A SPATIAL FRAMEWORK FOR MANAGING SEWER AND WATER NETWORKS USING SENSOR NETWORKS:

A case of the University of Zambia

BY

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DECLARATION

I, the undersigned declare that the work in this dissertation is original except were indicated by special reference in the text and no part of the research has been submitted for any degree, diploma, or academic qualification. I further declare that the research has not been presented to any other College/University for examination either in Zambia or outside Zambia.

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CERTIFICATE OF APPROVAL

This document by **Gabriel Chibuye** is approved as partial fulfilment of the requirements for the award of the degree in Master of Science in Geo-Information Science and Earth Observation of the University of Zambia.

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ABSTRACT

Public institutions generally have a lot of facilities and infrastructure catering for the population of the institution. Some important infrastructure such utilities which include water, sewer, electricity, and telecommunications require constant maintenance, management, and adequate monitoring for them to function effectively. This study aimed to build a framework for Managing Sewer and Water Networks Using Sensor Networks at the University of Zambia. The methodology involved understating the existing operations of the Resident engineer's office to ascertain the user needs. These needs formed the basis of the study, the development and design of the prototype of the Web based Framework. Data Collection was done using various methods. A presurvey (Reconnaissance Survey) was done to have an idea of the existing infrastructure and a more accurate survey was done using GPS GNSS equipment GIS software was used to process data and create shapefiles. A 15-digit coding system was created and was used to assign unique identification numbers and extra attribute information to the water and sewer network shapefiles. A QR code was generated for each node and the serial number recorded. Tagging was done using the QR code for each structure. All the shapefiles were loaded into a PostGreSQL spatial database and were used as input in the Web GIS application. The web application had some tools imbedded in it which were mainly for monitoring and management of the structures. Using internet of things (IOT) technology, water level sensors were placed in a prototype to mimic some critical manholes to help with the monitoring of the sewerage network. The system could therefore be used for identification of any infrastructure by scanning the QR code and a map showing the structure would be seen online by the field technicians. Students could also be able to send out notifications to the resident engineer in case there was a damaged or malfunctioning structure. Monitoring of the sewer system could be done using the sensors and ultimately the framework would ease the management of the water and sewer systems at the University of Zambia.

Keywords—*GIS, WEBGIS, Sensors, Internet of Things, Coding, tagging, QR Code*

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LIST OF ACRONYMS

AJAX	Asynchronous JavaScript and XML
CAD	Computer Aided Design
CSS	Cascaded Style Sheets
CSV	Comma Separated Values
DBMS	Database Management System
DEM	Digital Elevation Model
ERD	Entity-Relationship Diagram
ESRI	Environmental Systems Research Institute
FOSS	Free Open Source Software
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
IDE	Integrated Development Environment
JS	Javascript
KML	Keyhole Markup Language
OGC	Open Geospatial Consortium
OSM	Open Street Map
QR	Quick Response
RTK	Real Time Kinematic
SDK	Standard Development Kit
SQL	Structured Query Language
UML	Universal Modelling Language
UNZA	The University of Zambia
URL	Uniform Resource Locator
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
XML	Extended Markup Language

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

The University of Zambia is a rapidly expanding as observed from the new developments all around the campus. The University of Zambia is the first public university in the country, was established by the University of Zambia Act of 1965 and consequently opened in 1966. The University has undergone several transformations regarding its governance and operations since 1965. The University started with three Schools in 1966, namely Education, Humanities and Social Sciences, and Natural Sciences. In its first academic year, 1966, the University enrolled 312 students (CICT 2018). The university now has total number of schools to 13 schools and has over 30, 000 students that includes parallel and distance programmes (Lusaka Times 2017).

The growth naturally necessitates the acquisition of new properties and development of university infrastructure. One of the key areas of focus for managing the university facilities is optimal use of utility spatial information. Water and sewer utilities are essential for the smooth running of a university. Water provides inevitable sustenance to life and sewerage systems provide a means of discarding wastewater. As such, it is essential for water utilities to be managed and monitored well.

Currently, most of the water and sewer utility spatial information used in managing the university facilities are paper based maps which are inaccurate because they have not been updated in a long time. The maps can easily be torn and lost hence they are not a reliable way of storing and retrieving information. The sewer network has an existing autocad drawing but it is not drawn to scale and is not georefenced making it unreliable to get spatial related information off the drawing. Consequently, there is need to introduce better systems that are more efficient in spatial data organization, manipulation and visualization. This is a necessary input for making proper business decisions in the management of the university water utilities. According to Grise et al., the management of utility networks using Geographic Information Systems (GIS) is key in improving operations and reducing costs by managing assets, updating network information, providing easy access to spatial data, combining work-orders, locating information on customers and preparation of reports (Grise 2003). GIS technology offers techniques of leveraging database information and automating work processes. The web has been used as a distribution channel for maps. This has been a major advancement in GIS which has unlocked a lot of new opportunities such as real time maps, low-cost methods of distribution, sharing of spatial information, more personal map content and distributed sources of data.

This study aims to provide users web-based access to geographic data and basic query tools, increased data accuracy and integrity, prevent data duplication and provide a means of updating, monitoring as well as reporting mechanism for any malfunctioning water structure. It is envisaged that the availability and accessibility to such geographic information by users and other stakeholders will be very desirable for effective decision making in managing the university water utilities.

This chapter will introduce the study, its background, its significance and what it hopes to achieve. It will highlight the statement of the problem, which will give details about what the current situation is at the resident engineer's office. The chapter will further provide the research questions which will be used to formulate the objectives and ultimately the main objective of the study. The scope of the study in this chapter will describe the extents of the study and where it can be used as well as tools that will be adopted and hence provide the limitations for the study. Finally, the significance of the study will give details of how the study will benefit the university of Zambia population as well as the contribution to further studies related to water and sewer systems as well as location-based studies.

1.2 Statement of the Problem

The University of Zambia has a lot of water utility networks that run underground. There's uncertainty of the utility lines locations and there is no realtime monitoring of the infrastructure. This makes maintenance, management and planning of the utilities very difficult. The lack of updated locations causes destruction of water pipes and sewer lines when undertaking new constructions or any excavations. The Resident Engineer's office only has some old, scanned pdf sketches of both sewer and water networks. The field engineers locate water and sewerlines using memory and experience, but this is a very difficult to keep track of in such large area with various interconnections. In addition, there is no platform to submit or check the conditions of infrastructure. The students for example have no way of reporting any malfunctioning structure online, communication always must be done physically, and Job cards have to be submitted by paper to the resident Engineer's office. This sometimes take a long time to resolve issues because papers can easily be lost and there is no way of checking the exact structure in question.

1.3 Research Questions

i. Where are the water and sewer networks located and how are they currently identified?
ii. Can a framework be designed for the findings in (i) to monitor, manage and integrate the utility system with sensors?
iii. How can a prototype of the framework designed in (ii) be developed?

1.4 Objectives of the Study

i. To conduct a baseline study of the existing sewer and water networks at the University of Zambia
ii. To design a framework for the GIS sewer and water networks integrated with sensors based on the findings in (i).
iii. To develop a prototype based on the framework in (ii) using the web, mobile and sensing technologies.

1.5 Scope of the Study

The study was limited to the water utility network within the University of Zambia. Land surveying methods were used to gather information about the location of all the structures using tools like GPS, Total stations and some android apps. GIS mapping tools such as arcMap and QGIS were used to make the maps and produce data formats that could be used in the framework development. The framework used Free Open Source Software (FOSS) i.e. QGIS, PostgreSQL, PostGIS, Geoserver, OpenLayers, leaflet and Apache server with their associated development tools and customized functions for users and system administrators. The prototype system integrated aduino sensors to mimic how the manholes can be monitored in the network in case of a blockage.

1.6 Significance of the Study

The University of Zambia facilities have developed over time and the recognition of the need for more infrastructure led to the creation new Schools over the years. In addition, the expansion of academic programmes and consequently the rising numbers of student enrolments, has further increased on the number of infrastructures to date with new developments all around campus. All this population increase and infrastructure development demands for facilities such as water and sewer networks and other utilities that meet their needs. These utility networks need to be adequately maintained and monitored in order to be able to efficiently meet these day-to-day incessant demands from the various users. The traditional monitoring and maintenance of utility networks at the Resident Engineer's Office is by use of un-updated old, scanned maps, and ungeoreferenced AutoCAD drawing. Therefore, this study was going to provide a tool which would be used to accurately map the underground sewer water networks which would greatly improve the spatial knowledge of the utility networks and improve the management maintenance and planning. The integration of sensors would improve service delivery as well as provide a way of monitoring any faults within the underground utilities. The networks would further be coded for easy identification. The tool can also be used to integrate utilities with other infrastructure such as electricity, telecommunication, and fibre optic to enhance infrastructure development in the University.

Studies at the University of Zambia that look at Water and Sanitation as well as locations of these structures have not been with webGIS approach which integrates most aspects of the structures. This study may be used for more studies towards the building of smart University of Zambia as well as smart cities in general.

1.7 Area of Study

The area of study was the University of Zambia, Great East Road Campus. It is in Lusaka, the capital city of Zambia. It is located at latitude -15.3879 degrees and longitude 28.3297 degrees. It is bordered by The Great East Road on the North, to the West; there's Thabo Mbeki Road, on the south there's part of Kalingalinga compound, and part of mass media, and the East is Kamloops Road. The figure 1 shows the map of the location of the area of study.

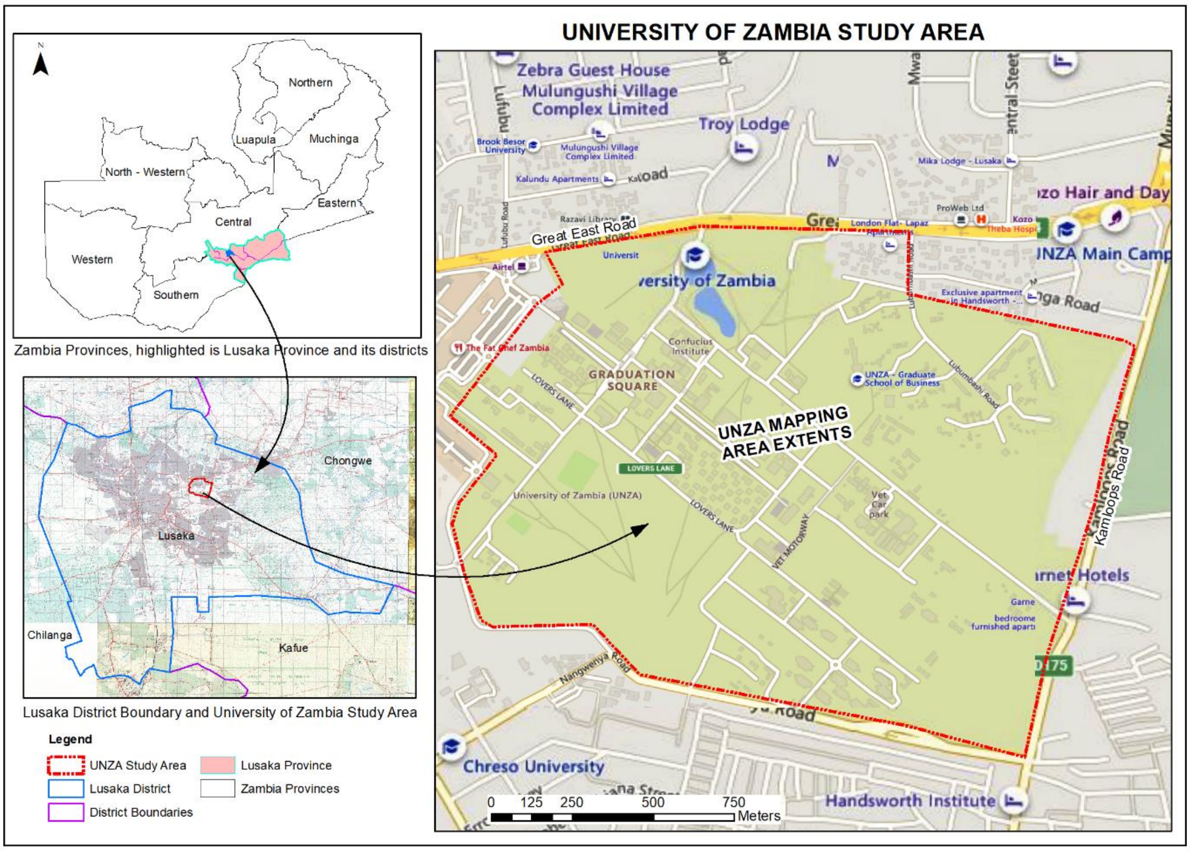


Figure 1: Location of University of Zambia (by Author, 2023)

1.8 Chapter Summary

This chapter introduced the study. It explained the statement of the problem and the formulated research questions. It further stated the aim and objectives of the study which were based on the research questions. The scope of the study which outlined the extents and limitations of the study was explained. Finally, the major significance of the study was stated to show what the study hoped to resolve and achieve. It also stated the study's contribution to future studies.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter will discuss the literature review which will involve looking at the various geospatial and other relevant technologies that will be used in water and sewer networks. The water and sanitation utility management will be reviewed including aspects of drinking water and wastewater pipelines. Mapping, Surveying and Remote Sensing will be discussed as well as GIS based utility network mapping technologies. Web Services and the WebGIS technologies will be introduced including the classification, architecture, and the development cycle. Database Technologies, Web and Mobile applications development tools will also be reviewed. Tagging, QR Code Technologies and the Internet of things technologies and various components will also be looked at. The chapter will conclude with a review of the related works to the study and gives a summary of their findings and some gaps in relation to this study.

2.1 Water and Sanitation Utility Management

Water and Sanitation are an integral part of development of a nation, the health of its citizens and the nation’s environment. However, water and wastewater utilities across many countries face common challenges. These include rising costs, aging infrastructure, increasingly stringent regulatory requirements, population changes, and a rapidly changing workforce. According to CDC, Community wastewater management and adequate sewer systems play important roles in sanitation and disease prevention. Wastewater can contaminate the local environment and drinking water supply, thereby increasing the risk of disease transmission (CDC 2015). Therefore, to improve health, it is vital to develop a system to manage community wastewater and sewage.

2.1.1 Drinking Water Pipeline

Drinking water system is a system which manages whole regularity of water to be potable and provides continuous supply of potable water at adequate pressure up to the consumer’s tap. The distribution system is the final barrier before delivery to the consumer’s tap. Even when the water leaving the treatment plant is of the highest quality, if precautions are not taken its quality can seriously deteriorate. A water system is composed of pipes, valve, hydrant, storage tanks, pumping station etc. as majority of pipes this system entirely identified as pipeline network (Ganesh 2016). Efficient management of such system provides reliable and efficient service to the consumer.

2.1.2 Wastewater Pipeline

Wastewater is sewage, storm water, and water that have been used for various purposes around the community. Unless properly treated, wastewater can harm public health and the environment. Most communities generate wastewater from both residential and non-residential sources. There are two types of domestic sewage which are part of the wastewater system: Blackwater - wastewater from toilets, and Graywater—wastewater from all sources except toilets. Blackwater and graywater have different characteristics, but both contain pollutants and disease-causing agents that require treatment (Kirsten 2004).

2.2 Mapping

A map is a symbolic representation of selected characteristics of a place, usually drawn on a flat surface (National Geographic Resource Library 2018). Maps present information about the world in a simple, visual way. They teach about the world by showing sizes and shapes of countries, locations of features, and distances between places. Maps can show distributions of things over Earth, such as settlement patterns. They can show exact locations of houses and streets in a city neighbourhood. Cartographers who make maps using various tools to represent the Earth such as symbols, grids, map projections and scale. Before making a map, cartographers decide what area they want to display and what type of information they want to present. They consider the needs of their audience and the purpose of the map. These decisions determine what kind of projection and scale they need, and what sorts of details will be included.

2.3 Surveying and Remote Sensing

Mapping relies on survey data for accurate information about the planet. Surveying is the science of determining the exact size, shape, and location of a piece of land. It is the process of determining the relative position of natural and manmade features on or under the earth's surface, the presentation of this information either graphically in the form of plans or numerically in the form of tables, and the setting out of measurements on the earth's surface (Schofield 2001). It usually involves measurement, calculations, the production of plans, and the determination of specific locations. Surveyors gather information from regions both above sea level and beneath bodies of water. Surveyors use tools such as Global Positioning Systems, total Station, theodolite and levels.

Surveyors use remote sensing to collect data about an area without physically touching it. Sensors that detect light or radiation emitted by objects are mounted to airplanes or space satellites, collecting information about places on Earth from above. One method of remote sensing is aerial photography, taking photographs of Earth from the air and drone surveys. Aerial photography has eliminated much of the legwork for surveyors and has allowed precise surveying of some places that are impossible to reach on foot. Satellites, spacecraft that orbit Earth, perform remote sensing. For example, Landsat, a satellite that circles Earth 14 times a day, transmits huge volumes of data to computers on Earth. The data can be used to quickly make or correct maps. It is with these advancements that earth explorers like google earth have been borne and portable online maps on smart phones have been made possible.

2.4 GIS Based Utility Network Mapping

A key element about the information used by utilities is the relative location of its assets in relation to other geographic features and objects. Mapping of these assets is therefore essential. Assets that are present on the surface of the earth are called vertical assets while assets that are underneath the surface of the earth are called horizontal assets.

GIS based utility mapping of assets offers advantages. GIS Landmark (2019) gives the following advantages: Systematic storage of asset locations, Easy sharing and retrieval of maps, Effective update of asset information, Easy comparison of thematic maps with different types of utility lines, Modelling interdependencies among different water utility networks, Project planning and policy making. Therefore, the most important applications of GIS for water utility management are mapping, monitoring, modelling, infrastructure planning, maintenance, water conservation and response to emergencies (EPA 2008). Utility mapping includes mapping of roads, water pipelines, sewerage pipelines, electric lines, fire hydrants, telecommunications lines and other miscellaneous services facilities.

