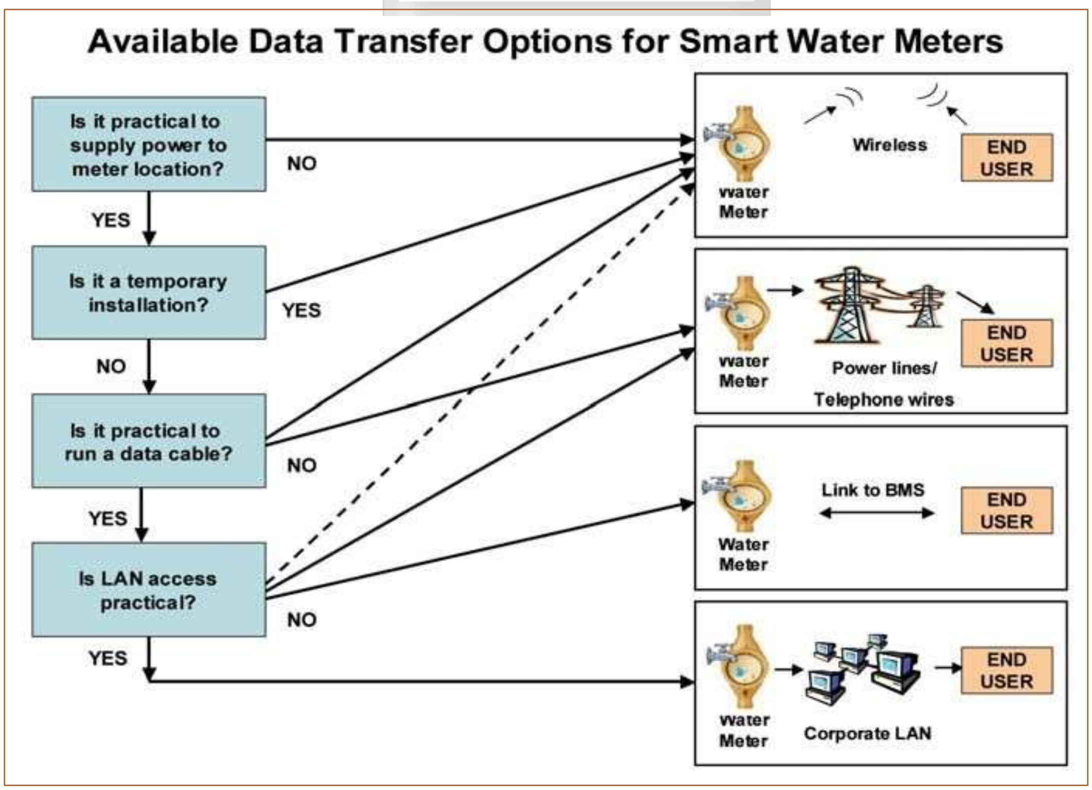

Figure 2. 15: Options to convey smart meter data from the field to a computer. (Davidson et al., 2016)

According to (Betty M, 2016), he notes that due to electronic nature of the smart meters, they are better integrated for data collection and analysis including tamper, empty, burst, and flow direction event recording, flow rate and usage logging, and even temperature.

She also notes that Ultrasonic meters have many advantages over mechanical meters. Despite this fact, they still typically have slightly higher initial cost than mechanical meters. However, focusing at cost saving from installation, tamper, improved accuracy, reduced inventory of meter types, and data collection capabilities, they will most likely yield to a lower total cost of ownership than a mechanical or electro-mechanical meter. The only maintenance needed is the replacement for battery every 15-20 years. Battery lives of ultrasonic meters are equal that of AMR/AMI transmitters used for meter reading and far exceed the recommended testing and replacement lives of intermediate and commercial mechanical water meters.

In a case study by (Davidson et al, 2016), he realized that in a car park which did not have any washing facility, consumed almost 2,000 liters of water per quarter. After four weeks of smart meter monitoring, it was evident that there was a significant leak of 10 L/min which occurred constantly throughout day and night. In addition, every morning at 6am the next door neighbour was drawing some "free" water for illegal irrigation of his landscaping. The outcomes of the study are depicted below.

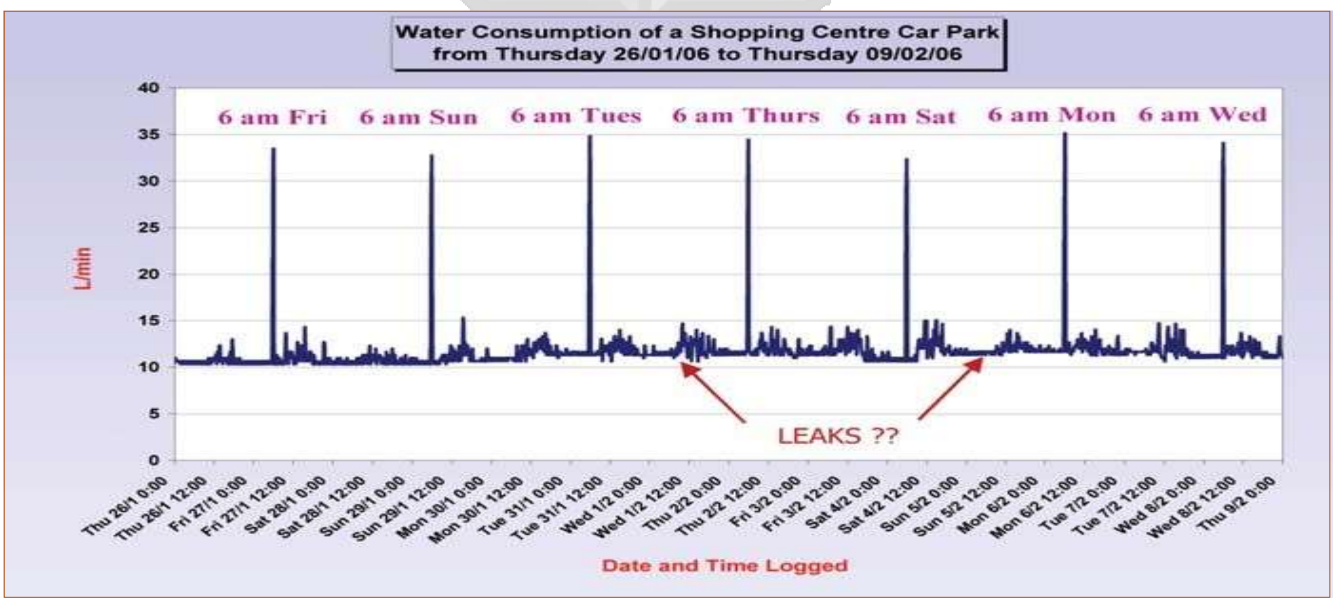

Figure 2. 16: Smart meter report indicating the smart metered water consumption pattern for a car park. (Davidson et al, 2016)

Barmet et al, (2012) states that the foremost costs associated with smart metering are mainly purchasing, installment and operating costs. Despite these investments costs, there are numerous benefits experienced in the energy sector with embracement of the smart metering technology. For instance, there are savings due to increased efficiency or sufficiency and due to load shifting. Reduced metering costs, improved security of supply and reduced non-technical losses are other benefits experienced. They also mention that increased costs and benefits vary with the technical specifications of the smart meters and the infrastructure to be implemented.

Barnet et al, (2012) also note the basic metering systems are less expensive than the advanced metering systems that offer more benefits and wider range of functionalities.

The table below mentions the various benefits enjoyed by the various stakeholders namely distribution network (or system) operators (DSOs), consumers, suppliers and society as a whole.

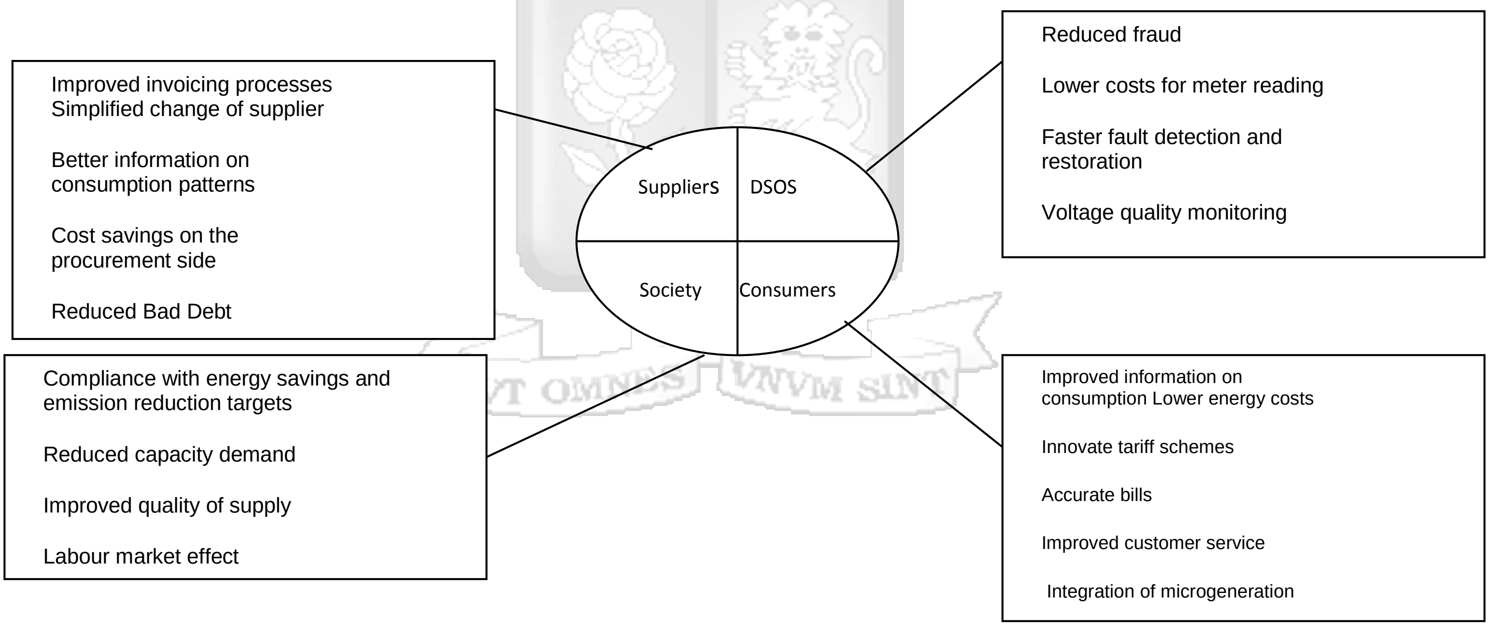

Figure 2. 17: Possible Benefits for Separate Stakeholders (Barmet et al., 2012)

According to (Crainic et al, 2012), there are myths and misinformation behind smart meters and as such they define smart meters as electronic measuring devices used by public utilities for remote reading to measure water consumed and ultimately issue invoices to the water consumers. They note the functions of the smart meters to include automatically capturing, collecting and communicating water used readings on a real time basis or near a real time basis. Figure 2.16

indicates the implementation of a smart meter system. The diagram shows how signals are transmitted and converged at a central point for analysis through current technologies. After data is downloaded through a data logger, computation is done and a customer is informed how much water has been consumed and its value. Processed information is shared not only to the customers but also to the facility managers and utility managers as well.

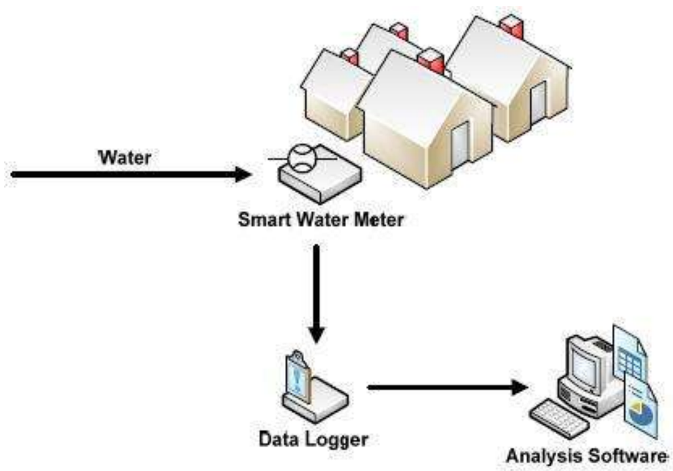

Figure 2. 18: The components of a typical smart water meter set-up for a residential household (Crainic et al., 2012)

According to (Milanpreet et al., 2012), utilities consumers are demanding for accurate measurement, timely data and excellent customer services. Smart metering has been noted as the best solution in achieving this end due to the various communication technologies which are also cost effective. The perfect implementation of the smart meters to achieve this is through the use of Ethernet communication via internet of things notes (Milanpreet et al, 2012).

According to Milanpreet et al., (2012), sensors and actuators are used as a medium of communication between the suppliers and the customers after they are linked through a web page. The automatic meter reading (AMR) is implemented using the general radio packet access and (GPRS) / global system for mobile system (GSM). The automated billing is achieved through GSM and adhoc wireless routing protocol which transmits the readings to each connected home using the radio frequency system. Once the utility office receives the updated readings it sends messages of the bills to the consumer. They noted that to automate the manual process which doesn't require any human intervention, the implemented hybrid automatic meter reading is enabled by using ZigBee and GSM module. The interface application ZigBee collects data while the messages are sent through the GSM module to the utility. Fig 2.17 shows how the information about energy from a smart meter is sent to the utility through ZigBee a software used for data management along with billing of total energy consumed.

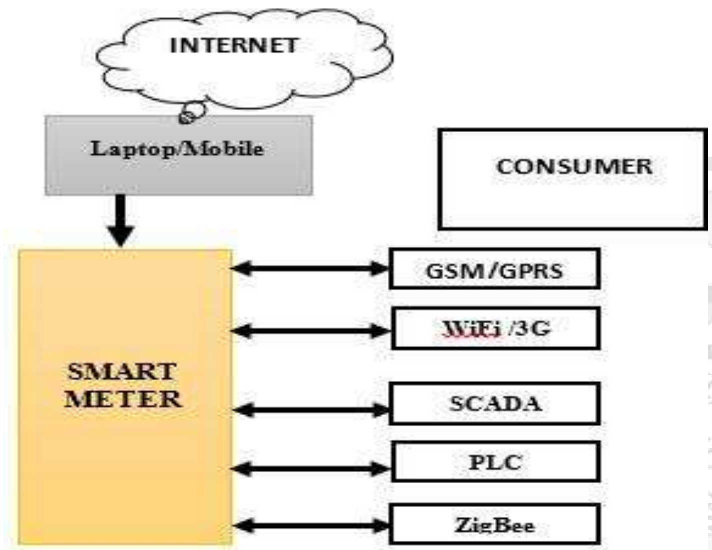

Figure 2. 19: The components of a smart meter based on internet of things (Milanpreet Kaur et.al, 2018)

2.7 Conceptual Framework

A smart phone system prototype that helps the water service providers read the water meters remotely, issues the bills to their customers, monitors, detects any unusual patterns, and informs the customer on the amount of water available in their storage tanks.