2.5 GIS and Other Technologies

A GIS is an organized collection of computer hardware, software, data and personnel designed to facilitate the phases of data acquisition and verification, compilation, storage, checking (includes updating and changing), management and exchange, manipulation, analysis and combination, data retrieval and presentation or display of spatial or geographically referenced data (Buckey 2018). Mohammad (2002) simply defines a GIS as a system designed for the collection, storage and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis. It is both a database system with specific capabilities for spatially referenced data, as well as a set of operations for working with data. GIS can therefore combine geographic and other types of data to generate maps and reports, enabling users to collect, manage, and interpret location-based information in a planned and systematic way. GIS technology offers combined power of both geography and information systems an ideal solution for effective management of water and sewer utility infrastructure. The effective management of water utility network can be possible by proper representation and analysis of network data (EPA 2008).

According to ESRI, there are four primary frameworks for implementing GIS in an organisation. The frameworks provide a scalable framework for implementing GIS for a single user or many users on desktops, in servers, over the Web, and in the field. Desktop GIS is a comprehensive set of professional GIS applications used to solve problems, to meet a mission, to increase efficiency, to make better decisions, and to communicate, visualize, and understand an idea, a plan, a conflict, a problem, or the status of a situation. Server GIS provides the basis for building an integrated, multi-departmental system for collecting, organizing, analysing, visualizing, managing, and disseminating geographic information (ESRI 2014). Server GIS solutions are intended to address both the collective and individual needs of an organization and to make geographic information and services available to both GIS and non-GIS professionals. Mobile GIS is creating fundamental changes by adding the ability to take GIS into the field and interact directly with the world by means of focused application solutions on mobile devices. Developer GIS provides customized and focused applications that enable many end users to leverage the full capabilities of GIS. It provides developers with a comprehensive series of developer frameworks to customize and deploy GIS.

2.6 Web Services

Web services is a standardized way or medium to propagate communication between the client and server applications on the World Wide Web (GURU 99 2018), the following are available technologies for creating web services:

a) XML (EXentsible Markup Language)

Extensible Markup Language (XML) is a simple, very flexible text format derived from SGML (ISO 8879). Originally designed to meet the challenges of large-scale electronic publishing, XML is also playing an increasingly important role in the exchange of a wide variety of data on the Web and elsewhere (W3C 2016).

b) JSON (JavaScript Object Notation)

JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language Standard ECMA-262 3rd Edition – December 1999 (The JSON Data Interchange Standard 2019). JSON is a text format that is completely language independent but uses conventions that are familiar to programmers of the C-family of languages, including C, C++, C#, Java, JavaScript, Perl, Python, and many others. These properties make JSON an ideal data-interchange language.

JSON is built on two structures:
A collection of name/value pairs. In various languages, this is realized as an object, record, struct, dictionary, hash table, keyed list, or associative array.

An ordered list of values. In most languages, this is realized as an array, vector, list, or sequence.

These are universal data structures. Virtually all modern programming languages support them in one form or another. It makes sense that a data format that is interchangeable with programming languages also be based on these structures.

c) SOAP (Simple Object Access Protocol)

SOAP is an XML-based protocol for accessing web services over The Hypertext Transfer Protocol (HTT). SOAP is known as the Simple Object Access Protocol, but in later times was just shortened to SOAP v1. 2. SOAP is a definition of how web services talk to each other or talk to client applications that invoke them. It is a platform-independent protocol that uses XML to facilitate remote procedure calls, typically over HTTP (Net-informations.com 2019).

d) REST (Representational State Transfer)

Restful Web Service is a lightweight, maintainable, and scalable service that is built on the REST architecture. Restful Web Service, expose API from your application in a secure, uniform, stateless manner to the calling client. The calling client can perform predefined operations using the Restful service. The underlying protocol for REST is Hypertext Transfer Protocol (HTTP). REST stands for Representational State Transfer. It performs all the same functions Remote Call Procedure (RCP) SOAP and WSDL (Web Service Description Language) web services (Net-informations.com 2019).

REST is popular because it is implemented using standards such as HTTP, XML and JSON which hence makes it lightweight. However, it is an architectural style and not a web standard as such is not recommended by renowned international web organisations like The World Wide Web Consortium (W3C).

2.7 WebGIS

Much recent attention in GIS has been focused on developing GIS functionality on the internet, Worldwide Web, or a private intranet, which is sometimes termed WebGIS. It hosts traditional GIS functionalities on the internet web, coupled with the powerful ability to integrate information and tools from multiple sources. The basic tasks of Web GIS are:

- Visualization - spatial representation of the existing information
- Simplification of work with the spatial information in a web;
- Managements and publication of spatial data, search and other services based on a site of objects (LBS - location based services)

2.7.1 WebGIS Classification

There are many different WBGIS systems on the Internet. Ahmed (2011) defines the types of WEBGIS based on the data source and web page technologies. At the top level, the WEBGIS systems can be divided into two broad categories based on their data source, namely Heterogeneous source, and Single source. Single source systems mean that all spatial data are stored in a single web server. In contrast to single source systems, heterogeneous source systems allow spatial data storing in multiple web server. Furthermore, single source systems can be divided into static pages and dynamic pages according to their different types of web pages (see Figure 2). The key difference between them is that whether the page is predefined or dynamic generated. Static pages are such that the browser sends the predefined request to the web server where data has already been prepared. Dynamic pages are that browser sends request to the web server and receives the content which is generated by web server dynamically.

Dynamic pages adopt capabilities of procedural languages, server side scripting languages, internet standards or vendor specific GIS and graphics software to achieve it while static pages just requires image maps or vector display plug-ins.

According to whether they can provide basic or advanced operation, the dynamic pages are divided into two groups. One group can provide simple operations like layer overlay, visualization, distance, and location calculation. Another group of dynamic pages can provide senior operations like querying spatial data using spatial operators. Many companies migrate the advanced capabilities from their conventional GIS to WEBGIS which can provide advanced feature by using software package or middleware.

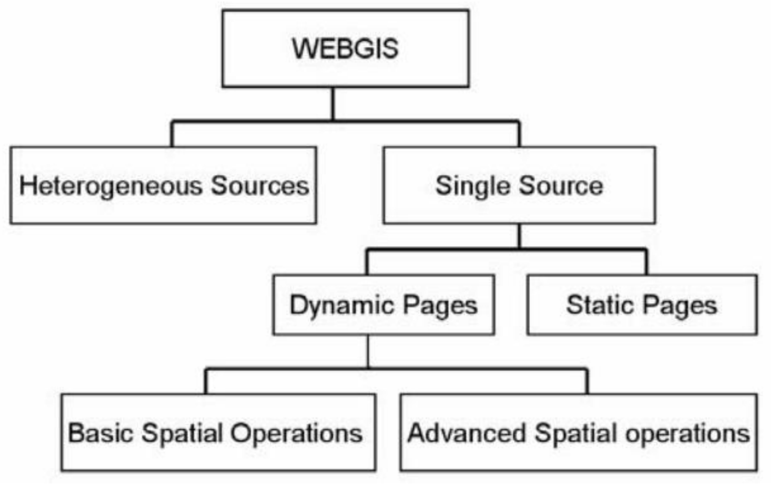


Figure 2: Different WBGIS systems on the Internet (by Ahmed, 2011)

2.7.2 Architecture of a WebGIS

The main parts of any WebGIS are the client, the server, and the network. The server houses the GIS database and applications which are used to process the client's request. Client applications are web, mobile, and desktop applications that connect over HTTP to internet services or to local services over a Local Area Network (LAN) or Wide Area Network (WAN) (ESRI 2018). The figure 3 shows the webGIs architecture; the web browser (client), sends request to the web server which in turn uses the application server to obtain the required request form the database. Then sends the data to the mapserver which gives the response back to the webserver which in turn sends it back to the browser.

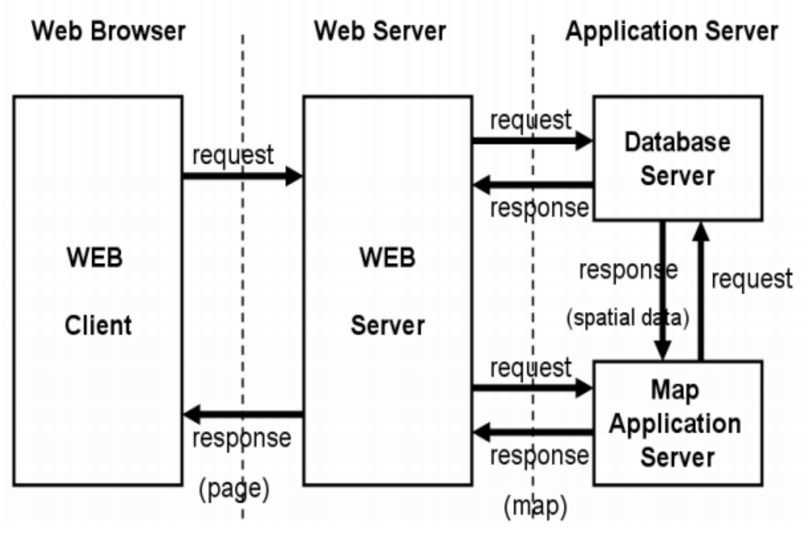


Figure 3: webGIs architecture (by author, 2019)

2.7.3 WebGIS Development Cycle

The development of WebGIS strategies goes beyond acquiring the right software and hardware for successful implementation within minimum cost and time constraints. There are eight major activities for the development process described by Alesheikh (2002):

1. Requirements Analysis: This stage identifies the needs of the development process. These include data to collect, system usage and functions etc. This information is used in the design of the conceptual framework.
2. Conceptual Design: The data model that represents the real-world entities and relationships is designed. The data will be sent via a central server.
3. Hardware and Software Survey: Suitable software and hardware should be then surveyed and selected based on functionality and performance.
4. Database Design: Actual model setup of the database design at conceptual, logical and physical levels.
5. Database Construction: Defining procedures for data conversion, building, managing and maintaining the database.
6. Acquisition of GIS Hardware and Software: Concurrent and iterative design, testing and hardware and software acquisition.
7. WebGIS System Integration: To initiate the WebGIS procedures different components of software and hardware are integrated.
8. Application Development: Implementation of basic and complex functionality of the WebGIS.

2.8 Database Technologies

A database is a very vital component of a system. Database design, development, implementation were the phases carried out in the process of ensuring that the resulting database met user requirements, had efficient data structures and retrieval mechanisms, normalization principles, support for data sharing, multi-user access through the WebGIS portal, easy editing, update and maintenance. The process for the database design involved looking at the available technologies.

a) MYSQL

MySQL, the most popular Open-Source SQL database management system, is developed, distributed, and supported by Oracle Corporation (Oracle Corporation 2019). It is an Open-Source Relational Database Management System that can run on both desktop application and on servers. MySQL is popular due to its wide interoperability and its ability to run on multiple platforms such as Windows OS, Mac OS X, GNU/Linux, UnixWare etc. It is widely used for web applications, especially in conjunction with PHP and Ruby Programming languages amongst others.

b) SQLite

SQLite is an in-process library that implements a self-contained, serverless, zero-configuration, transactional SQL database engine. The code for SQLite is in the public domain and is thus free for use for any purpose, commercial or private. It is the most widely deployed library database in the world with countless applications (The SQLite Development Team 2019).

SQLite is said to be a light version of MySQL as it only implements necessary core features. It is popular because it is widely used as an embedded database in software applications especially in mobile apps.

c) ORACLE

Oracle database is a Relational Database Management System from the Oracle Corporation. Originally developed in 1977 by Lawrence Ellison and other developers, it is one of the most trusted and widely used relational database engines. It is built around a relational database framework in which data objects may be directly accessed by users or an application front end using structured query language (SQL) (Shafiya 2020). It is said to be popular due to its robustness and flexibility and its self-management capabilities which are built in its kernel.

d) POSTGRESQL

PostgreSQL is a powerful, open-source object-relational database system. It has more than 15 years of active development and a proven architecture that has earned it a strong reputation for reliability, data integrity, and correctness. It runs on all major operating systems, including Linux, UNIX (Mac OS X, Solaris, Tru64), and Windows (The PostgreSQL Global Development Group 2014).

It is said to pride itself as the words most advanced open-source database due to the powerful underlying technologies it uses that enable it to efficiently execute Multi-version Concurrency Control (MVCC) whilst ensuring strict ACID (Atomicity, Consistency, Isolation, Durability) compliance.

2.9 Database server

.PHP

PHP is a server scripting language, and a powerful tool for making dynamic and interactive Web pages (w3schools.com 2019). PHP is a widely used, free, and efficient alternative to competitors such as Microsoft's ASP. According to Welling and Thomson (2016) some of the strengths of PHP are;

- Performance - PHP is very fast. Using a single inexpensive server, you can serve millions of hits per day.
- Scalability - can effectively and cheaply implement horizontal scaling with large numbers of commodity servers.
- Database Integration - can directly connect to PostgreSQL, Oracle, MongoDB, and MSSQL, among others. Using the Open Database Connectivity (ODBC) standard, you can connect to any database that provides an ODBC driver. This includes Microsoft products and many others.
- Built-in libraries for many common web tasks
- Low cost
- Ease of learning and use
- Strong object-oriented support – Once you can program in Java or C++, you will find the features (and generally the syntax) that you expect, such as inheritance, private and protected attributes and methods, abstract classes and methods, interfaces, constructors, and destructors.
- Portability - PHP is available for many different operating systems.
- Flexibility of development approach
- Availability of source code
- Availability of support and documentation

PHP + MySQL Database System

MySQL is a very fast, robust, relational database management database enables you to efficiently store, search, sort, and retrieve data. The MySQL server controls access to your data to ensure that multiple users can work with it concurrently, to provide fast access to it, and to ensure that only authorized users can obtain access. Hence, MySQL is a multiuser, multithreaded server.

PHP combined with MySQL are cross-platform (you can develop in Windows and serve on a Unix platform).

2.10 Application server

GeoServer is the map server to link the database to the client. It is used to acquire and process requests coming from the user and return output results. It is an inbuilt application server with components that consist of many different modules or services that actively interact with each other (Open-Source Geospatial Foundation 2018).

OpenLayers is another software which displays dynamic map data in web browsers from multiple sources. It provides easy access to OGC web services such as WMS, WFS etc. It is also used as middleware to establish, maintain and terminate the connection between the map server and web server (OpenLayers 2018).

2.11 Web server

The Apache Tomcat software is run in conjunction with GeoServer. It is an open-source implementation of the Java Servlet, JavaServer Pages, Java Expression Language and Java Websocket technologies (Apache Tomcat 2018). The figure 4 shows the flow of communication between the database server, the application server and the web server.

Figure 4: Database server, Application server and web server (by author, 2019)

2.12 Graphical User Interface (GUI)

The Graphical User Interface or GUI is an interface which makes use of the computer's graphic abilities to make a program easier and simpler to use. A well-designed GUI can avoid the need for a user to learn a command or complex programming languages. It is a type of an interface which makes it possible for users to interact with electronic devices through graphical icons, as well as visual indicators like secondary notations rather than text-based interfaces (CLEVERISM 2019).

2.13 Mobile Application Development

Mobile Platforms

Mobile platforms are part of the system ecosystem. These platforms helped to determine the right Software Development Kits and Programming languages which fit the scope of the study. Below is a list of available mobile technologies which could be used:

a) Android

Android is a comprehensive open-source platform designed for mobile devices. It is championed by Google and owned by Open Handset Alliance. The goal of the alliance is to “accelerate innovation in mobile and offer consumers a richer, less expensive, and better mobile experience.” Android is the vehicle to do so. As such, Android is revolutionizing the mobile space (Oreilly 2019). For the first time, it is a truly open platform that separates the hardware from the software that runs on it. This allows for a much larger number of devices to run the same applications and creates a much richer ecosystem for developers and consumers.

Comprehensive - Android is a comprehensive platform, which means it is a complete software stack for a mobile device.

For developers, Android provides all the tools and frameworks for developing mobile apps quickly and easily. The Android SDK is all you need to start developing for Android; you don’t even need a physical device. Yet, there are numerous tools, such as Eclipse, for example, that help make the development life cycle more enjoyable.

For users, Android just works right out of the box. Additionally, users can customize their phone experience substantially. It is, according to some studies, the most desirable mobile operating system in the United States at the moment.

For manufacturers, it is the complete solution for running their devices. Other than some hardware-specific drivers, Android provides everything else to make their devices work. That means that manufacturers can innovate at the highest level and bring up their game a notch.

Open-Source Platform - Android is an open-source platform. Most of the stack, from low-level native, Dalvik virtual machine, application framework, and standard apps, is totally open. Aside from the Linux kernel itself, Android is licensed under business-friendly licenses (Apache/MIT/BSD) so that others can freely extend it and use it for variety of purposes. Even some third-party open-source libraries that were brought into the Android stack were rewritten under new license terms.

So, as a developer, you have access to the entire platform source code. This allows you to see how the gut of the Android operating system work. As a manufacturer, you can easily port Android OS to your specific hardware.

There is no need to license Android. One can start using it and modifying quiet easily. In addition, Android has many hooks at various levels of the platform, allowing anyone to extend it in unforeseen ways.

b) iOS

iOS is derived from Mac OS X and is a Unix-like OS. There are four abstraction layers within iOS:

- Core OS Layer: Provides low-level features as well as frameworks for security and interaction with external hardware.
- Core Services Layer: Provides services required by upper layers
- Media Layer: Provides the necessary technologies for graphics, audio and video.
- Coca Touch Layer: Where frameworks are located, which are often used when creating an application.

iOS comes with a lot of default apps, including an email client, a Safari Web browser, a portable media player (iPod) and the phone app.