The smart meters adopted use the Industrial Wireless Sensor Networks (IWSN) technology known as Wireless Meter Bus (M- Bus). For the M Bus to establish remote meter reading with smart water meters, it is accomplished via a drive-by, walk-by set up or through a fixed network. The technology will support the daily and hourly transmission of readings. Moreover, the capturing of the meter readings is through a data collection unit with an antenna that picks up the signals from the meter through the wireless M-Bus at a radius of 500 to 1000 M. The captured meter readings are then transmitted to the meter data management system via a secure android smartphone connection. To access the smart meter while in stationary mode, it is through defined frequencies of 868MHz and 433MHz with data transmission rate of 32.7kbps. This configuration optimizes the battery life span for data transmitted few times a day. The model similarly allows a configuration for frequent transmission at the speed of 100 kbps.

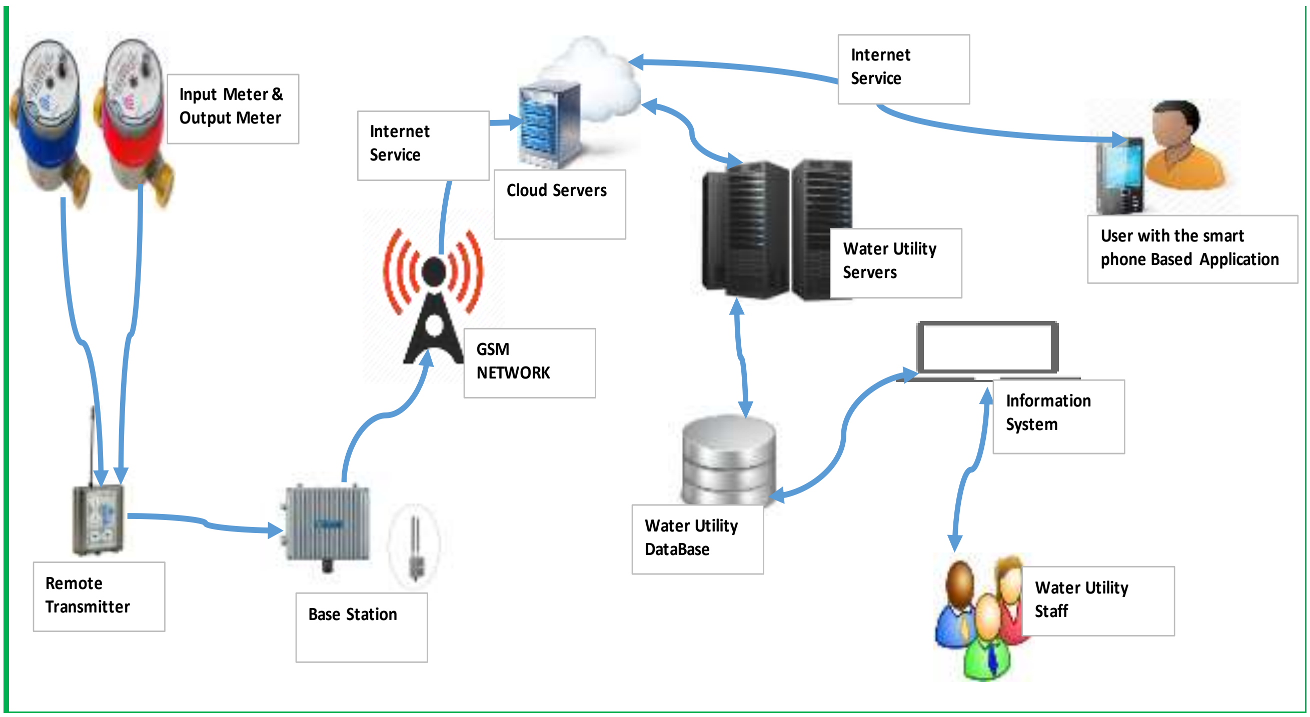

Figure 2. 20: Diagram showing the concept framework for the implementation of the proposed smart meter application for reading smart water meters remotely.

Chapter 3: Research Methodology

3.1 Introduction

This chapter explains the research approach used to study the challenges faced by the utility companies and their customers, location of the study, purpose of study, data collection techniques and data analysis adopted. It also brings out the future expectations of the customers from the water utilities.

This chapter contains details of the various methods used in the study and the tools used to develop the proposed smart meter model. It also explains how the methods have been used and why they have been used in this research. Finally, this chapter will also look at the system development methodology adopted while developing the proposed system.

3.2 Software Development Methodology

According to (Dingsoyr T et. al, 2018), agile software methodology is applicable for huge and small projects and it is able to accomplish projects completion on time and on budget. They note that this methodology is ideal as it can combine the software development methodology and traditional project management. Operators of the system and developers labour closely to achieve the desired goals. It also adopts iterative development and releases multiple versions to the users for verification. It offers a continuous design process that accepts change and tests throughout the development process.

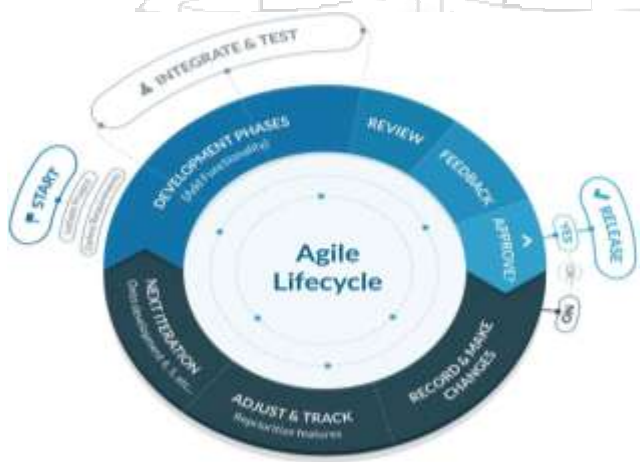

Figure 3. 1: Diagram demonstrating the phases in the Agile Development System Methodology (Burger, 2016)

This methodology contrasts other software development methodologies, as it is more flexible and provides developers with room for error and change. The methodology focuses more on people as it considers inputs from customers and end users. This software development process is more adaptive to change at all stages of development. It involves getting customer feedback on a regular and frequent basis and making necessary adjustments. In this study the agile methodology was used as its approach guaranteed quality assurance in ensuring that there was right functionality, reliability, user friendliness, performance and maintainability of the proposed system

3.2.1 System Design

In system design, systems architecture, system modules, data and components interaction are to relate in a particular manner. Unified Modelling Language (UML), which is a standard diagramming notation, has been used in this study in designing and detailing the systems blue prints. This therefore provided a pictorial notation that is easy to create, envision and to lay down the smart water meter based system.

3.2.2 System Architecture

System architecture as a conceptual model that defined the organization and behaviour of a system was used in the study. The proposed system used the client server architecture which encompassed the android mobile application, smart water meters and a web application back end. The server comprising of the system application is hosted within the water utilities premises.

The two water meters installed in the customer's residence were used to capture the meter readings at the water inlet and at the outlet. The meters installed transmitted their data to the water utility servers through wireless communication network and a monitoring system. The wireless communication was aided by a remote transmitter connected through wires and then the remote transmitters sent the captured data to the base station through wireless m-bus communication.

The base station thereafter transmitted the received data to the server and the monitoring system via the internet on a timely basis while the mobile meter reading application was designed to inform the customer of the quantity of the water stored, bill charged and meter status.

The staff of the water utilities were able to monitor and make decisions as they could remotely view usage patterns, meter functionality and payments through the web application.

The mobile application was developed in Android, the web application was developed using Hyper Text Preprocessor (PHP) and Hyper Text Markup Language (HTML). The data captured was stored in MySQL database.

3.2.3 Use Case Model

According to (Rumbaugh et al, 2012), use cases define a user's overall access and role in the system and the scope of a user's action. The Uses Cases outlines functionality of a system and represents the interaction of the system and the actors in essence they are functions of systems functionality and environment.

Fowler K and Scott K, (1999) have also defined Use Case as a set of scenarios tied together by a common user goal.

In this study therefore Use Cases were used to elicit the system requirements as well as predict the environment in the proposed system. The amalgamation of all the requirements was done and a graphic representation was formulated which made it easy to comprehend and determine all the requirements and the entire system model.

3.2.4 System Sequence Diagram

System sequence diagram showed the interaction between the system user, the system and the messages passed on as they interact. It is noted that the sequence diagrams are as a result of Use Cases. In this study therefore UML language was used to design the system sequence diagrams which showed how the collaboration of events generated by the system user, system feedback and the sequence of events emanating from them. This therefore made it possible to isolate and demonstrate the operations that the external actor's requests from the system and also enabled the system behaviour be well comprehended.

3.2.5 Sequence Diagram

Sequence diagram demonstrated how a system user, an object and a component within a system, interacted for a particular scenario of a single use case. It is a fast and easily created artifact that illustrated the input and output related to the systems. UML contains notation in the form of sequence diagrams to illustrate events from external actors in the system.

In this study, the sequence diagrams were used to portray the movement of the messages between instances of classes.

3.2.6 Design Class Diagram

Class diagram described the type of objects in the system and the various kinds of static relationships that existed among them. The class diagrams also showed the attributes of a class and the constraints that applied to the way the objects are connected. In the development of the mobile application process, the classes were developed using the UML language to benefit the researcher while implementing and enabling one to have a clear view of the system concepts and specifications.

3.2.7 Entity Relationship Diagram

Entity Relationship Diagram (ERD) as a data model was used to outline and narrate the process, information or data of a business domain in an abstract way that was to be implemented in the database. Relationships and designs within the database were communicated once the ERD was in place. In this study, the ERD was developed using the UML language to show the database relationships and the design of the proposed system.

3.2.8 System Testing

System testing was used to affirm that the developed system met the set expectations. In this study, unit testing was done during the system implementation. The system modules were subjected to their respective environments through running codes on the mobile device and on the web browser respectively, to ascertain the intended functionality attainment. After the subjecting all the modules through the tests and ascertaining that each was working as required, the final test was done on the entire program and it was confirmed that all integrated components worked as required.

3.3 Research Design

This study seeked to determine the information requirements for the meter reading application, investigation of the problems with the current meters used, as well as propose a mobile application model. To achieve this, the study has adopted applied research.

To determine the type of information requirements for meter reading application, a structured questionnaire was developed and distributed to the various stakeholders in Nairobi County. To obtain an understanding of the problem with the current water meters, a qualitative research method has been used. Personal interviews were used to aid in gathering facts about the meters as well as information relevant to meter reading applications.

Qualitative research method was used in collecting statistical data from the target population. In addition, Strathmore University's library E-resources, databases of conferences, journals, PhD thesis, technical reports and documents were used.

3.3.1 Location of the Study

This study targeted the residents of Nairobi County who live in Bururu and Westlands estates. The estates have approximately 8,600 and 9,600. As seen in the maps in figure 3.1 and figure 3.2, spatial view of the selected estates.

Figure 3. 2: Diagram showing the spatial distribution of water consumers in Buruburu estate in Nairobi County

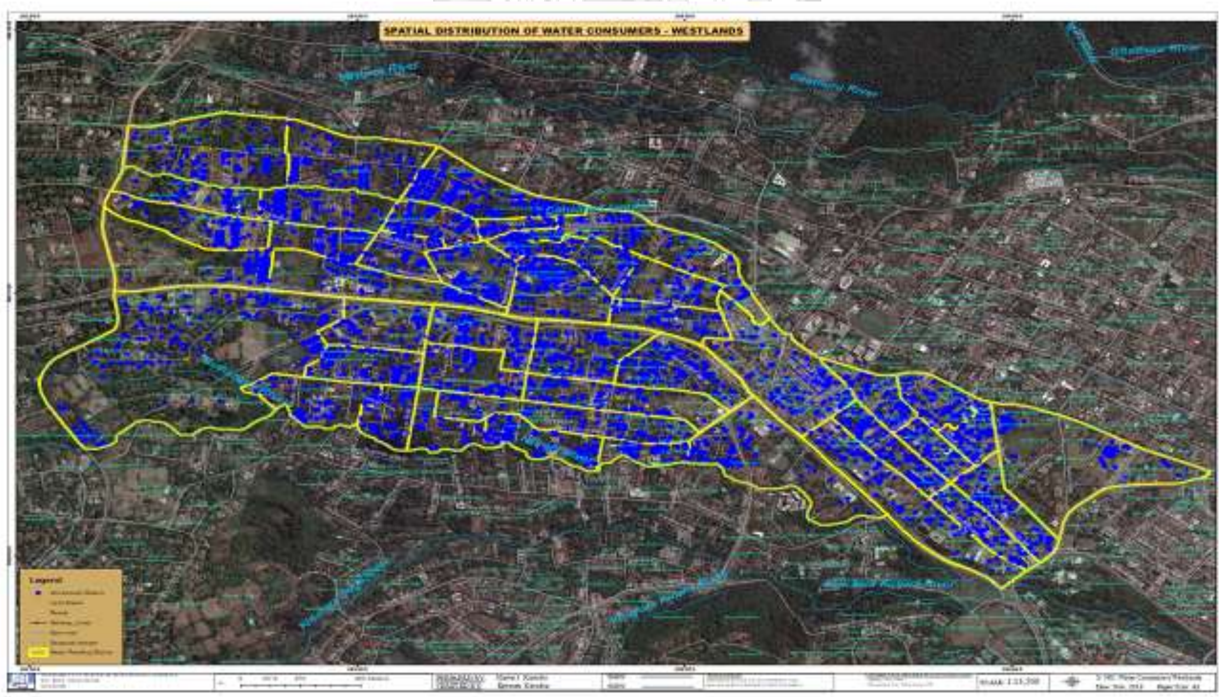

Figure 3. 3: Diagram showing the spatial distribution of water consumers in Westland's estate in Nairobi County

3.3.2 Target Population

According to (Babie, 1998), a population is defined as including all people or items with the characteristic which one is interested to understand. Due to the resources of constraints and time, the goal becomes finding a representative sample of the population. According to (Cooper & Schindler, 2008) they noted that target population does refer to the entire group of individuals or objects from which the researcher desires to make inferences. The research therefore focused on a population which involved adults of both gender. The preferred target population was that of the residents of Nairobi County who had mobile phones and are connected to a water supply connection. This assisted in determining the requirements before the system development and was also used while testing the suitability of the proposed system.

3.3.3 Sampling Technique and Sample size

Cooper & Schindler, (2008), noted that a sample is "a smaller (but hopefully representative) collection of units from a population". (Kolar, 2004) also notes that that probability sampling is also known as random sampling or chance sampling. He further notes that under this sampling design, every item of the universe has a chance of inclusion in the sample. This research therefore has embraced the probabilistic sampling technique as it has provided an equal chance to a resident in the target population be included in the sample. Further purposive sampling has been used as it entails a deliberate choice of a respondent based on the quality of the informant's responses (Creswell, 2004).

According to (United Nations Population Fund, 2013), stated that the Nairobi's population was estimated to surpass 3 million people by the year 2013. The report noted that only 40% of the 3 million people were to have direct access to piped water while the other 60% relied on boreholes and private vendors. As a result, the number of people living in Nairobi and have access to water had risen to above 1.2 million by the year 2013.