Developers can use the iOS software development kit (SDK) to create applications for Apple mobile devices. The SDK includes tools and interfaces for developing, installing, running and testing apps. Native apps can be written using the iOS system frameworks and the Objective-C programming language (Apple Inc 2019). Included in the iOS SDK are Xcode Tools, which include an integrated development environment (IDE) for managing application projects, a graphical tool for creating the user interface and a debugging tool for analyzing runtime performance. It also includes an iOS simulator, which allows developers to test apps on a Mac, and an iOS developer library, which provides all the necessary documentation and reference material.

c) Windows Phone

When the first Windows Phone was introduced in late 2010, it came pre-loaded with the Windows Phone 7 operating system. This was a considerably big deal at the time - the introduction of an entirely new mobile operating system - for consumers who had previously only had a choice between Apple and Android (MSPoweruser 2019).

Windows 7 was followed by five new operating system releases: 7.5, 7.8, 8, 8.1, 10 and, finally, 11. It followed Windows Mobile, an older operating system Microsoft designed, but stood on its own legs. Windows 7 and Windows Mobile were conflicting systems and could not share apps or data.

2.14 Programming Languages:

The following is a cumulative list of programing languages that could be used to implement the system from the client side to the server side for all user types;

a) PHP (Hypertext Preprocessor)

PHP is a popular general- purpose scripting language that is especially suited to web development. Fast, flexible and pragmatic, PHP power everything forms your blog to the most popular websites in the world like Facebook and Pinterest. It is a server-side scripting language and hence is usually used for in the development of dynamic web applications.

PHP is popular its platform independent implementations exist for major UNIX, Linux, Mac and Windows operating systems. It also supports popular databases like MySQL (CourseHero 2019).

b) Ruby

Ruby is a language of careful balance. Its creator, Yukihiro “Matz” Matsumoto, blended parts of his favourite languages (Perl, Smalltalk, Eiffel, Ada, and Lisp) to form a new language that balanced functional programming with imperative programming. He has often said that he is “trying to make Ruby natural, not simple,” in a way that mirrors life (Ruby Lang-Official Documentation 2019).

Ruby is said to be a flexible object-oriented scripting language because its syntax and conventions are intuitive as they attempt to mimic the way a developer thinks.

c) JavaScript (EXPRESS.JS)

Express is a minimal and flexible Node.js web application framework that provides a robust set of features for web and mobile applications. With a myriad of HTTP utility methods and middleware at your disposal, creating a robust API is quick and easy. Express provides a thin layer of fundamental web application features, without obscuring Node.js features (Javascript TutorialPoint 2019). This language is used as a server-side scripting language in some popular applications like the UBER cab hailing app.

The web portal (administration panel) was designed with web-based technologies with the combination of PHP for server- side scripting. JavaScript, HTML5 and CSS (cascading stylesheets) which was used for the front end coupled with the Responsive bootstrap framework.

The list below shows the available programming languages which were to be used to develop the proposed system in the study.

d) JAVA

Java is a set of computer software and specifications developed by James Gosling at Sun Microsystems, which was later acquired by the Oracle Corporation that provides a system for developing application software and deploying it in a cross-platform computing environment.

Java is said to be popular because it is the foundation for virtually every type of networked application and is the global standard for developing and delivering embedded and mobile applications, games, Web-based content, and enterprise software (Irvine Journal 2019).

e) C++

C++ is a high-level, general-purpose programming language created by Bjarne Stroustrup as an extension of the C programming language, or "C with Classes". C++ is a powerful general-purpose programming language. It can be used to develop operating systems, browsers, games, and so on. C++ supports different ways of programming like procedural, object-oriented, functional, and so on. This makes C++ powerful as well as flexible (Cplusplus 2019).

2.15 Utilities and Frameworks

a) Firebase Cloud Messaging

Firebase Cloud Messaging (FCM) is a cross-platform messaging solution that lets you reliably send messages at no cost.

Using FCM, you can notify a client app that new email or other data is available to sync. You can send notification messages to drive user re-engagement and retention. For use cases such as instant messaging, a message can transfer a payload of up to 4KB to a client app (Firebase 2019).

b) Google Maps Android Geojson utility

GeoJSON is an extension of the JSON data format and represents geographical data. Using this utility, you can store geographical features in GeoJSON format and render them as a layer on top of the map. To add and remove your GeoJSON data to and from the map, call addLayerToMap() and removeLayerFromMap() respectively. Similarly you can add and remove individual features by calling addFeature() and removeFeature() and passing in a GeoJsonFeature object (JSON Developer's Guide 2019).

c) Android Software development Kit

The Android Software Development Kit (SDK) is a crucial part of Android development for beginners to come to grips with. It's a selection of files bundled together that you will need to begin creating Android apps. It consists of tools like the virtual device manager (emulator) and ADB bridge, as well as a library of additional code for making Java programs work with the Android platform (Android Authority 2019).

d) GPS Essentials

GPS Essentials is a collection of a satellite sky view, a map and a waypoint database which are collectively called GPS Essentials. GPS Essentials stores information in a database on your SD card and in application preferences. The database holds all objects that are relevant for navigation such as waypoints, tracks, routes, tags 3 and messages. Since the database file resides on your SD card, GPS Essentials will not run while the SD card is mounted to your desktop computer. The database is in the folder com.mictale.gpsessentials/databases in the root of your SD Card. You can copy this file to a different location to make backups of your data (GPS Essentials Manual 2015).

Apart from the database, it has other components such as Domain Model which is a location based database that stores all your data into hierarchical streams. Streams are much like files in a text processing application. You can create, edit, share and delete them and the data that you create will reside in one and only one stream.

The other component is the Dashboard which is a fullscreen area to place widgets that show you navigation information, such as your current speed or the distance to the next waypoint. You can configure which navigation values to show. Other views such as Compass and Map also show these values. Camera is another component and it shows a HUD (head up display) of your waypoints. You can also shoot images. The HUD displays waypoints so that you can match them with landmarks. When a waypoint is close to the direction of view, additional info appears on the left side of the screen.

The Compass is another component of GPS Essentials. It is an orienteering compass that shows magnetic north, the direction to the next waypoint and a few widgets from your dashboard. Portable Maps is also a component that shows your waypoints, routes and tracks on a map from various data sources. In addition to Portable maps, GPS Essentials has an extra component of

Google Map which is a multi-layer map display that shows all your waypoints, tracks and routes.

GPS Essentials also has the following components for Navigation; Routes which are used to plan a trip. Routing guides you to a specific node with the ability to advance to a successive node when you reach a target. Waypoints component is a default place to store your waypoints. Satellites component is a sky view of all GPS satellites that are visible to your device. This view is good in cases when you don’t have a GPS location and you do not know why. Another component is Pictures, which locates and shares the pictures that you took within GPS Essentials. Messages component contain textual information about things that happened while GPS Essentials is running. Finally Tags components are used in GPS Essentials to structure your waypoints, tracks and routes. Tags are words or short phrases that you can attach to any one of these entities. The Tag view then groups the entities by your tags (GPS Essentials Manual 2015).

e) SASPlanet Software

SASPlanet is a program designed for viewing and downloading high-resolution satellite imagery and conventional maps submitted by such services as Google Maps, DigitalGlobe, Kosmosnimki, Yandex.Maps, Yahoo! Maps, VirtualEarth, Gurtam, OpenStreetMap, eAtlas, Genshtab maps, iPhone maps, Navitel maps, Bings Maps (Bird's Eye) etc., but in contrast to all these services all downloaded images will remain on your computer and you will be able to view them, even without connecting to the internet. In addition to the satellite-based maps you can work with the political landscape, combined maps and maps of the Moon and Mars (Open Hub 2019).

2.16 Tagging

According to Amazon Web Service (Amazon Web Services 2018), Tags provide identification and classification resources by the association of descriptive metadata, for example, application identifier, environment, or owner. Each tag consists of a key and a value, both of which are user-defined strings. Naming of the features in this study was done in preparation for tagging and accurate field survey.

2.17 Bar Codes and QR Codes

A barcode, consisting of bars and spaces, is a machine-readable representation of numerals and characters (DENSO Wave 2019). Today, stripes as shown below on packages of products sold at supermarkets, convenience stores and other stores are ubiquitous. These are barcodes. A barcode consists of bars and spaces of varying width that can be read with an optical barcode scanner.

Quick Response code (QR code) is a type of two-dimensional (2D) barcode that can be read using a QR barcode reader or camera enabled smartphone with QR reader software). Figure 5 compares the features of a bar code and a QR Code.

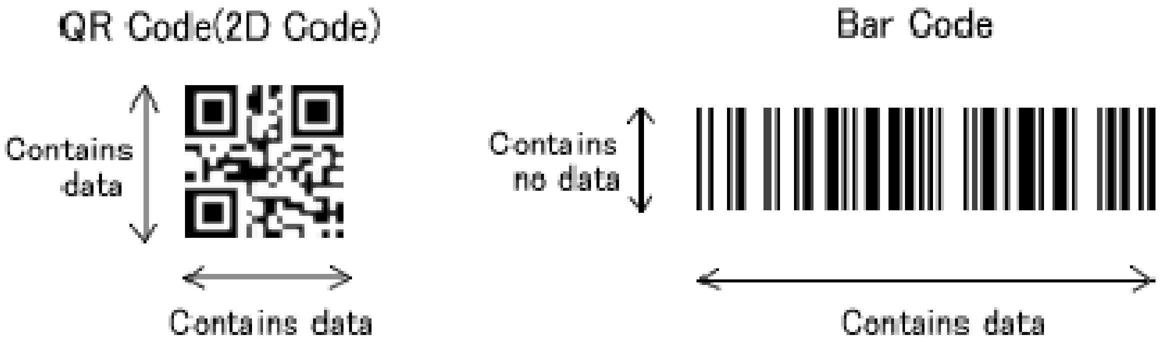


Figure 5: Comparison of QR code and Bar code (by Densowave, 2019)

A QR code is able to carry information in both the vertical and the horizontal direction, which is why it is called a 2D barcode (QR code.com 2011. This is why a QR code holds a significantly larger capacity of data. It can encrypt numerous sorts of information or data such as binary data, multimedia data, symbols and control codes. A basic barcode can hold up to a maximum of 20 digits, whereas QR codes can hold up to 7,089 characters for numeric data, 4,296 characters for alphanumeric data, 2,953 bytes for binary data and 1,817 characters for Japanese Kanji and Kana data (Mobile Barcodes 2019). It can encode a website URL, a YouTube video URL or any social media links, geo-coordinates, email addresses, email message and so on. QR Code is quicker to read than other two-dimensional code, because it comprises of three large square shapes in the corners that are used for position detection (QR Code Generator 2019). In addition, the shapes are used to sense the size, the angle and the outer shape of the symbol. When a reader scans a symbol, it first detects these shapes. Once the position patterns have been sensed the scanner can rapidly read the inside-code in all directions. The inside code comprises of several small blocks where the information is encoded. The decoding speed of the QR Code can be 20 times faster than that of other 2D symbols (Satya et al. 2012). The QR Code is a registered trademark of Denso Wave Inc. in Japan and other countries (QR code.com 2011).

The structure of a QR code is shown in Figure 6

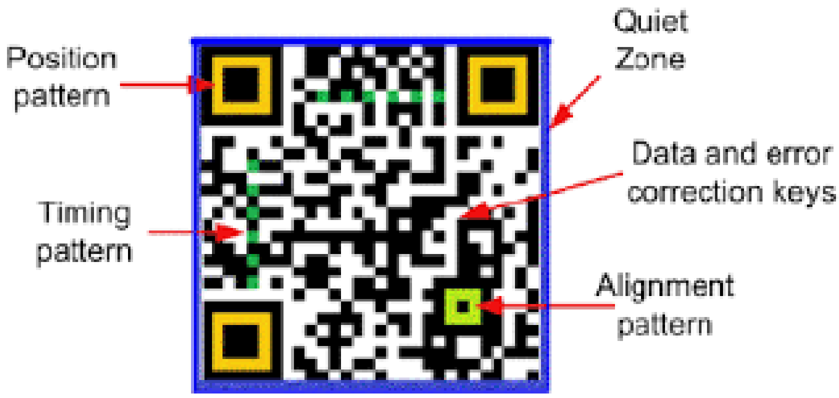


Figure 6: Elements of a QR Code (by Densowave, 2019)

Chin and Chen (2013) explained the elements contained in a QR code as follows: Position pattern/markings. Three big squares in the corners used for detecting the position, the size and the angle of the QR Code. Alignment Pattern/markings is a pattern used for correcting the distortion of the QR Code (Lalam et al. 2012). These distortions could occur for example when attaching the codes onto a curved surface. Timing Pattern consists in white and black modules arranged alternately and placed between two position patterns. It is used to determine the central coordinate of each cell in the QR Code. Quiet Zone is a margin space that makes easier to detect the QR Code from its surroundings. At least four cells are required for the quiet. Data error and correction keys is the area in the QR Code that contains the actual data (for example a URL) encoded in binary numbers (QR Code Generator 2019).

2.18 Internet of Things and Wireless Sensor Networks

Internet of Things (IoT) is the system of physical objects or things hooked up with hardware, software, sensors, and system connectivity which empowers these objects to gather and alternate information. IoT makes use of different kinds of protocols to work with exclusive objects (TutorialsPoint 2019).

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed devices integrated with sensors to cooperatively monitor physical or environmental conditions, such as temperature, pressure, humidity, vibration, motion or pollutants at different locations. Chibuye (2017) states that Remote sensor networks have relied on four components, a sensor to collect the data, an aggregator to centralize the collection of data, an uplink network to relay the data and a server to which the data is to be sent, the wireless sensor network can be further broken down into two main components, the remote sensor network and the uplink. Each wireless device is also called a node that behaves individually (Thomas Publishing Company

2019). Each node has one or more sensors integrated on it. In addition to these sensors, a node is also equipped with a transmitter and a receiver. These transmitter and receiver are used for wireless communications with other nodes or directly with the gateway. The gateway is responsible for transmitting sensor data from the sensor patch to the remote base station that provides wireless ad-hoc network (WAN) connectivity and data logging through a local transit network. Finally, the data is available to scientists through a user interface. The other parts of a sensor node are the microcontroller and the battery.

Sensors in IoT can generate high volume of raw data. Therefore, adequate storage is required to store the generated data. In addition, sufficient processing capabilities are required to turn raw data into useful information for purposes such as prediction (Ahmed 2015). Cloud computing and data mining provide sufficient processing, storage and analysis tools for understanding trends in raw data (Chibuye 2017). A reduction in latency and increased throughput has made it possible for remote computers to be managed and applications run as though they were physically local. Resource sharing in Cloud computing has enabled concepts such as Software as a Service, Platform as a Service and Database as a Service where the end user does not need to worry about the technical requirements of systems software and the technical specifications of the database but just focuses on service usage.

IoT also uses components like Android Things which make sensor networks be able to use a mobile device which takes advantage of the use of a mobile phone that sends and receives data. Android Things leverages already existing hardware platforms and development environments by installing an operating system on those capable hardware devices. That operating system called Android Things is built with an IoT architecture at its core and therefore supports native functions and routines that make implementing a prototype or developing a solution a very easy thing to achieve (Swan 2012). Other componetnts used by IoT include Messaging Protocol for example Mobile Queuing Telephony and Telemetry (MQTT), a wireless protocol stack for example zigbee which can be a wireless personal area network (WPAN). A device connected to the internet that can be sensor or an actuator which performs an action. There is also the broker which can be a centralized or cloud-based system that publishes messages to what are called topics (Kamal 2017).

Wireless Sensor Networks are part of the perception layer found in the Internet of things. Wireless Sensor Network requires multiple nodes to form a network (Kamal 2017). The sensor nodes continuously or at set intervals sense data from the environment and send the data to the sink node. The sink node collects the data from sensor nodes for viewing locally and sending for storage. The data from the sensor nodes can be accessed remotely over the Internet or other means by users (Patil 2017). The wireless sensor networks provide better methods of monitoring environmental conditions than manual methods (Zhang 2012). Wireless Sensor Networks are now a reality with applications in Smart Grids, Smart Environments and machine to machine communication (Nassef 2015).

2.19 Internet of Things Tools

2.19.1 Arduino and Sensors

The Arduino Uno in Figure 7 is a processing board using an 8-bit Atmega328 Microcontroller as the main chip. Arduino Uno operates with a voltage of 5 Volts. Arduino provides 14 digital pins, 6 analog pins, 32 kB flash memory, 2 kB SRAM, 1 kB EEPROM, 16 MHz clock speed and a USB connection (Aduino Uno 2019).

Figure 7: Arduino Uno Board (by Aduino Uno, 2019)

GSM sim900 module is a module that provides the intermediary microcontroller in the process of sending SMS. The SIM900 GSM module as shown in Figure 8 is a GSM / GPRS Quad-band GSM/GPRS which uses single chip processor LPC2148. The features within GSM SIM900 are capable of sending SMS and voice data (Components101 2019).

Figure 8: GSM sim900 module (by Components101, 2019)

The GPS U-Blox 6m module as shown in Figure 9 is a kind of stand-alone GPS receivers that feature high performance as a positioning machine. With optimized architecture, power, and memory this module is perfect for devices that use the battery as a resource with limited cost and space making it very suitable to use on CanSat. By having 50 channels of positioning engines, it can accelerate Time-To- First-Fix (TTFF) for less than 1 second (Satria et al. 2017).

Figure 9: GPS U-Blox 6m module (by Satria, 2020)

DAOKI Water Level Sensor Module Depth of Detection Liquid Surface Height Arduino, Water Sensor water level sensor in figure 10 is an easy-to-use, cost-effective high level/drop recognition sensor, which is obtained by having a series of parallel wires exposed traces measured droplets/water volume in order to determine the water level. Easy to complete water to analog signal conversion and output analog values can be directly read Arduino development board to achieve the level alarm effect. Its Specifications include: an Operating voltage of DC3-5V, Operating current: less than 20mA, Analogue Sensor Type, Detection Area: 40mmx16mm and it uses a Production process of FR4 double-sided HASL (Project Hub 2020).

Figure 10: DAOKI Water Level Sensor Module (by Project Hub, 2020)

2.20 Related Works

Most of the related works that haven done combine various technologies to develop frameworks and prototypes. However not much has been done to combine utility mapping with sensors and addition of the QR Codes to the web applications.

2.20.1 WebGIS for Water Utility Management for the Copperbelt University in Zambia

Nickolas Okello (2017) developed a GIS based decision support tool for effectively and efficiently managing the water utility networks at the Copperbelt University using PostgreSQL/PostGIS, QGIS, GeoServer and GXP template built on GeoExt and OpenLayers. The goal was to have a centralized system with easy access to accurate and updated information on water utility network spatial information throughout the university by means of the web. In his findings he sufficiently demonstrated the application's ability to act as a decision support tool for the end-users and decision makers in the management of water utility networks at the university. Prior to his study, the University was depending on paper-based utility maps which had not been updated in a long time. Some map details were sketched from memory over the years using field observations. These utility maps were still being maintained through different separate map sheets and had become inaccessible over time as most utility maps were torn or had gone missing. There were some AutoCAD drawings which were based on the utility paper maps and are primarily used for visualization purposes. The Universal Modelling Language was used to transform the existing water utility network data into suitable UML data models fundamental in the design and implementation of the system for the University water utility network.

The framework for the GIS based decision support tool was based on the evaluation of the needs assessment and workflows in the actual business processes detailing the current methods, techniques and tools used to manage the University water utility networks.

The results of the study showed the successful integration of PostgreSQL/PostGIS database with QGIS for desktop mapping and GeoServer for web mapping. The web application had several tools like query, zoom, view, search and identify, that provide an interactive interface to the spatial data without location restrictions. The desktop application provided both visualization and analytical functions that created patterns and relationships from diverse sources of information. The framework made it much easier to resolve spatial problems. The system validation was done using the User Experience Analysis. The interaction between the users and the application system was measured in the form of functionality, content and usability. The results of the evaluation and testing of the system using the User Experience Analysis showed that the application development efforts were successful based on the appropriate functionality of the system to the tasks, availability of appropriate data and general organisation of the data in the system, system response times, ease of learning and access to information.

The results showed that the functions were appropriate, well organised, with appropriate data content making the system user friendly. The findings sufficiently demonstrated the application's ability to act as a decision support tool for the end-users and decision makers in the management of water utility networks at the University. The data needs for the water utility networks with due respect to the new methods, techniques and tools that were to be used to manage water utility networks were catalogued successfully into the functional recurrent tasks and functional data reporting needs for the water and sewer network operations, planning and construction.

2.20.2 An IoT based Warehouse Intrusion Detection (E-Perimeter) and Grain Tracking Model for the Zambia Food Reserve Agency.

In Zambia government through the FRA ensures countrywide food sustainability and offers market access for rural based small holder farmers by maintaining a sustainable countrywide strategic food reserve. FRA also acts as a macro-economic stabilizer for food grown in the country, such as maize which is the nation's staple crop. Zambia's agricultural sector through Food Reserve Agency (FRA) while still underdeveloped faced many challenges that ranged from marketing, spoilage, infestations, and theft at site, spillage and storage among others. The government of Zambia through FRA despite ensuring national food security, almost every year experienced huge quantities of food are lost due to many factors such as spoilage, infestations, theft and spillage during transporting. Chihana (2018) carried out a baseline study to assess the existing system. It was noted the FRA faced challenges in efficient management of inventory.

It experienced maize shortages at various depots and the losses were attributed to theft and grain spoilage at the warehouse depots. Most of the challenges were as a result of poor monitoring and a poor inventory management approach which was largely manual and paper based. The FRA faced challenges to effectively monitor and inspect its storage facilities and organized crime was another factor that lead to shortages usually at the time of dispatch.

In order to help curb these problems, Chihana (2018) proposed and developed novel methods that could be used to sense real-time warehouse intrusion and grain tracking within the FRA circulation. The major objective of the study was to design a warehouse Intrusion detection (E-Perimeter) and grain tracking Model based on IoT, cloud storage and mobile communication for securing grain. To also develop methods based on the model for accessing grain status information in real-time and lastly to Develop a prototype application based on the web to provide real-time access to warehouse intrusion alerts and current warehouse grain quantities.

The literature reviewed explored the use of internet of things (IoT) and their applications in related research. It significantly provided a base for understanding the concept of IoT and their applications in intrusion detection and grain tracking.

The proposed model seeked to address the gaps in grain theft at FRA warehouse storage using motion sensing and grain tracking using RFID. The model was based on the current FRAs business processes but with a focus mainly on warehouse storage and grain tracking and tracing. The proposed IoT model was divided into two, intrusion detection which was achieved by putting in place an E-perimeter to monitor unauthorized entry in the restricted zone were the grain could be stocked so that the grain is secured. The IoT technologies adopted for this module were wireless data communication module APC220, GSM to alert management by sending an SMS once motion detection happened with the help of the motion sensors, GPRS via an HTTP GET REQUEST for data transfer to the cloud database and PIR (passive infrared) because these were mainly for intrusion detection, it was also capable of detecting any trespassing that occurred in the range of the motion sensor. The second module responsible for grain tracking, once the grain bags were tagged and ready for dis-patch, this module could be used for tallying to compare the number of dispatched bags against the received from one depot to another within the FRA circulation. This was to be achieved using an IoT device called Radio Frequency Identification (RFID) to uniquely identify each bag, additionally the use GSM, GPRS modules that were embedded in the SIM808 communication module. The RFID combined with GSM and Arduino microcontroller were responsible for grain tracking.

An experiment was conducted for the proof of concept to ascertain the working of the prototype model that was proposed. From the experiment conducted it was noted that the model proposed was not just a layout of the processes but the practicality behind it was possible. The modules and the methods were tested utilized and proved beyond doubt that they were a better option for FRA grain management. From the results obtained in the experiment conducted it was believed that once this technology was adopted, thefts would be reduced and grain management in the FRA satellite Depots dotted around the country would improve.

Based on the objectives of this study the authors concluded that Internet of things-based technologies RFID, WSN and cloud storage utilization reduced occurrences of theft and administrative errors, and aids in significantly improving efficiency and accountability. It was further drawn from the experiment and observation analysis on the model that the agency had an advantage of the modern proposed technology in this research.

2.20.3 A Remote Sensor Network using Android Things and Cloud Computing for the Food Reserve Agency in Zambia

To introduce modern warehousing, improve upon the storage of grain and grain marketing business processes for the Food Reserve Agency in Zambia, Chibuye (2017) developed a prototype of a remote sensor network and built as a proof of concept for a much wider deployment using cloud computing and the internet of things concept. It was determined that a wireless sensor network would aid the Food Reserve Agency in analytics, timely action, and real-time reporting from all its food depots spread-out throughout Zambia. Google's Android Things Platform was used to achieve the objectives. Advantages of Android Things over traditional platforms that had been used to develop wireless sensor networks were investigated and presented in this paper.

The agency generates a loT of data and information regarding Zambia's strategic food reserves that is a key for national planning. However, the organization has been facing a lot of challenges in managing this information due to lack of automation. The agency generated reports manually which resulted in errors and delays, warehouses are not monitored in real time and specialized personnel are required to assess the environment at both satellite and main depots where grain is stored. Weaknesses in grain management, Excess purchase of crops, Excess stock losses attributed to spillages, pilferage, warehouse Management – Poor Stacking making hard to take stock and poor State of Storage Facilities – Silos.

A baseline study was carried out to map out the FRA business processes and to see whether business process reengineering could be applied, and the processes automated. Selfadministered forms, interviews and observations were used to understand the FRA business processes. A mix methods research methodology was employed in trying to map out the FRA business processes. A descriptive approach was also employed to affirm the finding from the mixed method that was initially used.

In trying to develop a low-cost remote sensor network solution relying on cloud computing, the requirements, and components for such a network were determined and these were sensors, aggregators, an uplink and downlink network and a cloud-based storage service. The most usual method of creating a sensor network would be to connect a series of sensors to a personal area network and an aggregator that has a GSM shield. This GSM shield may support the common mobile network technologies such as GSM, 3G, LTE and most recently 5G. The GSM shield is connected to the aggregator and an operating system is used to communicate with the shield and upload data to a remote server. The cloud-based service earlier referred to for the purposes of the prototype was a broker that is used to gather all the information from the remote sensors, the most popular open-source broker being the Mosquitto server. Popular devices that are used for the aggregators are the Raspberry Pi or some other device with acceptable computational power and computer architecture as there would have to be some sort of operating system installed on the aggregator. The common setup was looked at and analyzed to know whether a low-cost solution based on the common architecture could be built and whether it could be improved upon. The conclusion was that since the Android operating system supported native sensors, it could be used along with its high-level API calls as the operating system of choice for the remote sensor networks aggregator.

The prototype developed used Google Cloud Platform but due to cost implications it was recommended that the National Data Centre of Zambia is leveraged for data storage and data processing. Since redundancy and resilience are a key factor in national data storage and indeed for the Food Reserve Agency’s everyday work, it was further recommended that Blockchain technology be explored as the standard for the backend storage and data processing. A universal model for a simple and possibly low-cost remote sensor network that may be implemented by the Food Reserve Agency in Zambia was developed and it was evident that modern warehousing relying on components such as sensors provided better grain storage, management, transparency of operations and hence lead to cost effective grain marketing which leads to better national food security.

2.20.4 Web Geographic Information Systems (Webgis) For Smart Campus and Facility Management at the Faculty of Science and Technology at University of Coimbra in Portugal.

Chilela (2016) developed a WebGIS at University of Houston in United States of America. It was capable of saving, organizing, and geo-spatializing information from all over the campus and facilities. The WebGIS could process data and manipulate devices connected to the internet using concepts and tools of Internet of Things and provide the number of people inside of buildings. The information about the number of people inside of buildings was a new technology known as smart door. In case of a public business building (bank or shopping for instance), the WebGIS was capable, for example, of showing the average time that a client would spend in that building to be attended. In addition, the study provided a mobile application to allow users to interact with smart campus and campus facilities and to facilitate access to basic information about public transportation and data sensors which had been placed in various locations around campus.

The study mainly concentrated on the guiding and navigation as two mutual facilities at certain times. There are applications which offers navigation services but majority of them are outdoor applications which cannot provide guidance inside the campus or a large area. The study also provided much significance to the Point of Interest (POI). Main drawback of today's technology in navigation is POI so this paper investigated it as well. Other problem was in what way we deliver guidance to the handler to give him exact information. This paper also reflected the category of smart devices required and how to deal with context aware computing on smart phone.

The techniques based on imagery and Augmented Reality (AR) which can show to be of great support when determining a new city location and seeing the development of the normal atmosphere were presented. It also looked at the several perceptions of pervasive augmented reality demonstrated by indoor and outdoor applications, and it displayed the use of augmented reality for facilitating people to determine new surroundings.

2.20.5 A Real-Time Data Capture Model for Accelerated Payment of Small-Scale Farmers: A system developed for the Zambia Food Reserve Agency

Mwansa and Phiri (2018) proposed a model for the inventory system based on Quick Response (QR) and cloud computing for real-time capture of grain bags brought in by farmers at the satellite depot for the Food Reserve Agency (FRA). The government supplied farming input to local farmers and bought the grain back from the farmers. The study looked at part of the buying process which required the movement of grain from the local farmer to the government. The proposed system first required tagging the grain bags then capturing the details of the farmer and attached this to the grain bags. Their proposed model based on cloud technologies was integrated with the mobile application used to read the QR code attached to the grain bags. These details were then linked to the details of the farmer in the database. These captured data regarding the farmer and grain bags supplied at the satellite depot were made available to the decision makers in real-time. The results of the study showed that the proposed model would help to address several challenges that the current system had been facing. These included accelerated process of paying the local farmers supplying grain to the government which used to take months. It would also help to give the grain stock statistics in real time per region and the country at large. This model would be very useful for most developing countries in managing their grain.

2.20.6 Fujitsu Develops Technology for Low-Cost Detection of Potential Sewer System Overflows

From rainfall data, patterns, and topography Fujistsu Technologies (2015) were able to come up with the best locations for placing sensors in a sewer network. They developed a technology that uses ICT for low-cost detection of early signs of sewer system overflows to mitigate damage in cities stemming from torrential downpours. The technology for determining the locations and number of manholes where sensors should be installed, based on an analysis of the time required for water to flow from upstream pipes to downstream locations in accordance with land topography and the shape and length of sewer pipes, which makes it possible to track and predict the overall flow through a sewer system using only about one-fifth as many sensors.

The technology that optimally controls measurement parameters in accordance with changes in measured water levels enables sensors to consume less power. This reduces costs associated with replacing batteries for individual sensors. Key features of the technologies include determining sensor locations based on required water flow time for changing water levels - this is based upon correlations obtained between water level changes and topography, data on sewer pipes, and rainfall patterns, takes the time considered to compute the degree of correlation between changes in upstream water levels and changes in downstream water levels. This makes it possible to avoid installing sensors in areas with low degrees of correlation and enables a determination to be made on where sensors should be installed based on topography, the layout of the sewer pipes, and rainfall characteristics.

The other key feature of the technology is the Sensing power control technology that adjusts to circumstances - In sensing, most of the power that needs to be consumed consists of the power used when taking measurements and the power used to transmit measurements to gateways on the network. By using longer intervals between sampling when there is clear weather and little changes in water levels, and shorter sampling durations when there is rainy weather and rapid changes in water levels, and by taking measurements and transmitting while performing control, less power is required for sensing. However, this had been insufficient to respond when it was raining. This newly developed technology predicted future changes in water levels based on past measurements and based upon the circumstances of sensors at any given time, automatically adjusts the three parameters of the measurement interval, the notification interval, and the measurement duration to maintain the required accuracy of measurement data based on the circumstances while conserving sensor power.

These technologies made it possible to install approximately one-fifth the number of sensors in manholes overall, while accurately tracking and predicting sewer water flow throughout a system. In simulations, selectively controlling sensors to match typical rainfall patterns was found to maintain measurement accuracy while reducing power consumption by roughly 70%. Assuming that sensors were operated using solar cells or other renewable-energy sources, the per-unit operating costs of a sensor would be reduced by roughly 90%.

Fujitsu Laboratories planned to develop technologies for further reducing the power consumption and costs of sensing devices and would continue to consider ways to use sensor data with the aim of achieving practical implementations of these technologies during fiscal 2015.

2.20.7 Web Based Document Archiving Using Time Stamp and Barcode Technologies – A Case of the University of Zambia

Mutale (2016) proposed a document archiving system which would integrate barcoding, time stamping and mobile technologies to improve on the achieving and retrieval processes. The study began with the baseline study to establish the challenges faced by institutions of learning in document archiving. The study was based on the University of Zambia. The results from the study indicated that 70% of the offices used the manual box file system in document achieving. They also lacked storage space for box files with 80% having difficulties in retrieving old documents. Based on this study, Mutale designed and implemented a document archiving system. The system was developed in C#. It had time stamp integrated with short messaging system (SMS) for reminders and barcode which was electronically stapled on the soft copies before being archived to improve on the identity of the document.

Prior to the system design, baseline study was conducted to determine the lack of storage space for box files and folders. The baseline also helped to determine difficulties that users face to retrieve old record and the ability to use a computer. A model of the solution was designed to alleviate archiving problems facing the university. Using this model, a prototype was developed using the waterfall agile method and a database was developed. The developed model was a web-based document archiving system that integrates bar-coding to improve on identity and retrieval of documents. It would also integrate time stamping for reminders through pop-ups, emails and Short Message Service (SMS) systems. The time stamp gave notices when a particular document was due. Each document was stamped with a barcode to improve on document identity and quick retrieval.

2.20.8 An App based Garden Bot for Regulation of Water Level in plants

Chawla (2016) developed an automated irrigation system to optimize the use of water for plants and verify water scarcity problem. The app-based garden bot was developed for the automatic regulation of water level in plants. The system used Raspberry Pi board as a base and low-cost capacitive sensor for providing the low power consumption and cost-effective solution to automatic irrigation of plants. The system was programmed using Python and Java based App where the communication between them was carried out based on the concept of socket forwarding.

The Android app was developed using Java to interface with raspberry pie microcontroller. The app provided the user interface to authenticate the user identity for automation of irrigation system. The user login information was stored in the database and could be retrieved to verify the identity of authenticated users. The users upon successful login could send the sensor data request to microcontroller and the requested data was retrieved from the sensor database to identify the water level in plants. Thus, upon receiving the sensor data on android app it was processed using water level threshold to give on/off command to microcontroller. Hence the microcontroller upon receiving the on/off command from user, the motor was on/off accordingly for the supply of water to plants. The python script ran on microcontroller to process the command received from android and store the sensor data in database.