The (Population Reference Bureau, 2011), stated that there were about 1,710,000 adults in Nairobi. Further according to (Salim et al, 2014), they noted that there were estimated 16.64% users of Android phones. There is therefore an estimated number of above 285,000 people in Nairobi who have smart phones.

It therefore follows that the probable number of residents with water connection are above 162,450 people. Nairobi County has approximately 221,000 as at August 2018 customers connected with water supply. Each area had a customer's population with water connections of approximately 8,600 and 9,600 respectively.

The sampling formula used to aid in the random sampling applicable in this research is as below

$$n = \frac{z^2 * p * q}{C^2}$$

Equation: 3.1 Random Sampling *(Rusli, 2006)*

Where:

n = sample size.

z = z value (e.g. 1.96 for 95% confidence level).

p = sample proportion of successes, expressed as decimal.

q = 1-p

c = confidence interval, expressed as decimal.

Table 3. 1 Sample population at 95% Confidence Level

Population	Confidence Level of 95%			
Confidence Interval	3%	5%	7%	10%
222,100	1062	383	196	96

3.4 Data Collection Procedure

Research tools are for the sole purpose of collecting data from research subjects on a topic of focus. An ideal instrument on the other hand is one, which leads to measures that are objective, accurate, sensitive, efficient and relevant. In this study, the following tools have been used.

3.4.1 Interviews

Interviews were carried out as a research instrument for purpose of collecting data from residents in Nairobi County and the water utility workers. The process was carried out by having various respondents answer questions put to them while the interviewer noted their responses. Users were able to raise their expectation on how they would benefit from the proposed system at the same time comparing their past experience with the service rendered earlier.

3.4.2 Prototyping

Prototyping involved sharing out the modules of the developed application to the masses with an aim of obtaining constructive criticism especially on the satisfaction and inclusion of desired functionalities. This process was necessary for the purposes of refining the application and by users assisting in identification of missing functionalities.

During the development processes of the proposed smart meter mobile application, the study involved work mates and some classmates who offered invaluable feedback that went towards improving the application.

3.4.3 Questionnaires

Questionnaires were presented to the respondents with the intention of collecting accurate information of interest once the respondents submit their feedback. The questionnaires were used in this study as they were easy to administer, cost effective to use, especially when submitted to many people within a short period. The questionnaires were issued to respondents physically while the soft copies were emailed to respondents. The questionnaires were self-administered but had the mobile contacts and email for the respondents to seek any clarification with ease. The questionnaires used are appended as appendix a and b.

3.4.4 Documents reviews

Documents have been reviewed in this research which involved looking at related study in the mobile phones and smart meter application which have been developed so as to offer constructive criticism of the existing implementations and broaden knowledge on how the proposed solution will be successfully implemented.

3.5 Data Analysis and Presentation

Information received from participants was presented in numerical form through statistical data used in quantitative research methods. In the study, accurate findings were done following application of quantitative research method and it yielded accurate results. Pie charts and bar graphs were used in this research to represent the findings after the collected data and analyzed through Microsoft Office Excel 2013. The response rate was calculated using the formula in below.

$$\text{Response rate} = \frac{\text{Total number of respondents}}{\text{Sample size selected}} * 100$$

Equation: 3.2 Response rate Formula

3.6 Validity

Validity determines whether the research truly measures that which it is intended to measure and how truthful the results are. According to (Cohen and Manion, 2012), they state that validity is the degree to which the instrument measures what it is supposed to be measured. Validity of the research is therefore determined through asking a series of questions relevant to the study. It ensures that the researcher does not collect the wrong data and that the research questions yielded valid results. In this study, the selection of sample size, research type, sampling strategy and research instruments guaranteed the validity of the research.

3.7 Reliability

Reliability is attained when similar questions are asked to various respondents and the outcome is the same. However according to (Croker et al., 2011), they note that reliability of the research is affected when answers to similar questions are not the same. They note that it behooves the researcher to ensure a certain level of accuracy is attained while responding to similar questions or they should ensure there is a minimal difference especially in quantitative researches.

In this research, reliability was guaranteed by having a series of similar questions asked but rephrased to test if similar results were obtained. Reliability was also realized through the approval by the academic supervisor of the entire process of data collection and use of other related fruitful researches done earlier.

3.8 Ethical Consideration

During the period of this study, all participants were briefed the purpose of the study. Further according to (Creswell, 2003), while researchers expect to collect data they also need to respect the participants and the places where they obtain data. In this regard, permission was sought allowing for data collection prior to the implementation of all the research designs and methodologies. This therefore shunned the possibility of ethical and illegal issues arising therefore confirming validity of this research.

During the study, due consideration was taken to harmful information disclosed during data collection exercise while personal information was handled in confidence.

In this study, all information obtained during this research has been stored privately to avoid any infringement of privacy for the participants while the material used in the research has been referenced as required.

Chapter 4: Requirements Analysis

4.1 Introduction

This chapter concentrates on data analysis and its presentation as collected during the research.

4.2 Data Analysis

The research instruments adopted did target the people living in Westland's and Buruburu areas and staff of Nairobi county water utility. Questionnaires handed out and interviews done to the target groups were aimed at investigating the problems with the current water meters and whether they were able to serve the customers adequately. The research also aimed at collecting the public's view on the proposed application development and how it could influence the water consumption patterns based on the features enumerated. The researcher sought to know the willingness of the users to adopt the new system. A total of 320 respondents participated out of 383 yielding to a response rate of 83%. This therefore informed the researcher on the validity of the project as responses obtained below aided in further progress.

Appendix B was the questionnaire used to collect data and the following data was obtained.

4.3 User Responses

4.3.1 Mobile Phones

Mobile ownership was key to success of the study. The study enquired on the phones commonly used by the target population and which operating systems they were running on. It was also important to determine that whether the target population owned any phone. The study revealed as shown in charts 4.2 and 4.1 respectively that 91% of the participants owned the phones while 88% of the phones were Android phones. This outcome aided the study in verifying that the development in Android application would ensure there was compatibility with the proposed model with most customers. The outcome enabled the study consider developing an application which was also compatible with other mobile application as from the study 12 % did not have android mobile phones but were still water utility customers.

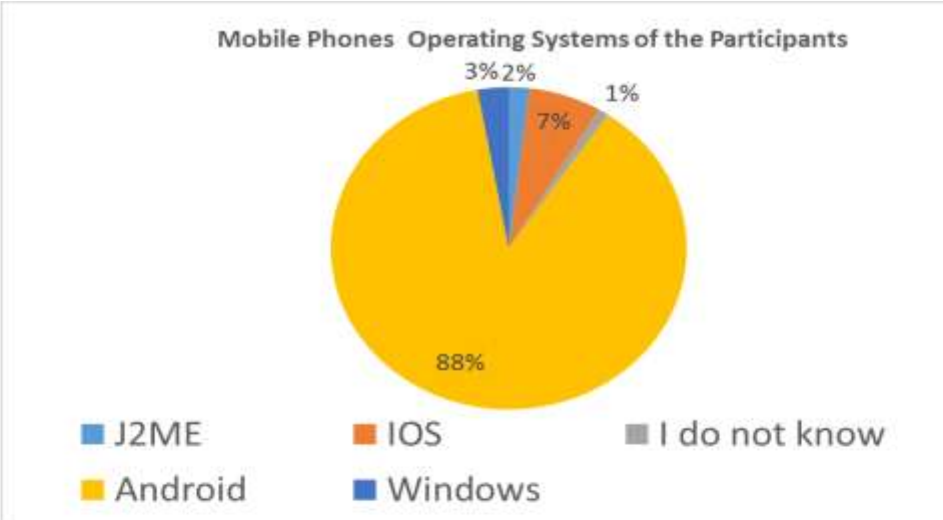

Figure 4. 1: Operating systems Statistics

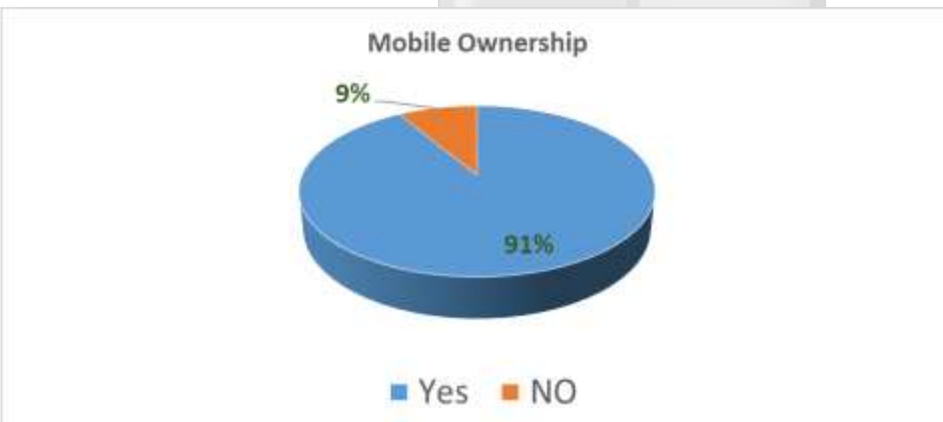

Figure 4. 2: Mobile Phones ownership statistics

4.3.2 Information Adequacy

The study aimed at determining whether the information sent to the respondents, relating to their consumption patterns was enough. A higher percentage of the respondents indicated that the information sent to them largely informed on water payments and bills charged only. The statistics therefore informed the study of the need for more information that would increase the customer interaction. Information about consumption patterns, expected rationing programs and generate sensitization on use of water would add value to the customer.

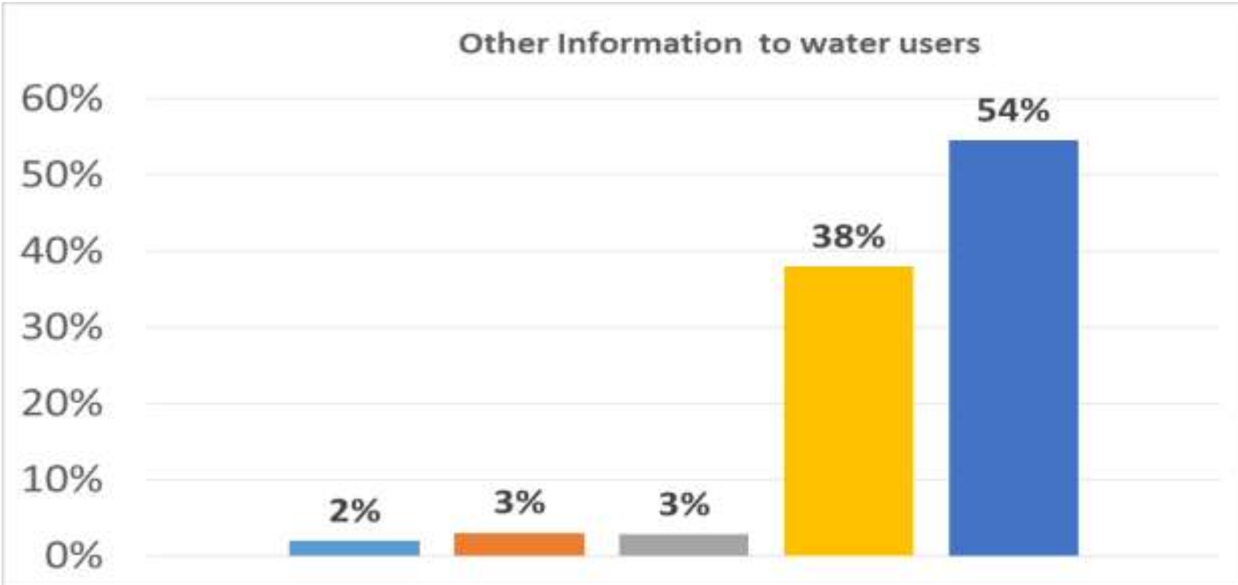

Figure 4. 3: Adequacy of Information sent to customer’s statistics

4.3.3 Meter Reading Challenges

During the study, the challenges emanating from the current water meter used were important, as their elimination would determine the value addition of the proposed system. In the study, therefore it was evident that of the current water meters available 67% were not accessible as they are behind the perimeter wall. This therefore means that resources deployed by the water utility company do not have optimal returns as seen in chat 4.3. The study also revealed that the greatest challenge rated at 41 % and 37% adding up to 78 % of the customers never in their homes to provide access to their water meters as seen in chart 4.4.

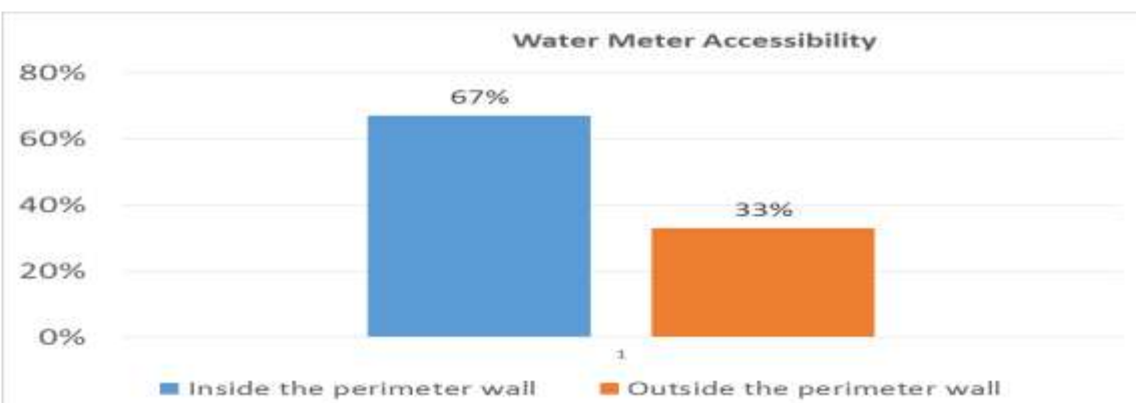

Figure 4. 4: Water Meter Accessibility statistics

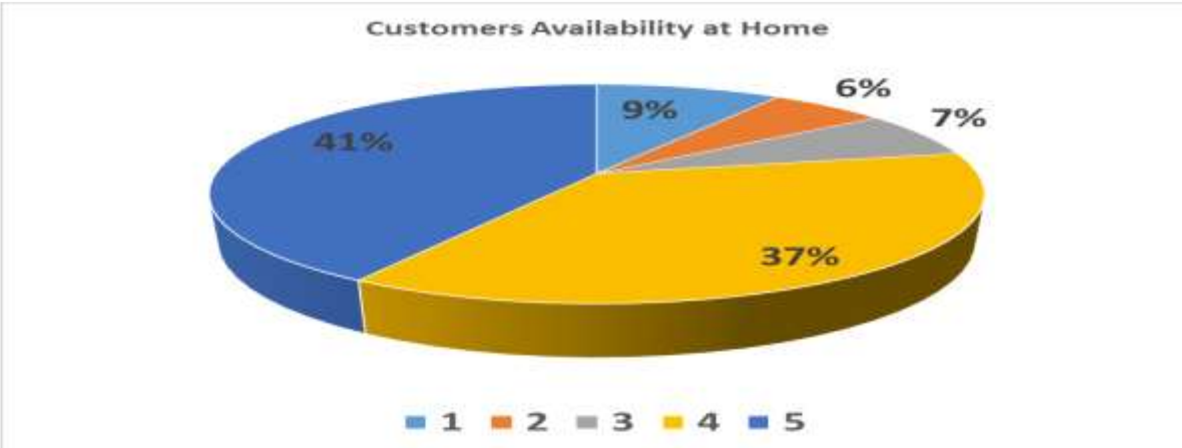

Figure 4. 5: Customers Availability in their homes statistics

4.3.4 Level of Education

The level of education was important to qualify the information obtained during the research. The proposed prototype was a smart phone based one and it was critical that the target population be able to engage in the research knew how to use the phones. The respondents upon being asked their level of education they ascertained that 13% were of primary education while 57% and 37% were above secondary education. This therefore high percentage of individuals above secondary education represented a very good opportunity of the responses from the questionnaire.

Figure 4. 6: The statistics for level of Education of the target population.

4.3.5 Validity of the Proposed System

To establish the soundness of the research, the study revealed that 90% of the respondents strongly agreed that the application was important to the residents as seen in chart 4.7. One of the features proposed in the new system, was for the customer to be able to ascertain the water storage level of the tank at any given time automatically. This was found to be necessary to the users as shown in chart 4.8. Most of the respondents noted that they only had a manual way of confirming the water levels in their storage tanks while only 3% never seemed to be know.

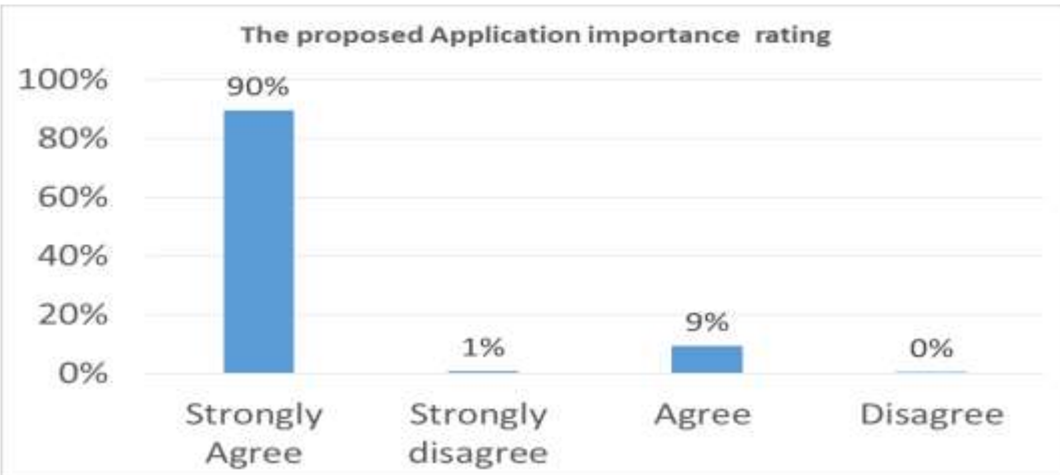

Figure 4. 7: The statistics as rated on the importance of the proposed application.

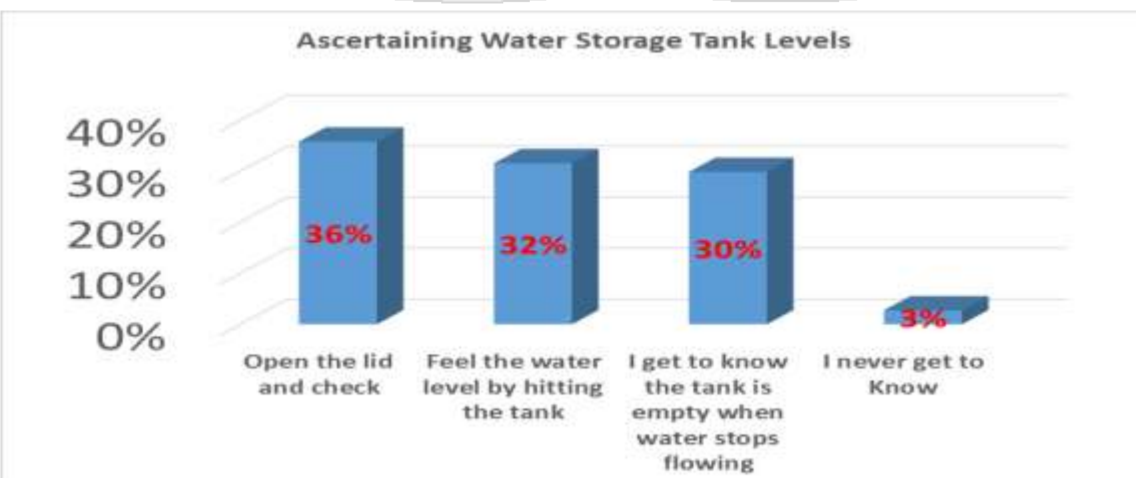

Figure 4. 8: The statistics as rated on the need to confirm water tank levels.

The respondent also thought that if the system was to be implemented, it would reduce corruption. It would most likely regulate water wastage as shown in the chart 4.9 below, as the respondents who strongly agreed on reduction of corruption and influence on water use were 87 and 81% respectively.

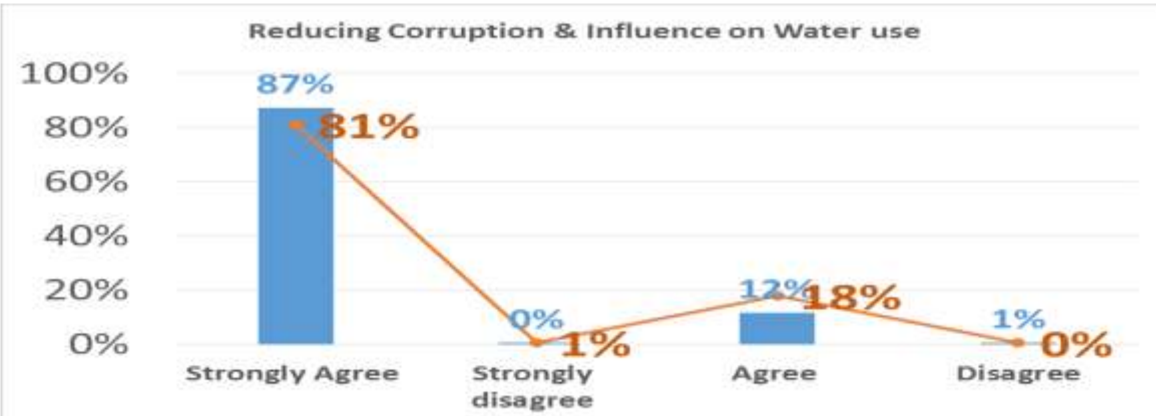

Figure 4. 9: The statistics as rated on the reducing corruption and influencing on water use.

In the study, corruption stemmed from manual meter reading which allowed frequent customer and water utility staffs interactions. However in the proposed model, water meters will be read remotely thus minimizing the interactions. Due to the smart meters architecture, it is not easy to tamper with the smart meter as it is with the mechanical meter. This would also forestall corruption.

It was evident from the study that with more information relating to status of the water available in the storage tanks, it lead to reduced wastage. To the customers therefore, information was useful, for with awareness of the consumption patterns, it awakened focus on the adequacy of water storage levels in their premises. It would therefore either make them see the need to increase the storage level or otherwise.

Chapter 5: System Analysis & Design

5.1 Introduction

This chapter examines the functional and non-functional requirements arrived at after scrutinizing the user's requirements observed during the survey.Further, the chapter will explain the System Analysis and System Design done using the Unified Modelling Language (UML). This will include the Use Case Diagrams, System Sequence Diagrams, Context and Data Flow Diagrams, Partial Domain Models, Class and Entity Relationship Diagrams

5.2 Requirements Analysis

According to (Chung & Do Prado Leite, 2009), a systems utility is determined by the functionality and non-functional characteristics. They noted that just as anything else quality of systems is fundamental and should be considered while developing quality software. In this research, the user's requirements were captured alongside the primary study objectives, and they have bee outlined as below as functional and non-functional requirements.

5.2.1 Functional Requirements

Based on the desired actions to be implemented in a system, the functional requirements were coined. These therefore included the various processes and abilities within the system which were found to be in tandem with the objectives of the study. They are as follows:

a) User Registration: - This function is necessary for any consumer, as they must undertake this process of registration before commencing to use the mobile application.

b) Log in & Log Out: - The mobile users and the web application users need to be logged in to use the applications and logged out so as to terminate use of the application.

c) Monitor water meter: - This function will allow the water utility manager to analyze the behaviour of the water meter

d) Sending a message: - This function is necessary to allow the customer send the message to the water utility and the water utility will send customers messages too.

e) The Customers should be able to manage their own profile and should also be able to check the information relating to the bills and water storage in the tanks.

f) Sending notification – This functionality allows the water utility send information to the customers

g) The system should generate reports when required.

5.2.2 Non-functional Requirements

"Soft is harder to deal with the hard." [Anonymous]. It has also been noted by (L. Chung & J.C.S. Do Prado Leite, 2009) that it's not sufficient to design and test applications without conceptualizing the real- world problems which are more non-functional as opposed to being functional.

In this research the non - functional requirements were elicited as they enabled the user to evaluate the operations of the system. These included the following: -

a) Availability – This ensures that the system can be used at all times. This is through ensuring there is internet connection when needed.

b) Accessibility – This ensures that that the system is designed to work for all people, whatever their hardware, software, language, location, or ability. This ensures that people with a diverse range of hearing, movement, sight, and cognitive ability can use the system.

c) User Credentials- This will allow the user be able to access the system. Both the administrators and users need these to log into the system.

d) Feedback- This is necessary as it ensures that adequate feedback once obtained it facilitates the knowledge transfer of working on the application.

e) Performance and Reliability– This ensures that the systems is able to be used optimally to executing the various operations efficiently

f) The system should be customizable so as to suit the user's requirements which keep changing.

g) The system should be able to run on any mobile device which use android based operating system.

5.2.3 Domain Requirements

In this study, the domain requirements identified were as follows

a) Android device. Versions preferred is Android 5.0 to more recent.

b) Smart phone Meter reading Application enable phone

c) Windows 7 operating system

d) Central Processing Unit – CPU core 2 Duo 2.4 GHz

e) Memory 2GB RAM

f) 1 GB free Hard Disk Space.

5.3 System Architecture

In this study, the modelling of the system was done based on the desired systems functionalities and a Client Server Architecture was adopted. According to (Kruchen and Stafford, 2012) a client server architecture consists of two sides, Client Side and the Servers side.The system is composed of two smart meters which convert the measured inflow and out flow into electrical signals. The smart meters send their signal to a data collection unit through the wireless M- Bus technology. After a handshake was established, the smart meters transmit the readings to the meter reading application through a secure android mobile connection.

The data is transmitted through intranet to the water utility server and finally to the database for further processing. Data from the database is processed by the Water utilities billing system and then transmitted back to the servers where it's disseminated to other users. The Android mobile application interconnects to the server and ensure its functionalities are achieved while the web application was developed using (Hyper Text Processor) PHP and (Hypertext Markup Language) HTML. The system data was stored in a MySQL database.

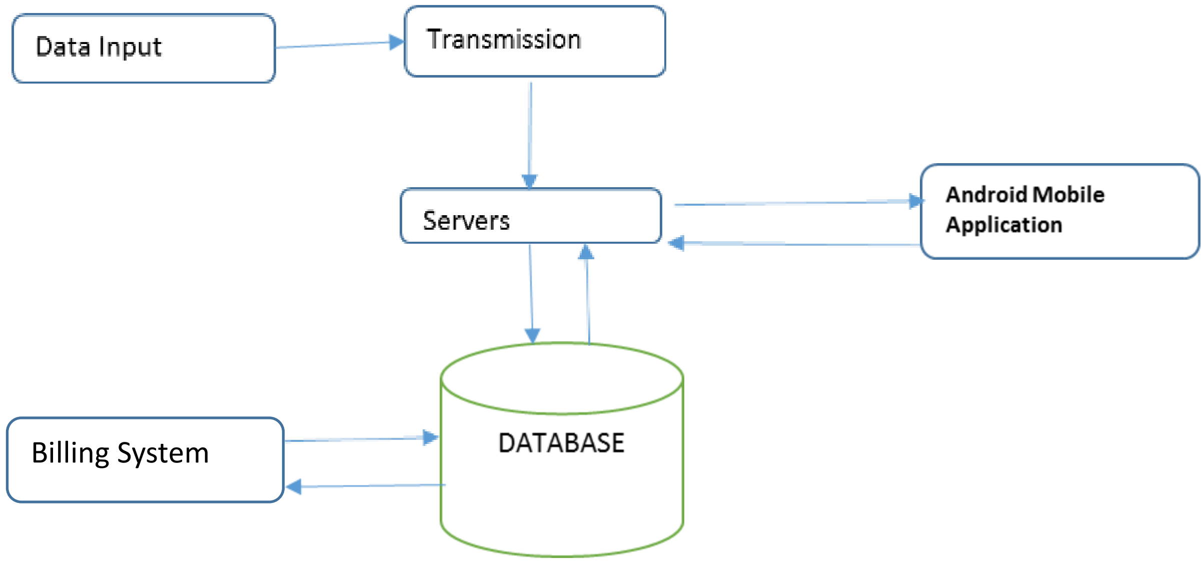

Figure 5. 1: System Architecture

5.4 System Design

System design involves us of Modelling Language (UML) diagrams. These include the Use Case Diagrams, System Sequence Diagrams, Context and Data Flow Diagrams, Partial Domain Models, Class and Entity Relationship Diagrams. All these were used in various stages of the design process to document, visualize, and specify the functionalities of the system.

5.4.1 Use Case Model

A Use case is a text-based method used to describe complex process through development of data models. Use case diagrams partition the system into set of actors and use cases. In this research to be able to place appropriately the various actors for the new system Use Case were used. The diagrams also assisted in representing the systems behaviour as seen in figure 5.2.