The experiment was conducted to test the automatic control of irrigation using android based app, raspberry pi and low-cost capacitor sensors. The hardware requirements were an android phone/emulator from android studio, raspberry pi (2B), Internet connection with port 80 forwarded to the IP address of Raspberry Pi (2B). The software requirements were: android studio, raspbian OS for the Raspberry PI, Apache 2 for the server to be run on the Pi ,PHP to create, modify and manage the databases and MySQL for the databases.

The database is created using server side PHP scripting. On client side java, Json parser library was used for making the app and the server communication. JSON Parser library was used for parsing the PHP code to Java and vice-versa, thus making app and the server, both, to comprehend the parameters correctly and the http connection could be established including the snapshot of json library and http connection with raspberry.

The system was run for several simulation using sensor reading and user input in order to obtain the optimal setting of sensors for automatic irrigation. By continuously monitoring the status of the soil, the flow of water can be controlled and thereby reduce the wastage. The design was low power, low cost, small size, robust and highly versatile. Thus, this system avoided over irrigation, under irrigation and reduced the wastage of water. The main advantage was that the system's action could be changed according to the situation (crops, weather conditions, soil etc.). By implementing this system, agricultural, horticultural lands, parks, gardens could be irrigated.

2.20.9 Development of an Agricultural Geographical Information System

Simukanga (2018) developed an information system to monitor grain storage facilities and small-scale farmer land parcels. The proposed module would assist in improving food security by providing a real-time record of stock levels in the various strategic grain reserves. It would also help the Government, through the Farmer Input Support Program, adequately target small scale farmers. Knowing where farmers are located was vital information for the planning process. The study aimed to display locations of FRA Storage Facilities, Small Scale Farmers' land parcels and track the crops grown on the land parcels as well as develop a mobile application for the collection of location data.

The system requirements were identified using a mixed methods methodology. This involved relying on multiple techniques for data gathering such as inter-views and document sampling. The requirements were split between the functional and non-functional requirements. An Agile Incremental Development approach was taken during the development of the map view component of the system. This process involved creating multiple prototypes of the required system. Each prototype was analyzed, allowing for any errors or omissions in the requirements to be revealed long before system handover.

The web development tools used included Google Maps Platform - Maps JavaScript Application Programming Interface (API), Java Script, HTML/ CSS, Hypertext Processor – PHP and PostgreSQL for the spatial database.

Backend of the system was the main web application which was developed using the PHP scripting language. This was the main module that interfaced with the PostgreSQL database. This module also contained the Google Maps Platform, application programming interface (API) through which the mapping module and mobile application communicate with the system. The Mapping module comprised of JavaScript and HTML. The required data was fetched through one of the backend system APIs and formatted as required. The mobile application used Java, PHP and JavaScript and a simple implementation of was created. The application kept track of all the points selected and sent the entire collection of points upon completion. The series of points were displayed on the application view.

2.20.10 A GIS-Based Parking Management and Dissemination System

Watene (2019) developed a Geographic Information System, GIS that enhanced the components of a Post GIS (PGIS) to run on a mobile phone platform thereby allowing a driver to access parking information whenever and wherever the driver was. The GIS-based PGIS provided the driver with a view of the near real time parking situation of his destination, allowing him to reserve a space as well as have his smart phone enabled to notify him once he approaches a vacant space or even perform routing functions. Thirty parking spaces were collected within Jomo Kenyatta University of Agriculture and Technology, were classified, mapped and published in a web map server. A Quick Response Code was installed on each parking space and a SMS server was established to monitor the reports and requests of drivers. An Android smart phone application was created that was able to reap parking information from the map server. The system greatly reduced the trial and error involved while in search of a parking space thus increasing a driver's confidence, cutting down on the amount of parking time and the emotional stress associated with finding a parking space.

The system design assembly started with mapping of parking spaces in the study area. Each parking space was uniquely identified with a special number and QR code generated for each space. The QR code included the dispatcher's mobile number. A database showing all the mapped parking spaces with their attributes was created. A SMS server was established that formed a link between the parking spaces and the geodatabase. A web server Application Programming Interface (API) was established and published over the internet which could be accessed and analyzed by an Android smart phone application. Diafaan SMS server was used to form a link between the drivers' messages and the geodatabase. The server received requests, reports, and bookings from the drivers, replied automatically to respective drivers and filtered the messages to get the unique numbers which would be used to update the database and consequently the web map.

Java programming for Android was used to customize and assemble an installable Android based smart phone application. The application could connect with the GPS and pocket data functions of the phone. There was a welcoming page that directed the user to a short menu. The user was given the option to have a view of the available parking spaces displayed as a list or alternatively launch the phone's browser hence display scaled version of the web map. A booking facility was incorporated that allowed the driver to send his car's registration number. A SMS would be sent to the driver confirming his request and alerting him that his booking would elapse after a span of half an hour. By identifying the driver's desired parking space and connecting to the GPS in the application, there was an option of performing routing function where the parking space and driver's position are treated as the destination and starting points respectively. A line could be drawn on the smart phone web map to be used as a guide to the driver.

2.20.11 Development of a web based GIS for health facilities mapping, monitoring and reporting: A case study of the Zambian Ministry of health

Mushonga (2017) reviewed recent literature on GIS in health care with particular emphasis on web GIS technologies and how they could aid in analysing health care needs, access, and utilization to support in the planning and evaluation of new service locations as well as use of GIS in disease surveillance. The study aimed at producing a web-based GIS that could be used to collect data from health facilities and in turn provide this data to public health administrators to support decision making, it also focused on creating a portal for public interaction with health facilities spatial information.

The online health facilities web-based GIS system was designed and implemented using MySQL as the spatial database management System. An Apache server was used as the application server. PHP was used as the scripting language to program the server side that manipulated the information in the database. A development cycle based on the waterfall approach to system development was used to ensure the successful implementation of the web-based GIS system. The waterfall approach makes it is easier to manage the system development because each phase of development has specific deliverables and thus can be evaluated separately.

The web GIS application had a hybrid architecture where, spatial functions were conducted on the client side to minimise data traffic between the web server and browser therefore ensuring smooth operation without processing lag. The web-based GIS could make requests for map tiles from the open street map tile service; the map tiles form the base map for the system showing regional boundaries, roads and other points of interest. Open street map tile service was selected for use for its lack of restrictions and for being free with an open license.

The user interface included some zoom in and out and navigation buttons. The system was built in such way that it could be responsive and thus the interface could maintain its display integrity and appeared the same across various screen sizes. Functionalities were added including nearest neighbour search, point buffering, heat map search and health facility search.

2.20.12 IoT Based Smart Garbage Monitoring System Using ESP8266 with GPS Link

Johar (2018) proposed an IoT based system, which termed smart garbage monitoring system along with the GPS link and real time monitoring with alerting facility. Earlier systems designed were not cost efficient and were bulky in size, as they were using Raspberry-Pi module, GSM module, used GPS antenna, etc. In this new system however, the hardware parts were removed to reduce the size of circuitry which also reduced the cost of the system. Additionally, Solar panels were used for power supply with the battery backup for cloudy situations. The level sensors in the garbage bin could detect the garbage level continuously and accordingly the system provided the information to the municipality office. This would avoid the overflowing of the garbage bins. Ultimately it would help with keeping the environment clean and reduce health issues.

The IoT system process started from the garbage bin where Infrared (IR) sensors are fixed on each level of the garbage bin. The system was provided with unique identification for each garbage bin. Levels were being taken at 5 levels of the garbage bin and a threshold level was selected for alerting purposes. The garbage level could be sensed by the IR sensors. The system was designed such that as soon as the garbage in the garbage bin crossed the threshold level, the alerting text message would be sent to the concerned person or in the municipality office. The message contained the garbage bin ID along with the GPS link. This GPS link would help to find the shortest path of that garbage bin. This was helpful especially for new drivers of municipality garbage collection vehicles.

This study used some of the methodologies from the various works outlined and the framework developed involved combining some of these methodologies. Table 1shows the literature reviewed of some related works and summarises their findings and some gaps compared to this study.

Table 1: The summary of the literature reviewed and some gaps in comparison to the study (By author)

No	AUTHOR	YEAR	TITLE	PUBLISHER	FINDINGS	GAPS
1	Okello, N. Nicholas, Banda Faustine and Tembo, E	2017	"WebGIS for Water Utility Management at the Copperbelt University"	Imperial Journal of Interdisciplinary Research (IJIR)	Developed the Web based GIS Using PostgreSQL, Geoserver, OpenLayers and Apache server	• QR Coding and Tagging was not done • The final output was a desktop application were as a web and mobile applications would be done for this study
2	Sipiwe Chihana, Jackson Phiri and Douglas	2018	"An IoT based Warehouse Intrusion Detection (E-Perimeter) and Grain Tracking Model for Food Reserve Agency"	International Journal of Advanced Computer Science and Applications (IJACSA)	Designed and developed a prototype for a warehouse Intrusion detection (E-Perimeter) and grain tracking Model based on IoT, cloud storage and mobile communication for securing grain	• Spatial Mapping was not employed in the study • QR Coding and Tagging was not done
3	Mulima Chibuye and Jackson Phiri	2017	"A Remote Sensor Network using Android	International Journal of Advanced Computer Science and	Developed a prototype of a remote sensor network for modern warehousing to improve upon the	• Spatial Mapping was not employed in the study

			Things and Cloud Computing for the Food Reserve Agency in Zambia"	Applications (IJACSA),	storage of grain and grain marketing business processes for the Food Reserve Agency in Zambia	• The study employed the Google Cloud Platform for data storage, were as PostgreSQL was used for storage.
4	Júlio Gabriel Chilela	2016	"Web Geographic Information Systems (Webgis) For Smart Campus and Facility Management"	Mathematics of Faculty of Science and Technology at University of Coimbra, Portugal	Developed a WEBGIS capable of saving, organizing, and geo-spatializing information from all over the campus and facilities. The WebGIS could process data and manipulate devices connected to the internet using concepts and tools of Internet of Things and provide the number of people inside of buildings.	• This system was more of a guidance and navigation system for use by university sudents. It did not look at water and sewer networks. • There was no QR Coding and tagging for the facilities mapped.
5	Natasha Mwansa and Jackson Phiri	2018	"Automatic Data Capturing At Satellite Depots Based On NFC Technology"	International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)	Proposed a model for the inventory system based on Quick Response (QR) and cloud computing for real-time capture of grain bags brought in by farmers at the satellite depot for the Food Reserve Agency (FRA)	The system developed did not use the mapping tools nor had a dashboard for location data monitoring.
6	Fujitsu Laboratories Ltd	2015	"Fujitsu Develops Technology for Low-Cost	Fujistu Technologies Solutions	developed low-cost technology detection of early signs of sewer system overflows to mitigate damage in cities stemming from torrential downpours. The technology for determining the	• There was no QR Coding or Tagging in the system

			Detection of Potential Sewer System Overflows”		locations and number of manholes where sensors should be installed, based on an analysis of the time required for water to flow from upstream pipes to downstream locations in accordance with land topography and the shape and length of sewer pipes, which makes it possible to track and predict the overall flow through a sewer system using only about one-fifth as many sensors	• The system was only web based and designed for sewer facilities staff not for other users
7	Brian M. Mutale and Jackson Phiri	2016	“Web Based Document Archiving Using Time Stamp and Barcode Technologies – A Case of the University of Zambia”	International Journal of Innovative Research in Science, Engineering and Technology	Proposed a document archiving system which would integrate barcoding, time stamping and mobile technologies to improve on the achieving and retrieval processes	• The system only used bar coding technology • The system was also web based and had no mobile technologies
8	Suruchi Chawla, Amita Kapoor, Shallu Sharma, Bhanvi Shukla	2016	“App based Garden Bot for Regulation of Water Level in plants”	International Research Journal of Engineering and Technology (IRJET)	Developed an automated irrigation system to optimize the use of water for plants and verify water scarcity problem. The app-based garden bot was developed for the automatic regulation of water level in plants	• The app only used mobile app technologies • The system used raspberry pi for water sensors were as Arduino was used in this study

9	Alinani Simukanga, J. Mulenga, J. Phiri	2018	“Development of an Agricultural Geographical Information System”	Zambia Information Communication Technology (ICT)	Developed an information system to monitor grain storage facilities and small-scale farmer land parcels.	There was no QR Coding or tagging of farmer’s parcels in the developed system
10	George Watene, Douglas Musiega, Charles Ndegwa	2019	“A GIS Based Parking Management and Dissemination System”	International Journal of Science and Research (IJSR)	Used Post GIS (PGIS) to run on a mobile phone platform to allow a driver to access parking information whenever and wherever the driver was	Only mobile app technologies were used.
11	Hilary Takudzwa Mushonga, Faustin Banda and Augustine Mulolwa	2017	“Development of a web-based GIS for health facilities mapping, monitoring and reporting: A case study of the Zambian Ministry of health”	South African Journal of Geomatics	Produced a web-based GIS that could be used to collect data from health facilities and in turn provide this data to public health administrators to support decision making. It also focused on creating a portal for public interaction with health facilities spatial information.	The system developed did not include tagging or QR code technology.

12	Eveneet Johar, Rahul Mishra, Pranali Redij, Sayali Patil , Ms. Jyoti Mali	2018	“IoT Based Intelligent Garbage Monitoring System”	International Journal of Engineering and Techniques	Developed a smart garbage monitoring system along with the GPS link and real time monitoring with alerting facility. In this new system, the hardware parts were removed to reduce the size of circuitry which also reduced the cost of the system. Solar panels were also used for power supply with the battery backup for cloudy situations.	The system developed used only id’s and did not include tagging or QR code technology for identification.

2.21. Chapter Summary

This chapter introduced some key concepts of the tools and theories used in this study. It also looked at some related works that were done across the world and in Zambia. A review was done on the findings and some gaps highlighted. Some tools methodologies used by previous researchers were also reviewed.

CHAPTER THREE: RESEARCH METHODOLOGY

3.0 Introduction

The methodology will involve the understanding of the spatial distribution of the utilities installed cross campus. This will involve the framework design, the tools and materials and the assessment of users' needs. The user needs assessment will include the collection of data from the Resident Engineer's Office and interviews of key personnel. Data processing, georeferencing of images, shapefile creating, naming, and tagging will be discussed to highlight how the tools will be used. The application development, database design and implementation will be explained. The application development which includes DesktopGIS and WebGIS will be highlighted to show how they will be utilised. Finally, the mobile application development and the prototype design and developed will be discussed.

3.1 Research and Framework Design

The research design provided the framework within which the research study was conducted. It constituted the outline for the collection, measurement, and analysis of relevant evidence with minimal expenditure of effort, time and money hence it was critical to the success of the whole undertaking. The research design addressed the following to answer the three research questions and ultimately satisfy the set objectives:

- Selecting appropriate methods and tools by which data is to be collected.
- Formulating the design and implementation of the system.
- Collecting, processing, and analysing the data.
- Reporting formats for the findings.
- Automation of the developed system

The framework design is summarised in the figure 11. It shows the five stages which were involved in in the project implementation.

1. Initiation stage - Identifying the challenges, Engagement with the users/ Resident Engineer and getting an idea of the current system processes.
2. Discovery/ exploratory stage - understanding user needs, understand current processes and practices and making observations as well as interviews of the users.
3. Ideate/ strategize stage - Literature Review of other studies, proposing a process design by identifying all process to be involved from data collection to prototype

implementation. This is the stage where the creation of the proposed system design is done.

4. Prototype Development stage - Creating Web and Mobile system for management of facilities as well as reporting mechanisms, physical tagging system and systems integration.
5. System Implementation stage – Testing and Debugging, User Reviews and system adoption as well as assessment of system's performance compared to the expected outcomes.

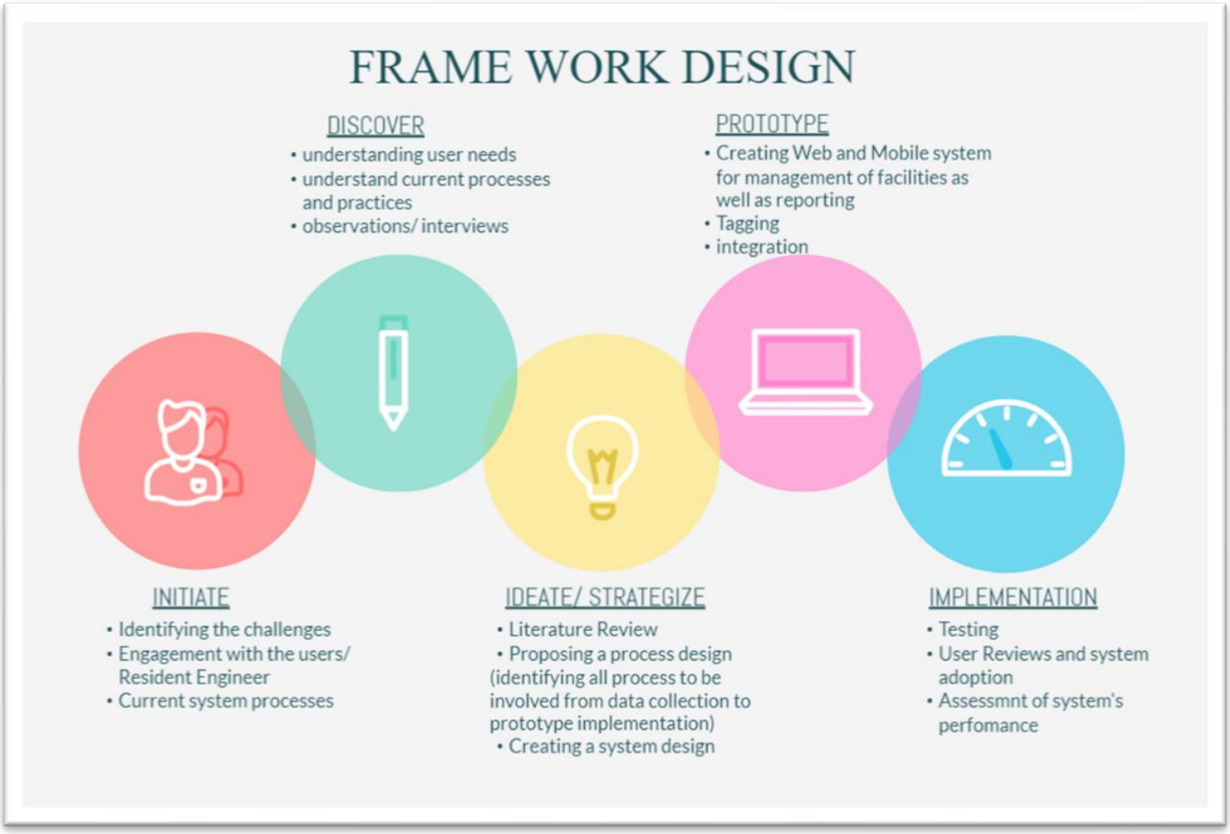


Figure 11: Framework design (by author, 2022)

Using the framework, the methodology used was based on the following activities.