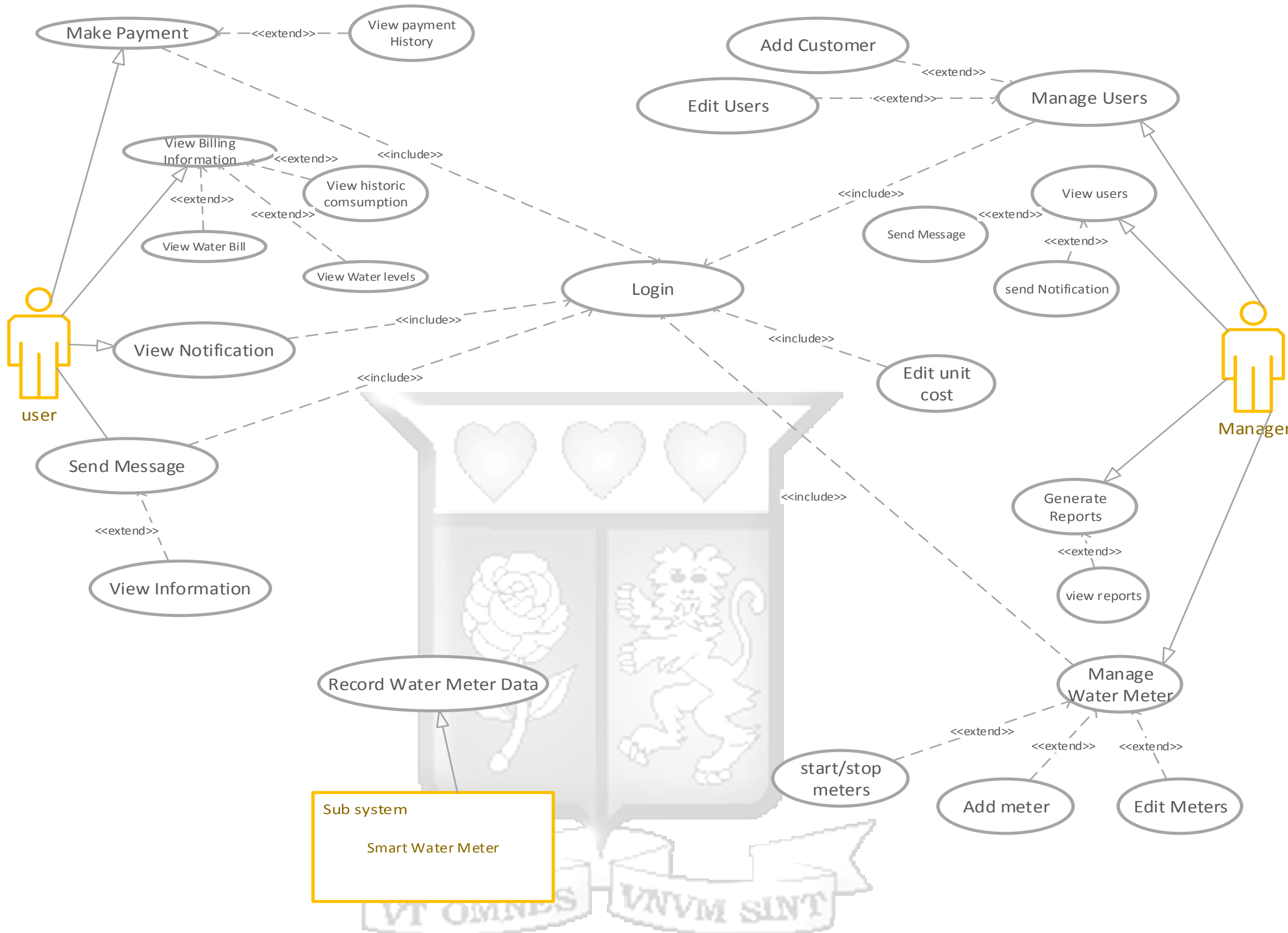

Figure 5. 2: Use case Diagram for the smart phone based system

5.4.2 Use Case Descriptions

5.4.2.1 Adding Customers

This is a use case detailing the process of a water utility manager adds customer into the system. The scenario is depicted in Table 5.1

Table 5. 1 Adding a customer use case description

Use Case Name	Add Customer
Brief Description	Manager adds a new water customer into the system
Source	Manager
Major Inputs	Water Consumer Details
Preconditions	1. Manager must be logged into the system 2. A customer must be above 18 years 3. A customer must not have existed before in the system.
Post Conditions	1. New customer exists in the system
Flow of Events	1. System presents the manager with a list of options to choose from 2. Manager selects "add a new member" option 3. Water consumer presents personal data 4. Manager enters details into the system 5. Manager submits the details into the system 6. New member is added into the system 7. Manager receives registration successful message

5.4.2.2 Generate Reports

This is a use case detailing the process of a water utility manager generates periodic reports from the system. The reports generated include information relating to a water meter, the customer, monthly bills and customer's consumption patterns. This scenario is depicted in Table 5.2

Table 5. 2: Generating report use case description

Use Case Name	Generate Report
Brief Description	Manager generates report from the system
Source	Manager
Major Inputs	Water Consumer Details and period
Preconditions	1. Manager must be logged into the system

	2. Manager must select the type of report
Post Conditions	1. A report is generated
Flow of Events	1. System presents the manager with a list of options to choose from 2. Manager selects “Generate report” option 3. Manager submits the details into the system 4. Manager receives an option to save or view the report.

5.4.2.3 View Billing Information

This is a use case detailing the process a user undergoes while viewing the billing information from the system. The scenario is depicted in Table 5.3

Table 5. 3: Viewing billing information use case description

Use Case Name	View Billing Information
Brief Description	User generates report from the system
Source	User
Major Inputs	Water Consumer Account.
Preconditions	1. User must be logged into the system 2. User must select the type of report required
Post Conditions	1. A report is generated
Flow of Events	1. System presents the user with a list of options to choose from 2. User selects “Generate report” option 3. User submits the details into the system 4. User receives an option to save or view the report.

5.4.3 Data Flow Diagram

In this research to understand how data would flow between the different systems components, a Data Flow Diagram (DFD) was the main tool adopted as shown in the figure 5.3.

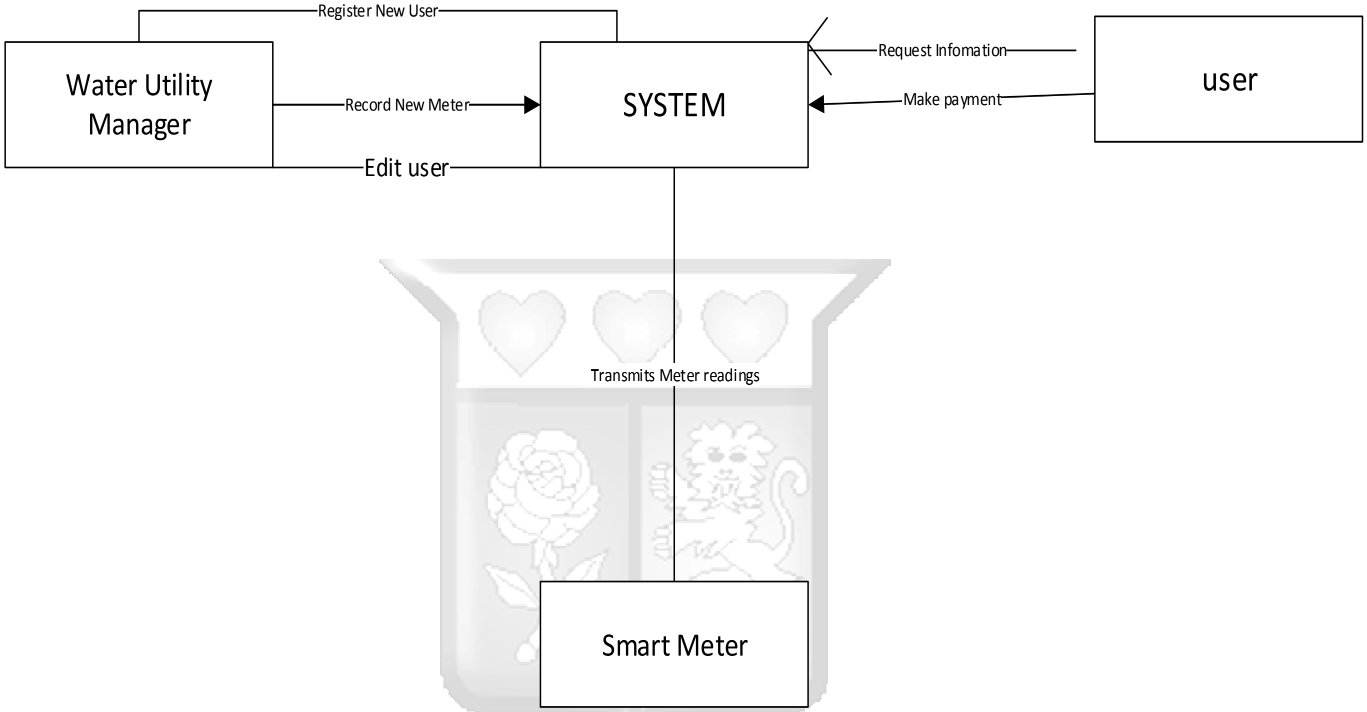

Figure 5. 3: Data Flow Diagram Level 0 for the smart phone based system

5.4.4 System Sequence Diagram

In this research to understand how data would flow between the various actors and the system, a sequence diagram was derived. The figure below indicates the sequence diagram for an actor obtaining water level and making payments.

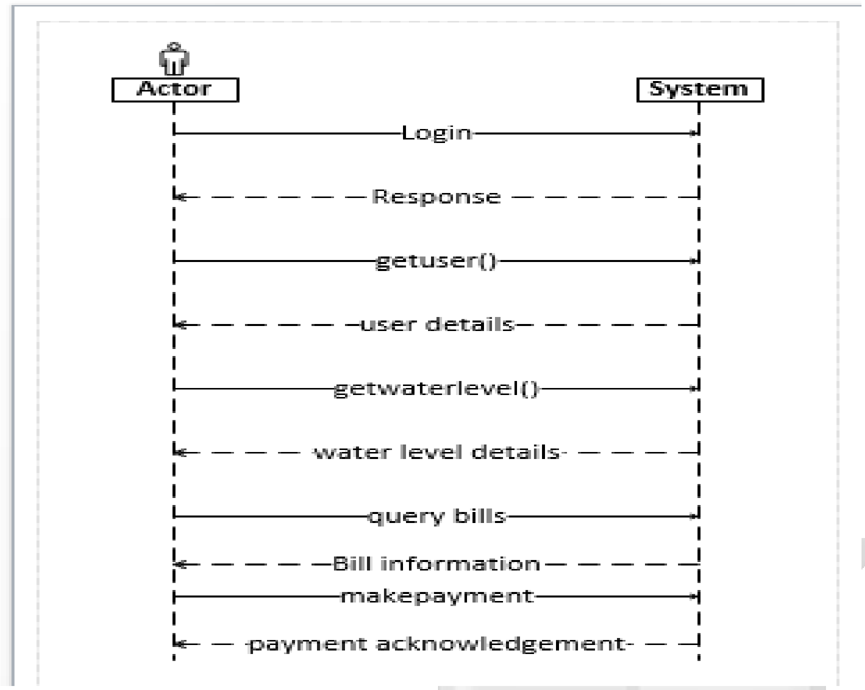

Figure 5. 4: Sequence Diagram for the smart phone based system

5.4.5 Entity Relation Diagram

In this study, the system was designed to accommodate all the data for the components and entities in the system. These included the details for the customer, meter inflow data, meter out flow data, consumption and billing data. The entity relationship diagram was used to show the relationships between the database entities.

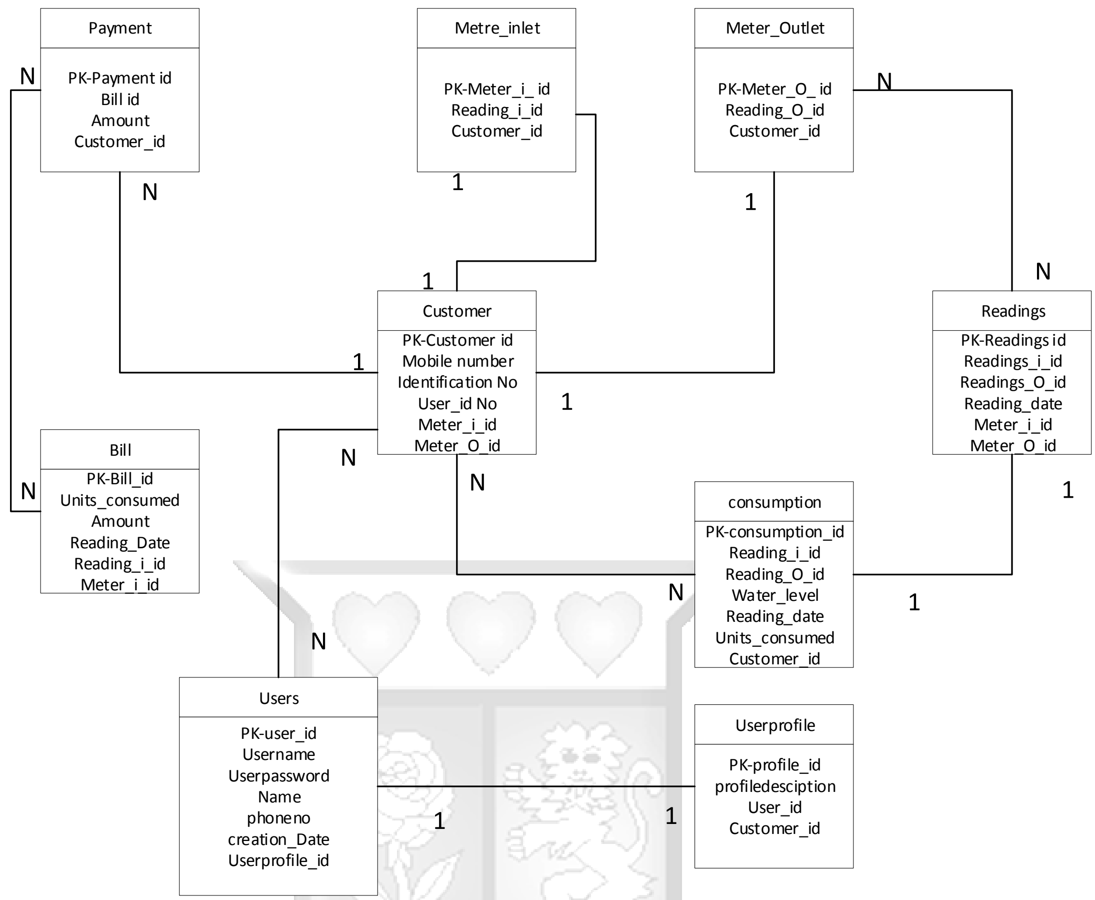

Figure 5. 5: Entity Relation Diagram for the proposed system

Chapter 6: System Implementation and Testing

6.1 Introduction

In this chapter, the study contains designs converted into real operational system and tested to ensure that all the systems functionalities implemented. The implementation done on the two clients' side involved the two smart meters' installation side and the mobile application. The server side had the component management system that resided at the water utility servers and was responsible for receiving the meter reading data as well as providing information to the client side.

6.2 Client Side

As per the design, the system is made up of two major parts consisting of the client side and the server side. The client consisted of the android mobile application phone through which the user used to access information from the internet relating to water consumed and bills.

The two installed smart meters are fixed at the end users site served as another client. One of the installed meters measured water flowing into the tank while the other smart meter measured the water flowing out of the tank.

The digital meters were connected to the remote transmitters through wireless communication gadgets that transmitted the meter readings to the base station. The base station received the data and transmitted the data to the server and the monitoring system through the internet.

6.3 Mobile Application Implementation

The mobile application was built to operate on the Android platform. This is based on the research done, that showed that 88% of the target population had phones that were running on Android application. The research further showed that 91% of the sampled population owned mobile phones.

The mobile application users click on the icon on their android devices to launch the application. The mobile application requests for the User ID and password for authentication purposes. The users are required to change password on first log on before granted access to the homepage. Screen shots below shows the log in and password change screens in the mobile application.

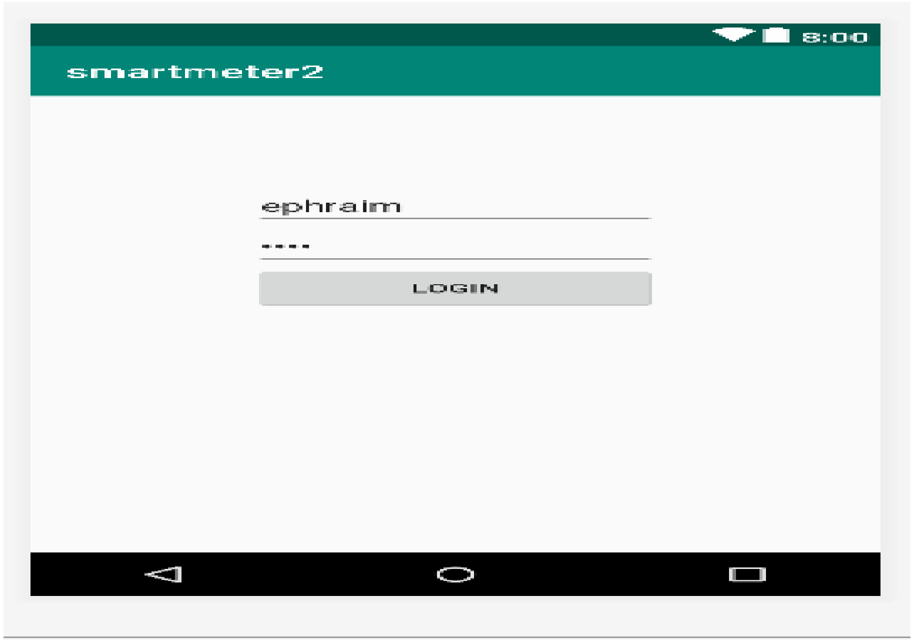

Figure 6. 1: Mobile Application Login Screen of the smart meter system.

6.4 Servers Side

6.4.1 Web Application Implementation

The Web application was developed using the PHP and while the web data was stored in MySQL database. In this module, the administration matters of the system were executed using the Web application. The Water utility staff manage users, monitors meters and generated reports through the application. To perform these functions, they access the system through the web application where they are required to provide authentication data i.e. used ID and password. After a successful log on, the user receives a welcome screen and is able to add customers and Meters and assign a customer to a meter successfully. After performing the above processes successfully, the user was able to see a list of readings that were streaming in the water utility server.

6.4.2 Viewing meter data

The system was configured such that it was possible to flag out the meter data with inconsistent data. In this case, readings that were constant were flagged as anomalies and in the reporting module, they were displayed in colour red for further attention while the meter readings which were consistent were flagged with colour green. The system was able to record the meter numbers and the timing when the data was transmitted.

It was also possible to view the customer's inlet, outlet meter data, consumption and water available for use in the water storage tanks.

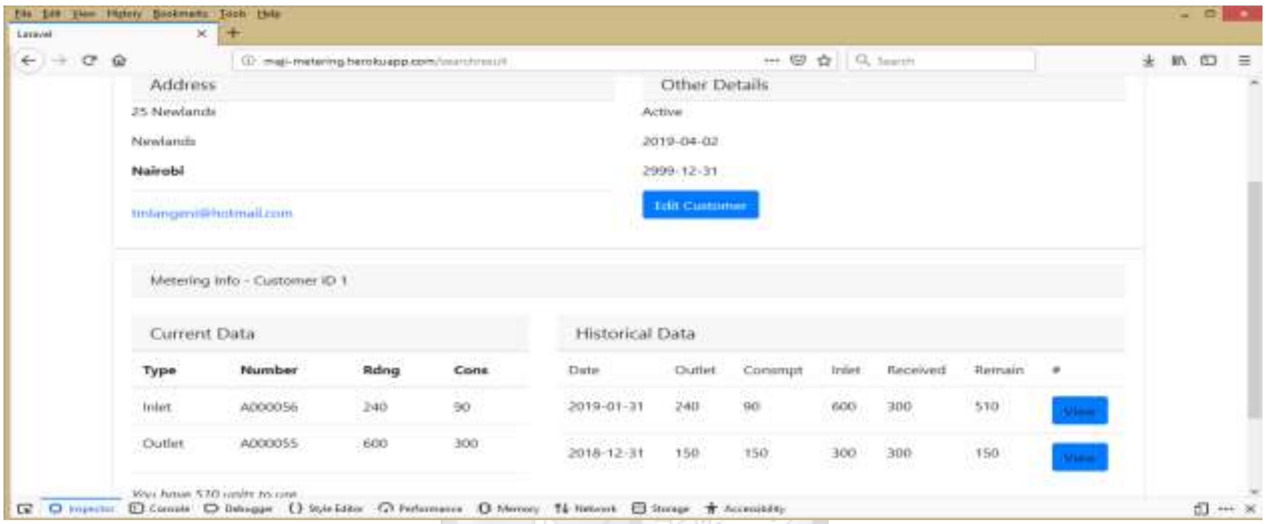

Figure 6. 2: Smart Metering System Module to View a customer's consumption in each meter and water available in the storage tanks

6.5 Database Structure

The Web application was developed using the PHP while the web data was stored in MySQL database. The list of tables created were populated.

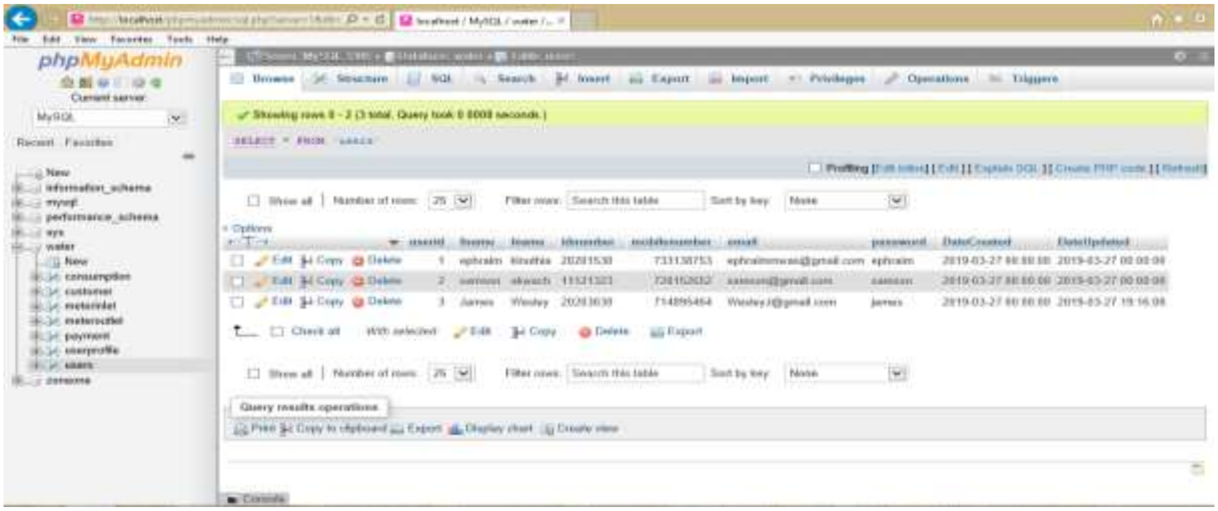

Figure 6. 3: Phpmyadmin database, with a populated list of tables.

6.6 Smart Meter Implementation Side

In this study, smart meters were installed, configured, and integrated with the smart phone based model. A Kamstrup smart meters were installed at the inlet and outlet of the underground water tank as demonstrated and the meter readings were captured. The meters transmitted readings to the mobile phone via Bluetooth after being interfaced by a wireless converter. The readings were then transmitted to the laptop to be uploaded to the server.

Figure 6. 4: Kamsrup smart meter installed at the inlet of an underground tank displaying the meter readings

Figure 6. 5: A smart phone installed with the meter reading application

Figure 6. 6: A smart phone paring up with the server in readiness to receive the meter data

Figure 6. 7: A smart phone transferring the meter data

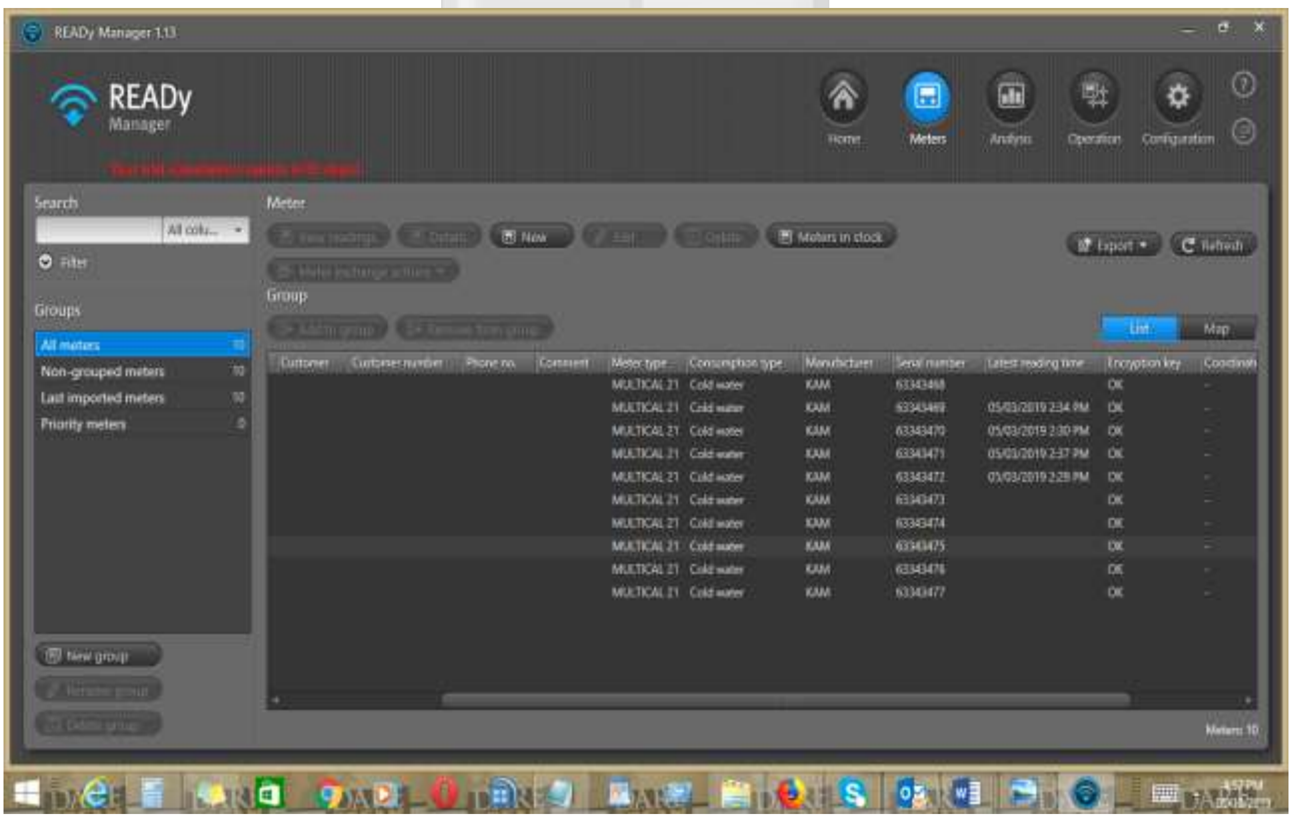

Figure 6. 8: Meter reading application showing meter details and readings status after uploading to the local database

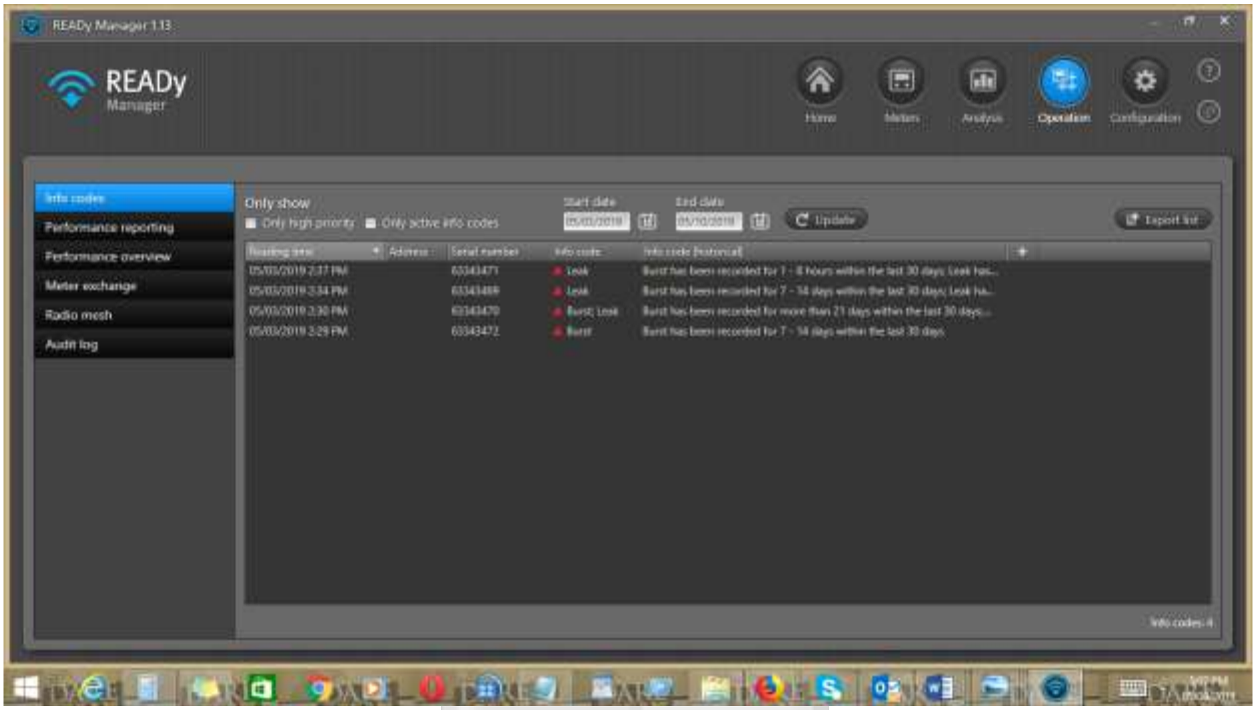

Figure 6. 9: Meter reading application showing additional information from the smart meter

6.7 Systems Testing

In this study, system testing was done to guarantee the system was working as expected. The testing was done in two ways, majorly the developer testing and user Assessment testing. The developer performed the initial test and ascertained that the functions worked as required. The tests involved unit testing, integration testing, compatibility testing, functionality testing and user testing.

6.7.1 Unit and integration Testing

In this study, unit testing was done on individual units to ascertain that they were operational. The isolated hardware components were separately tested to ensure that each component performed its required function. The source code was tested before deployment and it guaranteed if was free from error. Further, integration testing was executed to verify the system connectivity and functionality especially where more than one component was involved. During this test, multiple errors were deduced and corrected.