- A general assessment of the business processes, existing data and data formats, existing utility network systems, goals and objectives and proposed system use.
- Collection of data from primary and secondary sources. These included AutoCAD drawings, existing paper maps, downloading of satellite images and attribute data from reports and observations.

- Dataset creation and conversion of both collected and existing data in a geospatial database. These included database editing, CAD data conversion to shapefile formats, scanning of paper maps, geo-referencing, digitising, adding of attribute data and coding.
- Application development of DesktopGIS and WebGIS. Design of the geo-spatial database based on the general assessment and utility data models that support object relationships that simulate real world relationships. This includes analysis and report generation modules, integration of geo-spatial database with web portal.
- Sensor integration and Internet of things IoT – connecting of the sensors to the developed WEBGIS and inclusion of features to allow for both mobile and web app usage of sensor data.
- Physical tagging of QR Codes on the structures in the field – Placing of the generated QR codes on to each structure for easy identification. The figure 12 shows the workflow of the proposed methodology.

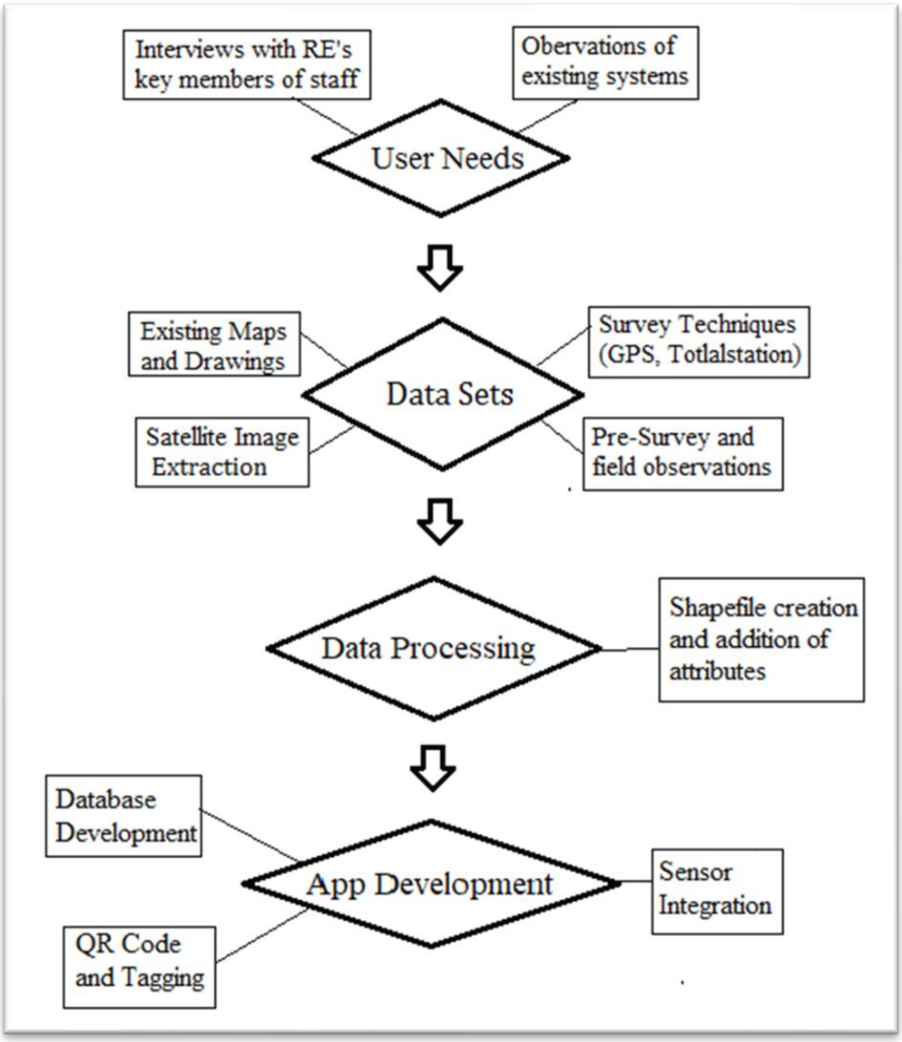


Figure 12: Workflow of the methodology (by author, 2019)

3.2 Materials and Tools

The tools (equipment), materials and software tools used in the study to realise the methodology are shown in the Tables 1 and 2

Table 2: Tools and Materials (by author, 2019)

Equipment used in the study			
Name	**Model**	**Accessories**	**Usage**
GPS GNSS rtk Base	Hi Target v30	Batteries, tripod stand, tape	Setting Base Station
GPS GNSS rtk Rover	Hi Target v30	Controller, batteries	Data collection using the controller
Total Station	Topcon	Tripod stand, prism pole, tape, prism	Data Collection for additional points inaccessible by GPS
Tablet PC	Galaxy Tab E, Samsung	Software Apps; GPS Essentials	Data Collection for the pre survey for validation of existing map data
Laptop	Toshiba Satellite L640	Software Apps; Microsoft Excel, word, ArcGIs, QGIS, Web and other Software development tools, Internet	Data Processing and other processes as well as prototype development
Water level Sensors and Arduino Uno R3		LED lights, resistors, Water and a bucket	Collection of water level data and sending notifications for any overflows

Table 3: Software used (by author, 2022)

Software (tools) used in the study	
Name	**Usage**
GPS Essentials	Pre Survey
SurvCe and Ht Target Software	Data Collection
Microsoft Office (Word, Excel, Access, Paint)	Data Processing and storage
Mapping Tools (ArcGIS, QGIS, Bing Maps, SASplanet)	Mapping and Data creation
PostgreSQL/PostGIS and Geoserver	Spatial Database and Map server
PHP, Java, Maps JavaScript Application Programming Interface (API), Java Script, HTML/ CSS	Authentication Web development
Android Studio	Mobile Development
Firebase Cloud Messaging	Messaging

Google Maps Api’s	Maps and Map Functionalities
Arduino Kit and IOT Software	Integration of sensors and the WEB app
Tinkercard	Simulation of aduino sensors
Arduino Kit and IOT Software	Integration of sensors and the WEB app

3.3 User Needs Assessment and Data Collection

The methodology involved understating the existing operations of the Resident engineer’s office to understand the user needs. In addition, existing data was collected to ascertain the current system to see how to best develop the framework.

3.3.1 Assessment of User Needs

The resident engineer’s office was engaged to find out what their current system for the management and maintenance of the utility is. These needs formed the basis of the research and the development and design of the prototype had this in mind in order to be able to answer or improve on the identified user needs.

3.3.2 Data Collection

The data collection began after the research problem was defined and research design/ plan had been formulated. Multiple data collection methods were used. Data Collection tools included the following, records, and Secondary Data, Field Observations, Interviews and field Surveys and Maps.

Records and Secondary data – included hard copy maps, scanned maps, electronic files (AutoCAD drawings). Unstructured interviews where adopted and using purposive sampling technique information was obtained from key members of staff from the resident Engineers office. The members of staff included; The Resident Engineer, The Water and Sewer Superintendent, The sewer System technician and the water system technician. The assessment of user needs was based on these interviews. The figures show 13, 14 the existing water and sewer layout respectively. Figure 15 shows both the water and sewer networks.

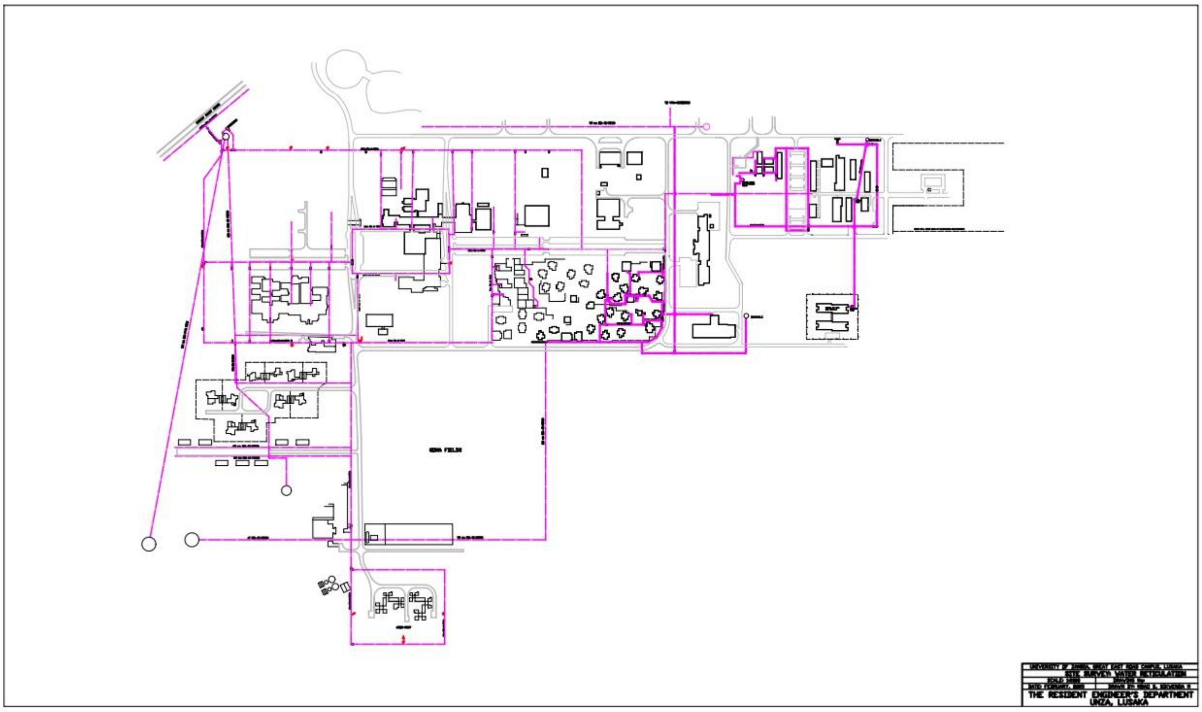


Figure 13: Water Reticulation System in AutoCAD (Not georeferenced) (The Resident Engineer's Office, 2020)

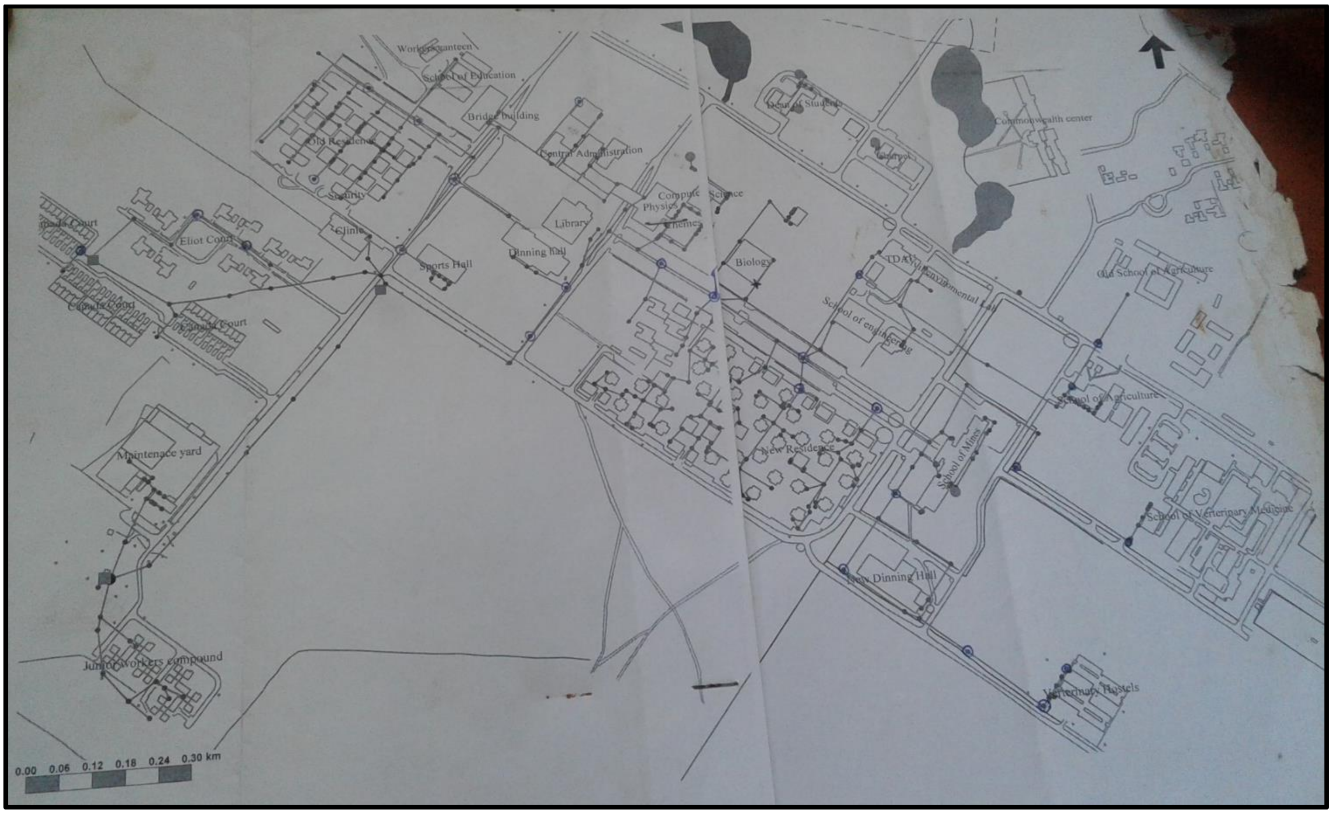


Figure 14: Hard Copy Map of sewer network (The Resident Engineer’s Office, 2020)

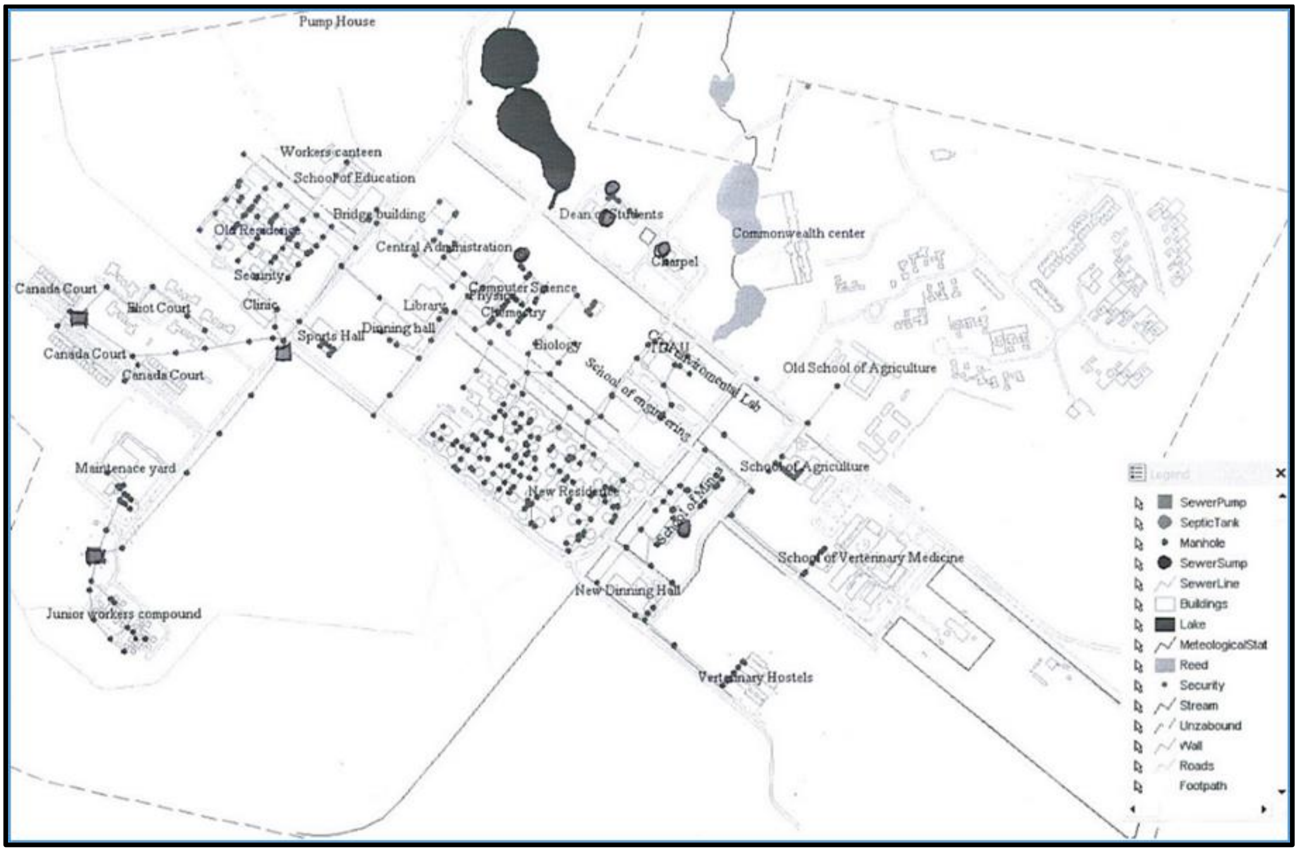


Figure 15: Hard Copy Map of sewer and water network (The Resident Engineer's Office, 2020)

Field Observations were done while interviewing the technicians and helped with the reconnaissance field survey. A reconnaissance (Pre survey) field survey was carried out to verify the Resident Engineer's Maps. Each manhole, sewer line, water line, water valves, fire hydrant, water tank and borehole was identified and its location collected using Google maps and GPS essentials android mobile applications. A Samsung tab E was used. The locations were to an accuracy of 5m. The figure 16 shows the screenshot image of how the points were picked on site. The survey was useful as it gave an idea where each feature was located hence helped in preparing for the method and equipment to be used when carrying out a more accurate survey. Old obsolete structures were identified and new structures were picked to update the exiting maps.