6.7.2 Compatibility Testing

In this study, the software and the web browsers compatibility were tested. This was done was done to ensure that the mobile and web applications are compatible with the available platforms. The mobile application was tested against the available Android versions while the web application was tested against the available web browsers that are commonly used and they were found to be compatible.

Table 6. 1 Shows the results of compatibility test conducted for each of the Android platforms available

Android Version	**Version Name**	**Compatibility**
Android 5.1	Lollipop	Yes
Android 4.4	KitKat	Yes
Android 4.2	Jellybean	Yes
Android 4.0	Ice cream sandwich	Yes
Android 3.2.1	Honeycomb	Yes

Table 6. 2 Shows the results of compatibility test conducted for each of the web browsers available

Browser Types	**Compatibility**
Internet Explorer (version 4 and above)	Yes
Firefox (version 8 and above)	Yes
Chrome All versions	Yes

6.7.3 Functionality Testing

In this study, the functional tests were undertaken to verify that the features of the system had been implemented based on use. This section tested both the hardware and software to determine whether all functionalities were achieved. For each use case, testing measures were set with results being considered successful or unsuccessful.

Table 6. 3 Shows the results of functionality to access the application conducted in the login in smart phone application

Tested Use Case	Login		
Steps	User Action	System	Pass / Fail
1.	The user clicks on the android login screen	The system displays the user name and password menu	Pass
2.	User keys in the user name and password	System prompts user to change password for the first attempt	Pass
Final Comment			Successful login for users

6.7.4 User Testing

In this study, to ascertain the user’s system uptake, a user test was done through interviews and questionnaires formulated. Out of 110 involved in the study, 45 users were involved in the testing process. An instruction manual was provided to the users with instructions on how to navigate the system. User testing was done to ascertain the degree to which the application interface was appealed to its users and the systems ease of use.

6.7.4.1 User Interface Appearance

In this study, to ascertain the acceptability rate of the interface of the mobile application, 78.6 % of the population indicated that it was pleasant while 21.4% noted that it was not overly pleasant.

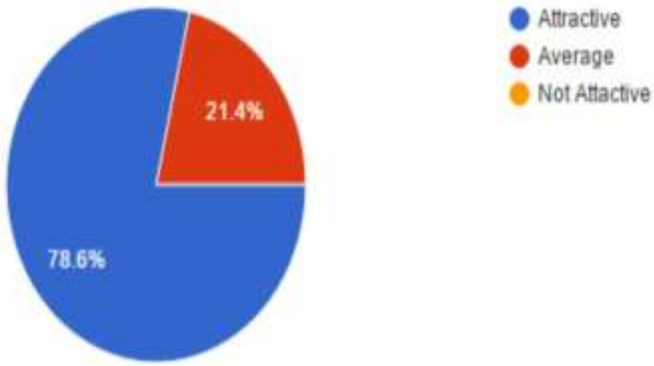

Figure 6. 10: Statistics indicating the outcome of the user interface testing

6.7.4.2 Ease of Use

In this study, the ease of use of the system in relation to ease to learn on learning and to navigate through the system was sought and tested. From the population tested 93.8 % confirmed that it is easy to use while 6.8% of the population said it was not easy to use.

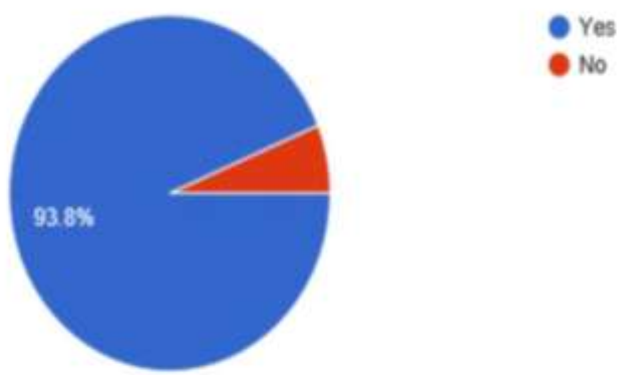

Figure 6. 11: Statistics indicate the rate of ease of use of the proposed system

Chapter 7: Discussion, Conclusion and Future Work.

7.1 Introduction

The purpose of this research was to determine the information necessary in meter reading, explore the advantages with the smart meters over the mechanical meters and to propose a smart phone-based model that would be used by customers. This chapter focuses on the various findings and achievements, how the research objectives were achieved, provides a review of the system in relation to the current systems. It also discusses the advantages and future works.

7.2 Findings and Achievements

The study focused mainly on the implementation of Wireless M Bus technology as an enabler to smart meter reading. The technology has used the standardized protocol (EN 13757-4) and operated under unlicensed 169,433 and 868 frequencies. The smart meter was connected to a data concentrator that transmitted meter readings through a secure android application. As long as the concentrator was near the smart meter, the smart meter was on call mode transmitting data after every 6 minutes a state that determined the battery life span.

The study revealed the possibilities of implementing various M-BUS network topologies. This affirmed that moving away from manual readings to remote meter reading yielded a better network optimization.

The wireless M-Bus technology made it possible to detect real time meter failures thus leading to faster response to situations thus abating huge losses. The technology enables a predictive maintenance forecast of the equipment's hence maximizing their use.

In the study M-bus, smart metering increased the operational efficiency and consequently influenced customer satisfaction. The study further showed that other than the economic benefits which were noted to be accruing in use of the smart meters, it also revealed that more information relating to payments and bills to the customers was not enough and therefore more information was necessary in the meter reading process.

7.3 Review of the Research objectives in relation to the developed system.

In this study, a mobile and web application was designed and developed based on the research objectives. This section describes the various objectives of the research in relation to the findings or results. In line with the first objective, which was to determine the type of information requirements needed for the meter reading application, it came out from the study that generally information to the customers was not sufficient. The study showed that the information of water stored in the customer's premises would be of assistance to the customers, as it would shape their consumption patterns while information available with a smart meter installation would be of great importance to the water utilities.

The second objective was to investigate the various problems with the current meters which were in effect contributing to the meter reading challenges. This objective was achieved by reviewing literature, reports and documentation obtained which showed the benefits of the smart meters over the mechanical meters. From the feedback obtained in the data collection phase, it informed that inaccessibility of water meters was real especially when the customers are not available in their homes when the utility workers visit to read the meter and sometimes when the utility worker and the person in the house are not able to trace the water meter in the compound. This was pointed out as not only a cause of revenue loss to the water utilities but it equally culminated to estimated high bills which led to disgruntled customers. The developed system and the deployed of smart water meters therefore eliminates these encumbrances because the meter readings are sent automatically without any human intervention. The frequency of the meter readings according to the study was not restricted to a particular period and this therefore guaranteed real time information to the customer on the water consumed and the water available in their storage tanks.

The third objective was to propose a mobile phone application to be integrated with smart meter reading. The application was designed and developed and it showed how the mobile phone would work with the smart meter's implementation.

The last objective of this research was to test the functionalities of the system developed. The following tests were conducted to prove the validity of the system; Compatibility testing, functionality testing, unit testing, integration testing and user testing. Testing of the system was also done during integration of the components. Testing to ensure a functional communication channel between the system and the server was also done to ensure data was transmitted. It was concluded that the system functioned as required.

7.4 Future Work

This research has proved that it is possible to integrate mobile phone application with smart meter reading which will ensure usefulness, answerability, and clearness in the water sector. Despite the emerging mobile technologies innovations within the water industry there are still challenges which call for improvements in this industry.

For instance, there is need to have a mobile application solution developed for other mobile platforms to allow users with phones other than Android to access the application's functionality. In future the application can also be integrated to the water regulatory and water utilities body systems, to automatically report any non-conformities and provide evidence of the same. The application can also be integrated with other government bodies e.g. Revenue Authorities and Credit Reference bureaus for the sake of detecting and flagging out tax evaders and debt defaulters respectively.

7.5 Conclusion.

This research was carried out to improve the meter reading services in the water sector, with an aim of making the water utility companies more efficient through value addition in the process, constant interaction with their customer's in the service delivery at reduced costs. The study was done within Nairobi County by designing and developing a system towards this end. Prior to design and development, a comprehensive study was carried out to determine the existence of the problem and viability of the study. The data collected from sample population was analysed and helped in designing a relevant system to curb the challenges in the water sector.

This system not only addresses the metering challenges but with proper utilisation it offers a platform which can enable other stakeholders access vital information which can lead to better formulation of policies within the water sector.

An android mobile application was developed to provide a platform through which information is shared with the consumer. A web application was designed and developed to enable supervisors to manage users, manage water usage, manage regulations and generate reports. The wireless M bus technology facilitated remote meter reading. M-Bus technology adopted eliminated or reduced the frequency of customers and staffs interaction thus addressing security and privacy concerns as well as abating corruption. The successful implementation of this system does guarantee efficiency, accountability, transparency and effectiveness in the water sector.

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APPENDICES

Appendix A: Letter of Introduction

Ephraim M. Kinuthia

P.O Box 51958 – 00200

Nairobi, Kenya

15th January 2019

Regional Manager

Nairobi Water & Sewerage Co. Ltd

P.O. Box 30956 – 00200

Nairobi, Kenya

Dear Madam,

RE: Letter of Introduction

I am a graduate student at Strathmore University undertaking a Master's degree in Information & Technology. I am currently conducting a study on use of a smart based phone model to be used in the meter reading process by a water utility.

The information obtained will be for the benefit of the researcher and in the near future, it will be freely available to the management.

Yours truly,

Ephraim M. Kinuthia

Appendix B: Questionnaire

QUESTIONNAIRE

Dear Respondent,

I am a graduate student at Strathmore University undertaking a Master's degree in Information & Technology. This questionnaire is allowing the researcher to conduct a study on use of a smart based phone model to be used in the meter reading process by a water utility and therefore the information you give will be of benefit in accomplishing academic goal.

Kindly answer the questions to the best of your abilities, there is no right or wrong question, your response will be highly appreciated. There is no need to give your name anywhere on the form, the information collected is used for academic purposes only.

(Please try to answer all the questions to the best of your abilities)

1. **What is your age group?**
   - Above 18 and below 30
   - Between 30 – 40
   - Between 40 – 50
   - Above 50
2. **Please indicate the level of your education**
   - Primary Education
   - Secondary Education
   - Tertiary Education
   - Others (please specify) _______________
3. **Do you own a Mobile phone?**
   - Yes
   - No

4. **Which operating system is installed in your Mobile phone?**
   - J2ME
   - Android
   - Windows
   - IOS
   - I do not know

   Other ____

5. **Do you own a house in Nairobi?**
   - Yes
   - No
6. **Do you rent a house in Nairobi?**
   - Yes
   - No
7. **Please indicate the location of your water meter?**
   - Inside the perimeter wall
   - Outside the perimeter wall
8. **How often do the staff of the Water Utility Company visit your premises?**
   - Once in a month
   - Twice in a month
   - Weekly
   - Never

Water service Challenge

Please rate the following water related issues on a scale of 1-5 on the severity of the challenge. In this case, 1 denotes the least severe level while 5 will denote the most challenging level**.** *Kindly tick as appropriate.*

9. **The staff of Water Utility Company inside your compound pose a security threat?**

1 2 3 4 5

10. **I receive misstated water bills?**

1 2 3 4 5

11. **I am always in the house when the staff of Water Utility company visit my premises**

1 2 3 4 5

12. **I always get more information of my water account other than the payment made to the account and the monthly bill**

1 2 3 4 5

13. **Do you have a water storage tank inside your compound?**

- Yes
- No

14. **If your answer is yes to the above question, how do you tell the quantity of water in your storage tank at any one time?**

- Open the lid and check
- Feel the water level by hitting the tank
- I get to know the tank is empty when water stops flowing
- I never get to know

Suggestions

15. **In your view, would a smart meter, which automatically transmits the meter reading without any manual intervention, eliminate incorrect water bills?**

- Strongly Agree

- Strongly disagree
- Agree
- Disagree

16. **In your view, would a smart meter, which automatically transmits the meter reading without any manual intervention, reduce corruption?**
    - Strongly Agree
    - Strongly disagree
    - Agree
    - Disagree

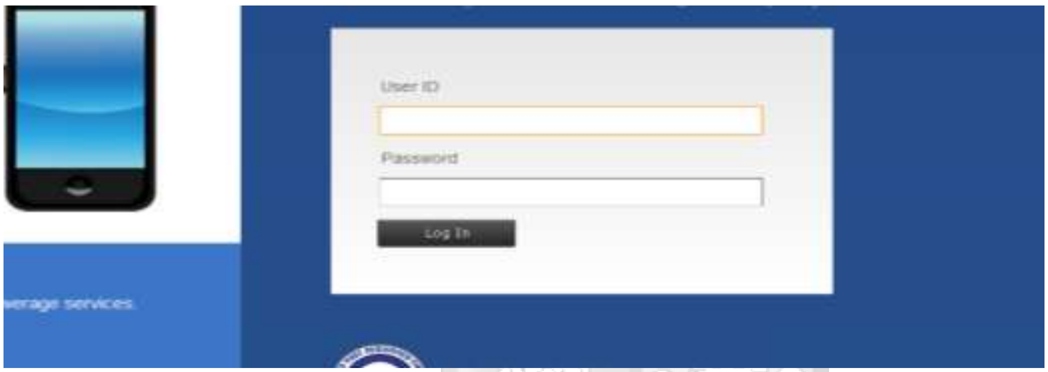
17. **In your view, do you think that an automated way to check the water level in your storage tank at any one time would be of great importance to you?**
    - Strongly Agree
    - Strongly disagree
    - Agree
    - Disagree

18. **In your view, do you think that an automated way to check the water level in your storage tank in any way influence water usage?**
    - Strongly Agree
    - Strongly disagree
    - Agree
    - Disagree

Appendix C: System implementation Screen shots

This section of the appendices displays that screen shots of the login and password change functionalities of the web page.

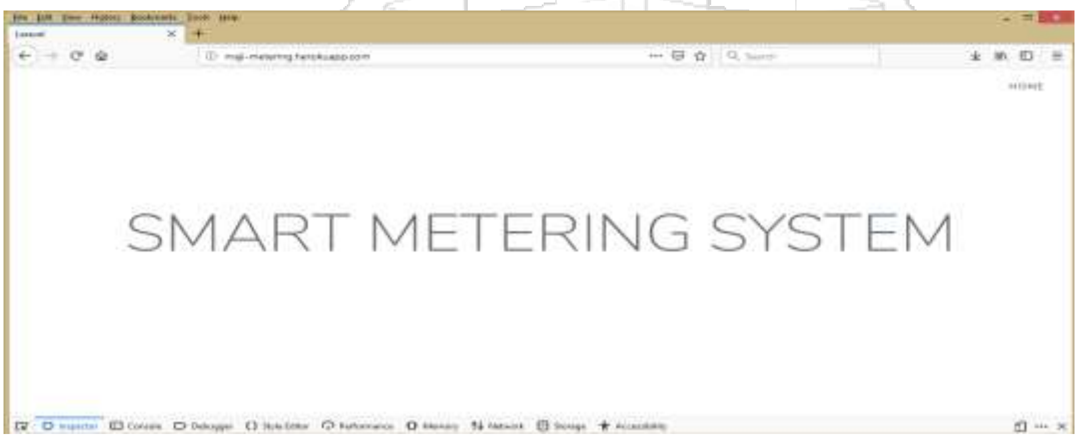
Appendix C.1: User Login Page



Appendix C. 1: Smart Metering System Web application login page

Appendix C.II: Welcome Home Page

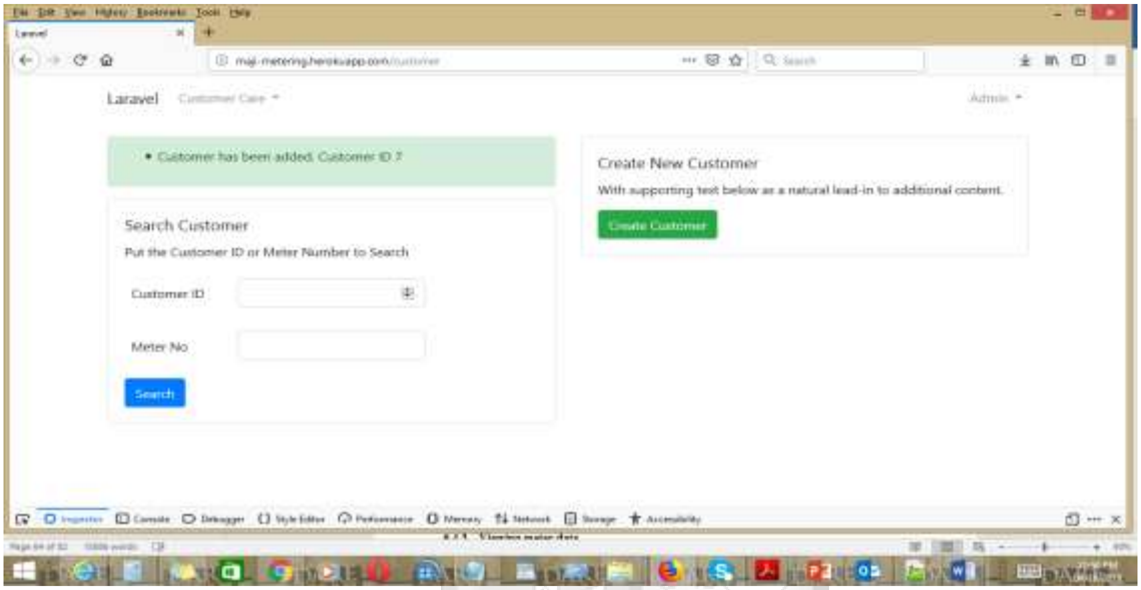
This section of the appendices displays the screen shots of the Welcome home page of the smart meter system



Appendix C. 2: Smart Metering System Welcome Home page

Appendix C.III: Module to Add a Customer

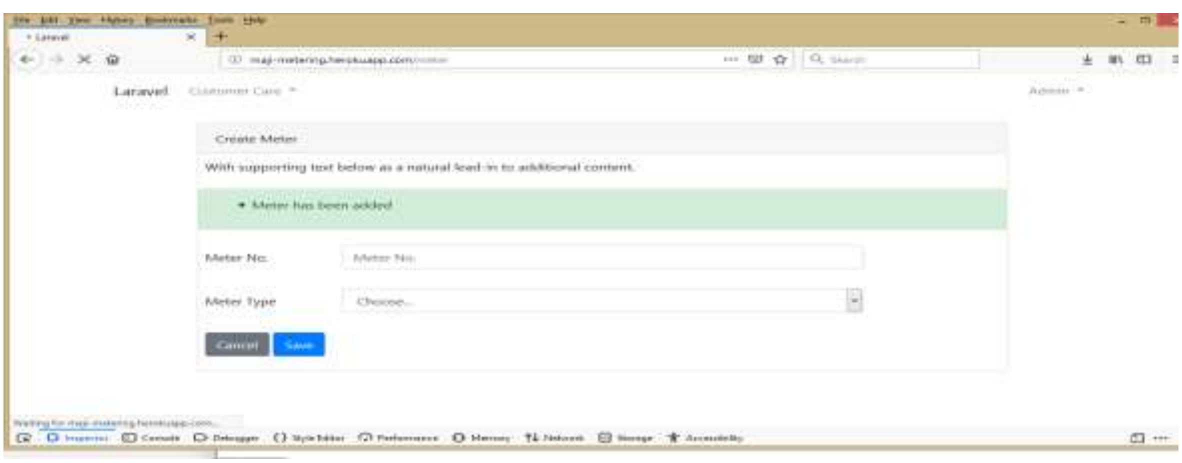
This section of the appendices displays the screen shots of the module that enables a user to add a new customer into the smart meter system.



Appendix C. 3: Smart Metering System Module to Add customers

Appendix C.IV: Module to Add a New Meter

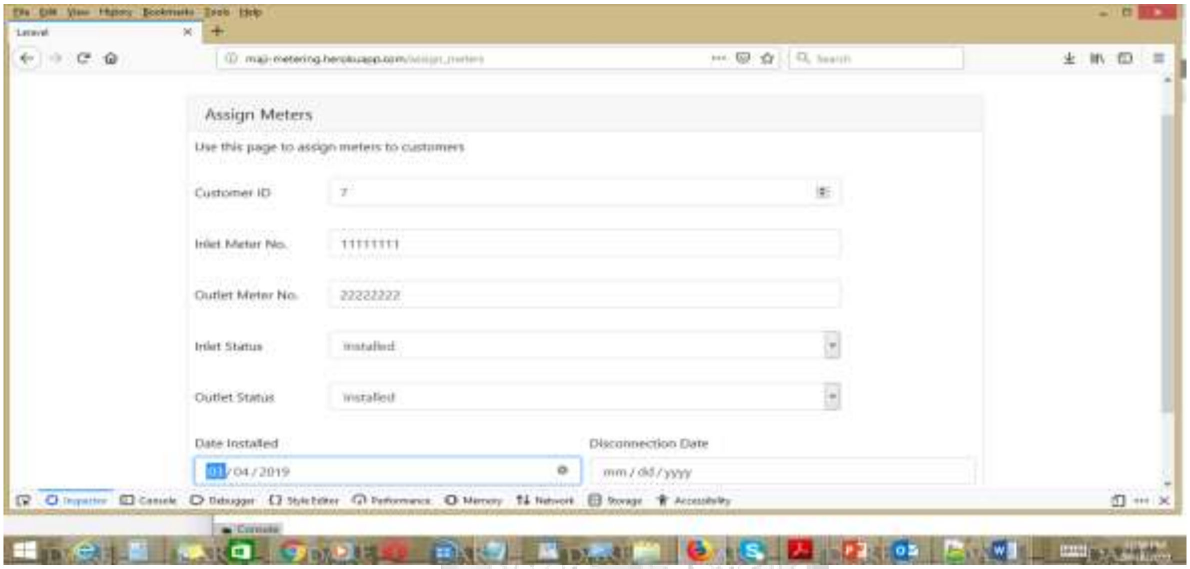
This section of the appendices displays the screen shots of the module that enables a user to add a new meter into the smart meter system.



Appendix C. 4: Smart Metering System Module to Add Water Meters

Appendix C.V: Module to Assign a New Meter to a Customer

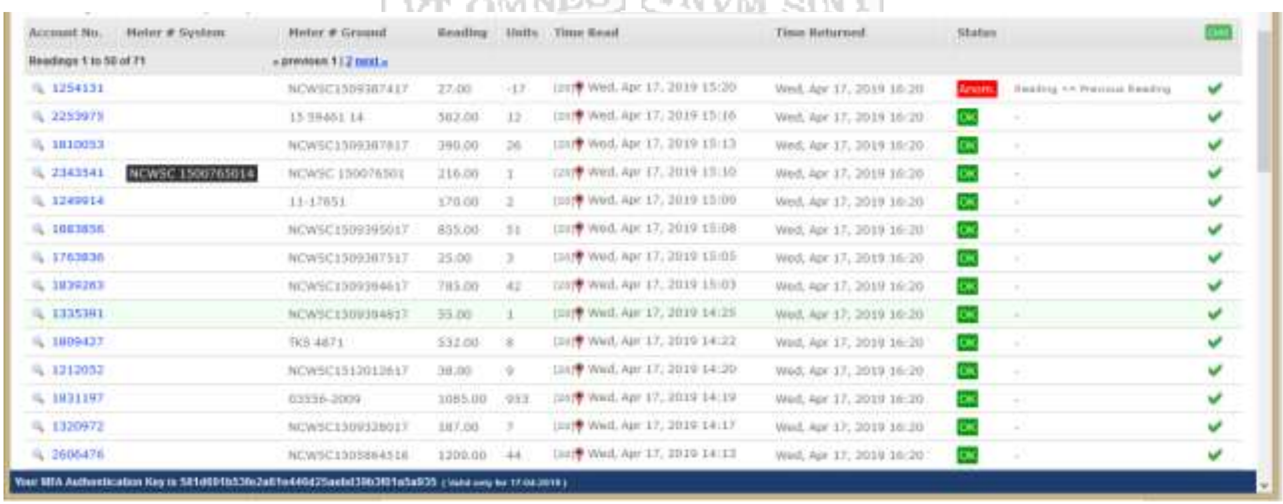
This section of the appendices displays the screen shots of the module that enables a user to add a new meter into the smart meter system and assigns it to a customer.



Appendix C. 5: Smart Metering System Module to Assign Meters to Customers

Appendix C.VI: Module to uploaded Meter Data View

This section of the appendices displays the screen shots the data from the smart water meter after uploaded in the water utility server



Account No.	Meter # System	Meter # Ground	Reading	Units	Time Read	Time Returned	Status		
Readings 1 to 50 of 71		« previous 1 | 2 next »							
1254131		NCWSC1509387417	27.00	-17	Wed, Apr 17, 2019 15:20	Wed, Apr 17, 2019 16:20	Error	Reading <= Previous Reading	✔
2253975		15 59461 14	502.00	12	Wed, Apr 17, 2019 15:16	Wed, Apr 17, 2019 16:20	OK	-	✔
1810053		NCWSC1509387817	390.00	26	Wed, Apr 17, 2019 15:13	Wed, Apr 17, 2019 16:20	OK	-	✔
2343541	NCWSC 1500765014	NCWSC 150076501	216.00	1	Wed, Apr 17, 2019 15:10	Wed, Apr 17, 2019 16:20	OK	-	✔
1249914		11-17651	170.00	2	Wed, Apr 17, 2019 15:00	Wed, Apr 17, 2019 16:20	OK	-	✔
1083856		NCWSC1509395017	855.00	51	Wed, Apr 17, 2019 15:08	Wed, Apr 17, 2019 16:20	OK	-	✔
1763836		NCWSC1509387517	25.00	3	Wed, Apr 17, 2019 15:05	Wed, Apr 17, 2019 16:20	OK	-	✔
1839283		NCWSC1509394617	785.00	42	Wed, Apr 17, 2019 15:03	Wed, Apr 17, 2019 16:20	OK	-	✔
1335381		NCWSC1509394817	55.00	1	Wed, Apr 17, 2019 14:25	Wed, Apr 17, 2019 16:20	OK	-	✔
1809437		TKS 4871	532.00	8	Wed, Apr 17, 2019 14:22	Wed, Apr 17, 2019 16:20	OK	-	✔
1212052		NCWSC1512012617	38.00	9	Wed, Apr 17, 2019 14:20	Wed, Apr 17, 2019 16:20	OK	-	✔
1831197		03556-2009	1085.00	933	Wed, Apr 17, 2019 14:19	Wed, Apr 17, 2019 16:20	OK	-	✔
1320972		NCWSC1509328017	187.00	7	Wed, Apr 17, 2019 14:17	Wed, Apr 17, 2019 16:20	OK	-	✔
2606476		NCWSC1505864516	1200.00	44	Wed, Apr 17, 2019 14:13	Wed, Apr 17, 2019 16:20	OK	-	✔

Appendix C. 6: Extract of data received in the water utility server

Appendix C.VII: A Dashboard View

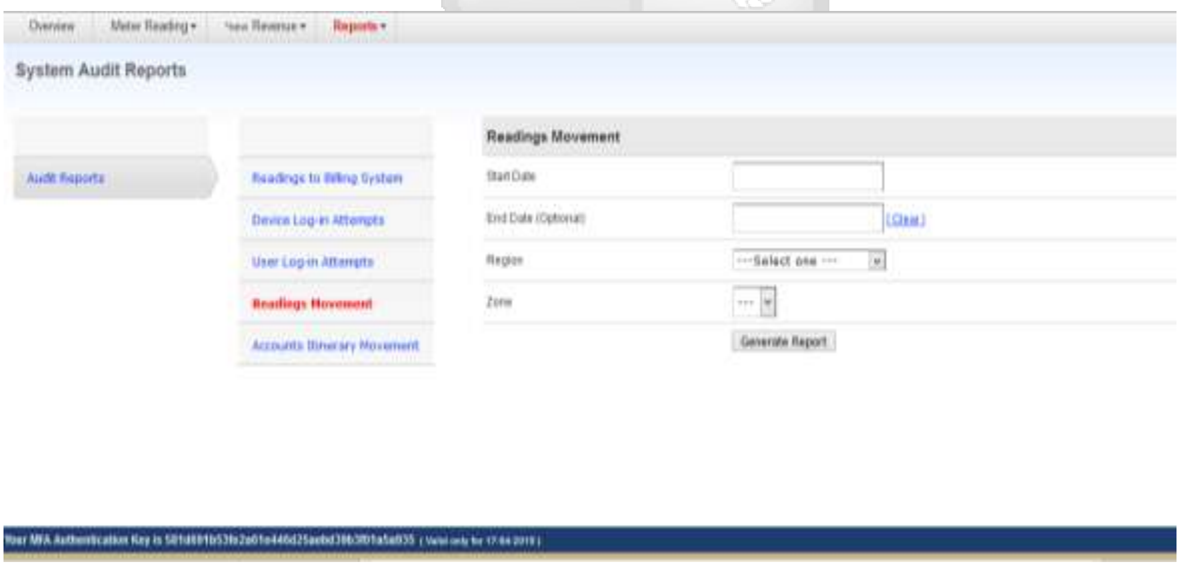
To enable the managers have at a glance the number of meters transmitted on a daily basis, the dashboard report was able to show the meters read within the target areas of the population.

Downloaded On Wed 17, Apr 2019 [?]	Returned On Wed 17, Apr 2019 [?]	Read On Wed 17, Apr 2019 [?]	OK Read Today Wed 17, Apr 2019 [?]
2,429	1,536	1,535	1,476
4,642	2,663	2,636	2,597
129	20	20	17
5,309	2,107	2,105	1,994
4,543	2,378	2,370	2,314
229	56	55	49
81	1	1	1
61	18	18	14
87	37	36	34
1,413	1,231	1,232	1,181
18,694	9,991	9,953	9,628

Appendix C. 7: A dashboard report of meters transmitting readings in certain areas

Appendix C.VIII: Module to generate Report View

The manager was able to extract various reports for further analysis and to ascertain the validity of the data received.



Appendix C. 8: System generated reports module