Figure 16: Presurvey using GPS Essentials on a tablet (by author, 2020)

The name and some attribute data were added for each feature. The geolocation was activated on the tablet to help show the condition and general outlook of each feature from the photo by location. New and old features were identified and marked. All the field findings were later verified with the resident Engineer's office by providing new map showing all the interconnections and having the resident Engineers technicians verify the connections and all attribute information related to each feature.

Field Survey was done based on the field observations. The physical measurements to collect positions of various features using survey tools such as Global Positioning Systems (GPS), Total Stations, Electronic/ automatic levels was done. The GPS RTK system was used for getting location data for most of the features though a total station was used where the GPS signal was poor for example under trees or very close to buildings. This greatly reduced on the amount of time that could have been spent in the field looking for features had this not been done in the reconnaissance survey. The control points used were survey points that are already connected to the national system in UTM arc 1950 Zone 35S coordinated system. Features that were picked included all the sewer and water related structures, Road center lines and some existing buildings and other features.

Maps and other Secondary data obtained from other available sources that provided data like satellite data, shapefiles. Some of the data was created by digitizing the existing data to have more shapefiles. Using the SASPlanet program a Bing map image was selected to extract the area of interest. It had a better resolution compared to the other types of satellite images. The area of interest was selected using polygon delineation, captured and saved as a jpeg image to a required resolution.

3.4 Data Processing and Georefencing

Raw field survey data processing was done in Microsoft excel, cleaning and correct naming and coding of all features was done based on the reconnaissance survey data. The cleaned data was imported into the ArcGIS software and the project was assigned to The World Geographical Systems (WGS84). The GPS survey data was converted to WGS84 coordinate using the coordinate projection function ArcGIS. The georeferencing of the SARs satellite image was done using the accurate control points from the survey i.e. road junctions and corners of some buildings that were clear on the image and had been picked on the ground. The points were connected to produce new networks (shapefiles) were that were up to date.

3.5 Shapefile Creation

Shapefies were created after digitizing for the Sewer lines, Sewer manholes, Waterlines, Water valves, fire hydrants, water tanks, boreholes, roads, buildings. Attribute data was included for each feature. The naming and tagging were done for each of the features too.

3.6 Naming and Tagging System

Naming of the features in this project was done in preparation for tagging after the shapefiles were created for each feature. There were basically two types of features i.e. nodes and Line segments. Nodes included point data like manholes, water tanks, water valves; fire hydrants. Line segments included line features which were sewer lines and water lines. Each feature was given a unique code, line segments were also given a tag including their starting point and finishing point. The tagging system that was used had 15-digit code e.g. for a manhole RE01MHS10000001; see figure 17.

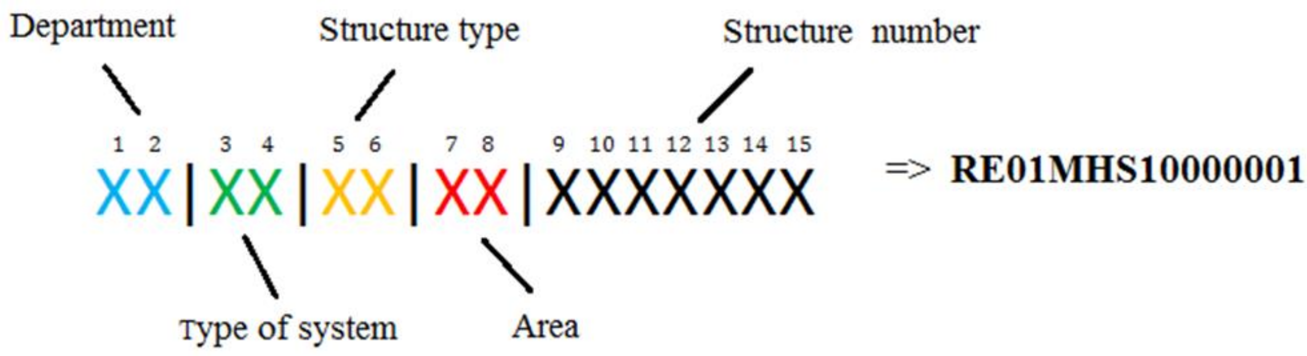


Figure 17: 15 digit serial number (by author, 2020)

The created shapefiles were loaded into a spatial database PostgreSQL and using PostGIS the dataset was connected to geoserver for uploading on to the web app. The layers were customized, and functionalities were added using open layers and JavaScript library tools.

3.7 Application Development: Database Design and Implementation

To ensure the database met the WebGIS requirements, Database design, development, implementation phases. The process for the database design was carried out at all the levels of conceptual, logical and physical modelling. The conceptual model describes a partially structured model of objects and processes. The logical model describes how the system will be implemented, irrespective of the DBMS in the form of diagrams showing objects and relationships between them. The conceptual model of the water and sewer network was based on the Universal Modelling Language (UML) (Visual Paradigm Community Circle 2018). It was used to prepare the entity relation diagram. The model took into consideration all the network appurtenances as entities and the relationships were created based on the connectivity of network appurtenances with each other. The physical model describes how the system will be implemented using a specific DBMS in the computer, representing information such as record structures, record ordering, and access paths. A geospatial database was created with a schema that matched the entity relation model of the water and sewer network.

These model abstractions concentrated on the essential and inherent aspects required to describe and manipulate data, relationships between data and constraints on the data (Wilson 2013).

The spatial databases designed and developed for the university utility management comprised of thematic layers of water supply lines, sewer lines, fire hydrants, valves, bulk meters, roads, buildings etc. extracted from existing CAD map layers, digitised features and GNSS surveys.

Fields were created for the attribute data collected from labels from CAD data, record books and field sketches and associated with its related spatial features. The figure 18 shows the Geospatial Entity Relationship Database Model that was used when creating the spatial database.

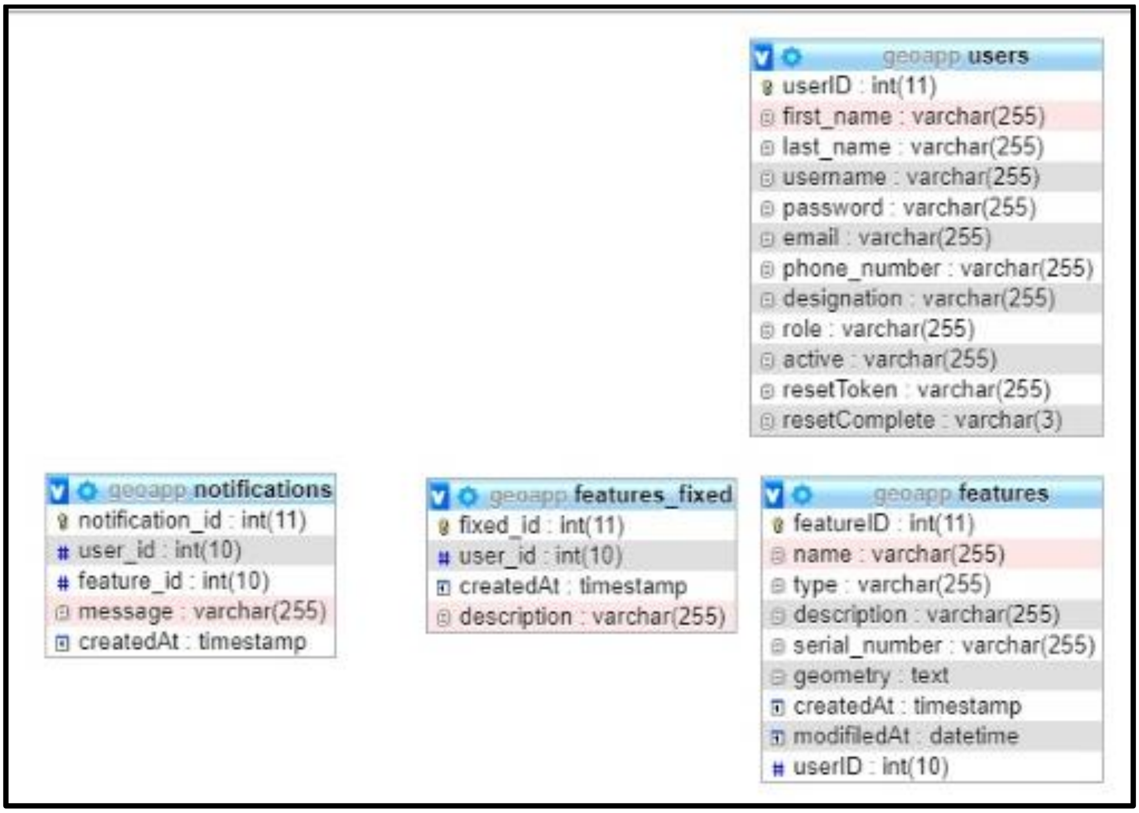


Figure 18: Geospatial Entity Relationship Database model (by author, 2020)

3.8 Application Development: DesktopGIS and WebGIS

Application development made use of both off the shelf software packages (ESRI DesktopGIS) and Free Open-Source Software (FOSS) i.e. OpenGeo Suite which is a complete geospatial platform for building WebGIS applications across web browsers, desktops, and mobile devices. OpenGeo Suite has a robust and flexible architecture that reliably manages and publishes geospatial data. OpenGeo Suite contains all the required software such as PostgreSQL/PostGIS, GeoServer, OpenLayers, etc. in a single suite.

DesktopGIS application development involved the installation and operating of GIS desktop software on a computer. QGIS was installed and used to create semi-interactive digital thematic maps using spatial data from the geo-spatial database created using PostgreSQL/PostGIS. ESRI's DesktopGIS was initially used to create shapefiles which were later exported to the

PostgreSQL/PostGIS database. Methods were planned for distributing, capturing, storing, analysing and visualising spatial data or digital maps (Oussous 2018).

The WebGIS portal was the main access for users to the university GIS utility data. The methodology adopted to develop the WebGIS application used PostgreSQL, PostGIS, Geoserver, OpenLayers and Apache server. It would provide users with data and mapping services. Access to data and services was designed to require a user name and user password. The password had to be alphanumeric with a minimum of six characters. The requirements for the portal development, interface, and specific GIS functions were defined following a structured methodology from the requirements to model development and testing. Custom designed and default widgets were used to add interactivity functionality to control the display data in the WebGIS. The platform had a main dashboard which had a map to show all the structures in different layers, a management platform for adding, editing, and monitoring of each structure, other functions included a notification pane, administration pane, asset pane. The WebGIS application was also designed to allow for quick view and download reports as excel or pdf for any asset.

3.9 Mobile Application Development

The mobile app was developed using the android studio and a collection of android development tools. The skeleton for the app was developed and other features were then included. The leaflet map was loaded onto the app with the layers for the point and line structures, The QR Code panel was also included linking it to the QR Code database. Mobile access was later provided for mobile web browser access instead of users downloading the app.

3.10 Prototype Design and Development

The design of the prototype system was done in two stages: integrated module construction stage and programming. Generally, the construction of integrated component or module is designed using the block diagram method as shown in Figure 19. The design of the system began with a Water level sensor and the GPS module which sent water level data and coordinates of the blocked or overflowing manhole location to Arduino Uno as data processor. Both data are sent in the form of SMS data to the information system station received by the modem. Data is received by computer and processor to be a water level information system based on Google Maps. The notification was received on the dashboard and an email notification was received by a technician.

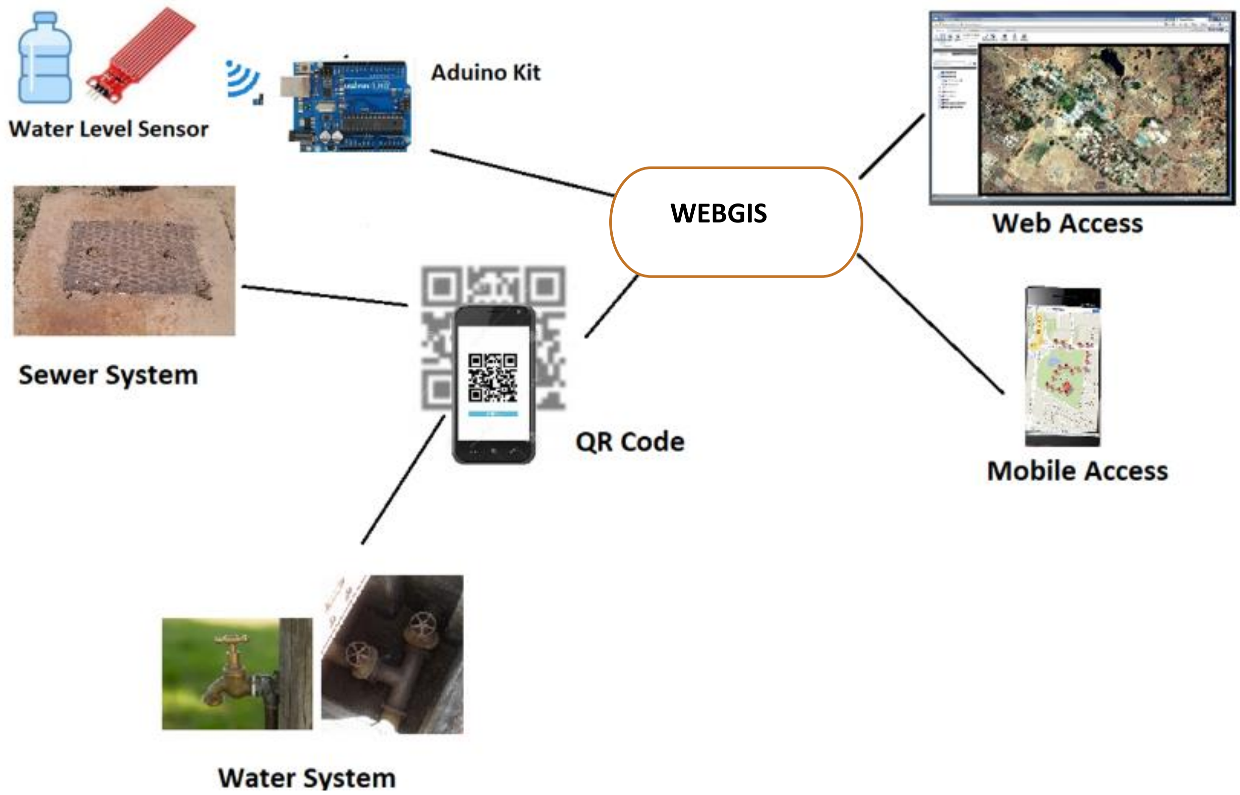


Figure 19: Water and Sewer Network Systems WebGIS Prototype (by author, 2020)

In the prototype development, the structure was tagged with the generated QR Codes. A user with a mobile device and QR Code reader could scan the code on any tag to know which structure was being looked at by clicking the link which would open a web map app where more details could be obtained. For the Web app the user could view the whole network immediately the page was opened. In both mobile and web browsers, there were login requirements before any user could proceed. For some manholes, water level sensors were installed to monitor the water level. The sensors could send data to the arduino kit which would send data to the web app as an alert. Figure 19 shows a pictorial summary of the prototype.

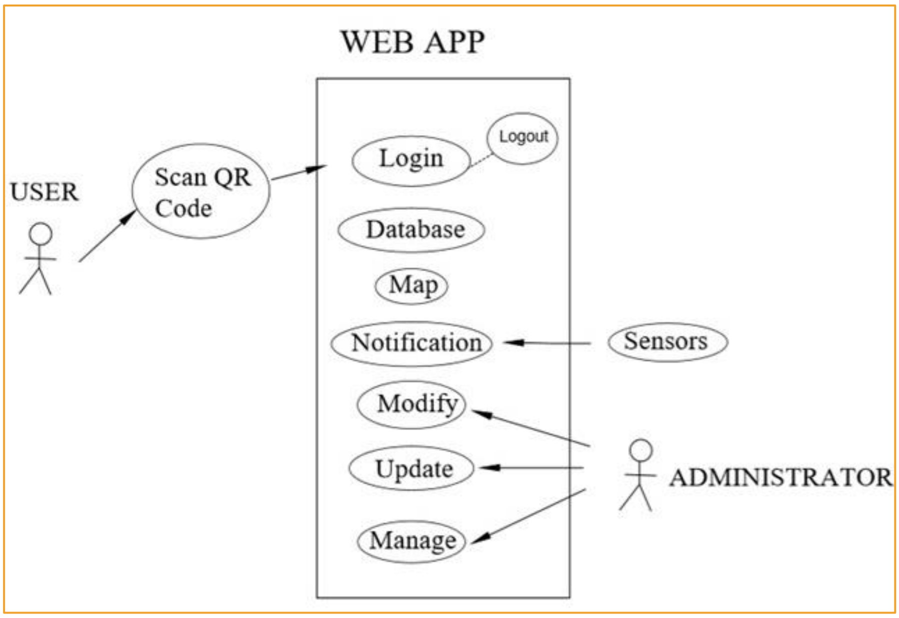


Figure 20: Use case Diagram of the system (by author, 2020)

Figure 20 shows the use case diagram of the process. The user scans the tag with the QR code using a phone, logs into the system (mobile or web) was able to view the map and details of the structures. Sensors could send notifications for any blocked manhole. Administrator had additional privileges of modifying and editing any structure.

3.11 Chapter Summary

This chapter outlined the tools and methods used to come up with the web app, database creation and mobile app development. The steps taken to collect field data using surveying techniques, data collection, and development of the web-based applications were discussed.

CHAPTER FOUR: FINDINGS, ANALYSIS AND PRESENTATION

4.0 Introduction

This chapter will discuss the data collection and user needs assessment process. It will further give details of the analysis and data processing which will include the extraction and creation of new datasets. The procedures and findings will be presented in forms of maps, images and tables. The chapter will also describe how the naming and tagging system was formulated as well as the QR Code generation. The web map development, spatial database design, mobile application development and sensor integration will be explained as well as the components will be used to come up with the developed system. Finally, the system's features will be discussed highlighting what all the features can do.

4.1 User needs

The user assessment needs helped to understand their operations and what the Resident Engineer's office needed. The framework was then based on the final output that would help the department in their operations. The following needs where identified.

- Need for way to identify all the infrastructure both on site and in the office
- Need to keep track of the maintenance and maintenance history of all infrastructure.
- Need to monitor the conditions of infrastructure.
- Need for more accurate and better way of visualizing the infrastructure.

4.2 Data Collection and Data Processing

The raw primary data obtained using Land Surveying techniques was cleaned converted to shapefiles and used to georeferenced other datasets (Satellite image, Sewer Network and Water Networks).

The pre survey done using the tablet greatly reduced the amount of time that could have been spent in the field looking for features had this not been done in the reconnaissance survey. The GPS RTK system was used for getting location data for most of the features though a total station was used where the GPS signal was poor for example under trees or very close to buildings. Table 4 shows an extract of the raw data of how the data was recorded in the GPS Rover controller after downloading it and loading it into Microsoft Excel.

Table 4: GPS GNSS Field Survey Raw Data (by author, 2020):

Version : 1														
Name	E	N	Z	B	L	H	Antenna H	Nrms	Erms	Zrms	Solution T	StartTime	EndTime	D
BM1	642076.704	8297458.505	1243.199	15:23:01.6	28:20:59.4	1249.023	0.0765	0.0073	0.0017	0.009	RTKInt	7/7/2018 19:46	7/7/2018 19:46	
BM2	642114.626	8297463.693	1244.618	15:23:01.7	28:20:59.4	1250.443	0.0765	0.0037	0.0049	0.0208	RTKFloat	7/7/2018 19:46	7/7/2018 19:46	
Wp	642759.153	8297999.201	1243.533	15:23:01.8	28:20:59.5	1249.358	0.0765	0.0038	0.0066	0.013	RTKInt	7/7/2018 19:46	7/7/2018 19:46	
mh	642761.988	8298006.375	1243.687	15:23:02.0	28:20:59.4	1249.512	0.0765	0.0176	0.0128	0.017	RTKInt	7/7/2018 19:47	7/7/2018 19:47	
Mh	642766.535	8297995.283	1243.811	15:23:01.8	28:20:59.1	1249.636	0.0765	0.0057	0.0049	0.0098	RTKInt	7/7/2018 19:47	7/7/2018 19:47	
mh	642870.263	8298053.835	1244.317	15:23:02.2	28:20:58.9	1250.142	0.0765	0.0088	0.0114	0.0106	RTKInt	7/7/2018 19:48	7/7/2018 19:48	
Mh	642895.906	8298034.536	1240.409	15:23:02.2	28:21:01.4	1246.234	0.0765	0.0048	0.002	0.0107	RTKInt	7/7/2018 19:49	7/7/2018 19:49	
Pt	642898.000	8298045.000	1240.181	15:23:01.7	28:21:01.6	1246.005	0.0765	0.0018	0.0079	0.011	RTKInt	7/7/2018 19:50	7/7/2018 19:50	
Mh	642900.000	8298052.000	1240.298	15:23:01.5	28:21:01.7	1246.122	0.0765	0.0007	0.0026	0.0062	RTKInt	7/7/2018 19:50	7/7/2018 19:50	
mh	642902.000	8298053.000	1240.318	15:23:00.7	28:21:02.1	1246.142	0.0765	0.0051	0.0038	0.0057	RTKInt	7/7/2018 19:51	7/7/2018 19:51	
mh	642900.000	8298053.000	1242.901	15:23:00.6	28:21:00.4	1248.725	0.0765	0.0037	0.0039	0.0041	RTKInt	7/7/2018 19:52	7/7/2018 19:52	
mh	642900.000	8298054.000	1242.859	15:23:00.5	28:21:00.4	1248.682	0.0765	0.004	0.0088	0.0061	RTKInt	7/7/2018 19:52	7/7/2018 19:52	
mh	642907.308	8298055.930	1243.06	15:23:00.6	28:21:00.3	1248.883	0.0765	0.0024	0.0011	0.0042	RTKInt	7/7/2018 19:52	7/7/2018 19:52	
mh	642910.000	8298064.000	1243.275	15:23:00.6	28:21:00.2	1249.099	0.0765	0.0098	0.0125	0.0109	RTKInt	7/7/2018 19:53	7/7/2018 19:53	
SP	642897.000	8298029.000	1242.957	15:23:01.1	28:20:59.6	1248.781	0.0765	0.0038	0.0008	0.0073	RTKFloat	7/7/2018 19:54	7/7/2018 19:54	
mh	642912.000	8298018.000	1243.969	15:23:01.5	28:20:59.4	1249.793	0.0765	0.0074	0.006	0.0108	RTKInt	7/7/2018 19:55	7/7/2018 19:55	
mh	642924.000	8298007.000	1243.947	15:23:01.6	28:20:59.4	1249.772	0.0765	0.0133	0.0072	0.0036	RTKInt	7/7/2018 19:55	7/7/2018 19:55	
mh	642925.459	8298005.477	1243.683	15:23:01.7	28:20:59.6	1249.508	0.0765	0.0048	0.0027	0.0094	RTKInt	7/7/2018 19:55	7/7/2018 19:55	
mh	642932.000	8298001.000	1243.976	15:23:01.5	28:20:59.4	1249.801	0.0765	0.0084	0.0059	0.0037	RTKInt	7/7/2018 19:57	7/7/2018 19:57	
SP	642978.000	8297948.000	1240.278	15:23:00.7	28:21:02.1	1246.102	0.0765	0.0016	0.008	0.0059	RTKInt	7/7/2018 19:58	7/7/2018 19:58	

The data from the GPS controller was cleaned up in Microsoft excel to make it in a format compatible with drafting and mapping software. Table 5 shows the extract of the cleaned data of the excel sheet;

Table 5: Cleaned Survey Data (by author, 2020)

No.	Longitude	Latitude	Name	description
1	28.3239170	-15.3958150	Wp	Main Booster Pump
2	28.3242700	-15.3957660	mh	Inspection Manholes
3	28.3302440	-15.3908900	Mh	Man Hole
4	28.3302700	-15.3908250	mh	Service
5	28.3303130	-15.3909250	Mh	Man Hole
6	28.3312760	-15.3903900	Pt	Man Hole
7	28.3315160	-15.3905630	Mh	Man Hole
8	28.3315349	-15.3904683	mh	Man Hole
9	28.3315531	-15.3904049	mh	Man Hole
10	28.3315717	-15.3903958	mh	Man Hole
11	28.3315531	-15.3903959	mh	Man Hole
12	28.3315530	-15.3903868	mh	Man Hole
13	28.3316210	-15.3903690	SP	Septic Tank
14	28.3316456	-15.3902959	mh	Man Hole
15	28.3315265	-15.3906130	mh	Man Hole
16	28.3316669	-15.3907116	mh	Man Hole
17	28.3317793	-15.3908103	mh	Man Hole
18	28.3317930	-15.3908240	SP	Septic Tank
19	28.3318542	-15.3908641	mh	Man Hole
20	28.3322858	-15.3913406	mh	Man Hole
21	28.3322530	-15.3913760	SP	Septic Tank
22	28.3322959	-15.3914580	mh	Man Hole

QGIS and Environmental Systems Research Institute's (ESRI) DesktopGIS - ArcMap were both used for desktop mapping for the research study. Most shapefiles were created in ArcGIS and later exported to the PostgreSQL/PostGIS database. QGIS was used for displaying, querying, updating and analysing data directly from the database in Postgres/PostGIS.

4.2.1 Extraction of the Satellite image

Using the SASPlanet program a Bing map image was selected to extract the area of interest. It had a better resolution compared to the other types of satellite images. The area of interest was selected using polygon delineation, captured and saved as a jpeg image in figure 21 to a required resolution.

Figure 21: Extracted satellite image from SARs planet (by author, 2020)

4.2.2 Georeferencing a raster

Georeferencing a raster to a vector method in arcGIS was used to georeference the raster data using the vector data obtained from GPS GNNS survey. The raster data included the Bing image extracted from SASplanet, the scanned sewer network and the water networks. Road junctions and corners of some buildings that were clear on the image and had been captured on the ground during the survey and were used as control points to reference the images. A minimum of four control points were used for each image. The final RMS Error was computed from the link table. Figure 22 shows the georefencing process and a georeferenced image.

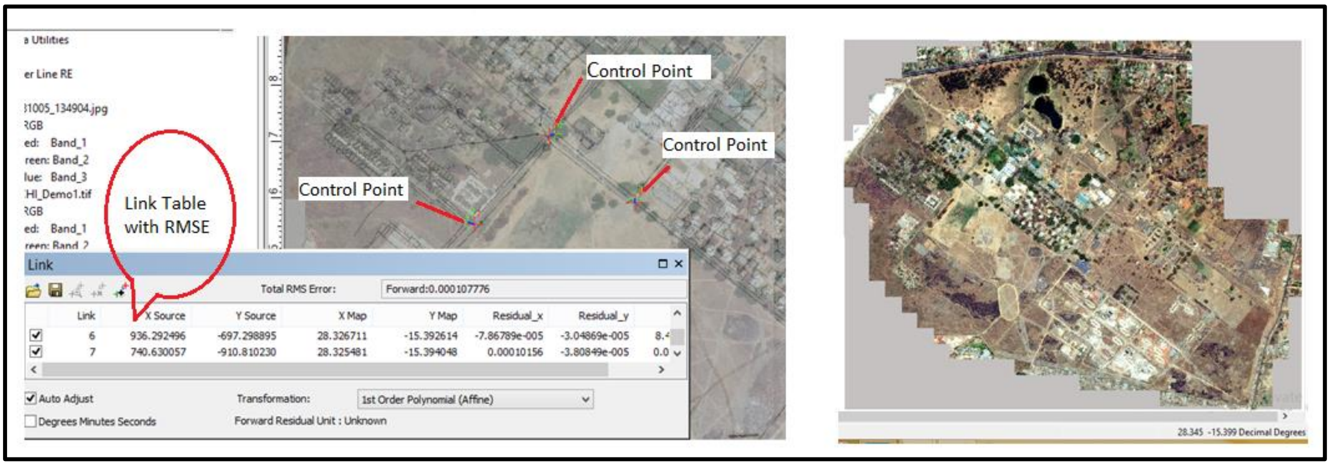


Figure 22: Georeferenced control points and link table (Left,) Georeferenced image in WGS84 (Right) (by author, 2020)

After Georeferencing of both the Satellite image and the jpeg sewer layout as well as water network in arcMap, the sewer map was overlayed on the SAS map image. Its transparency was increased in order to view the SAS image below in figure 23. The same procedure was done for the water network.

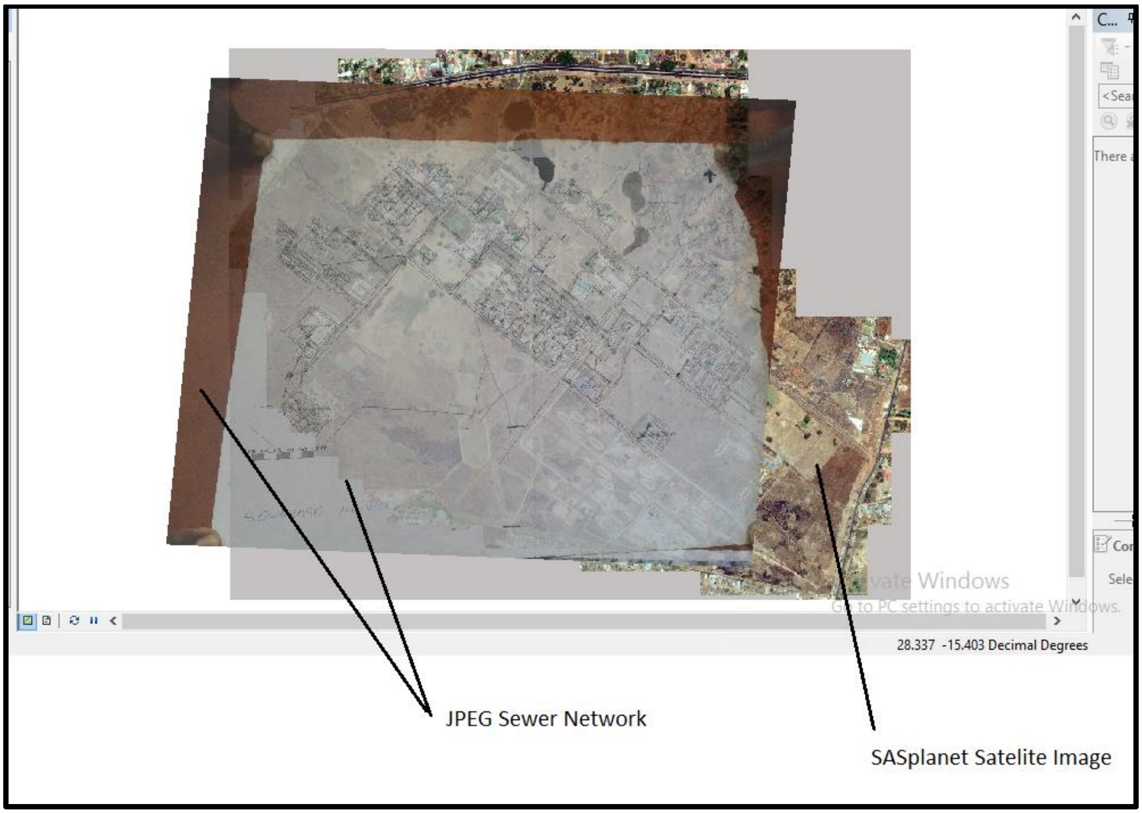


Figure 23: Satellite Image and Sewer network (by author, 2020)

4.2.3 Creation of new datasets

The existing buildings, roads and other significant features were digitised to produce shapefiles for each feature.

All the data was merged one coordinate system WGS84. Shapefiles were created for each feature and using the surveyed data, points were connected following the respective Image maps from the RE as shown in figure 24.

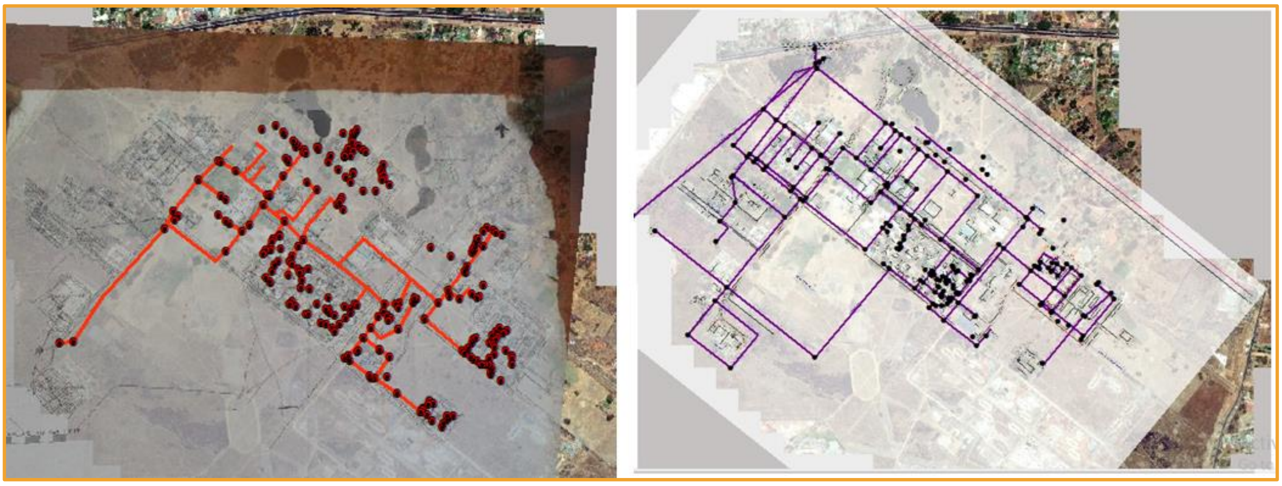


Figure 24: Connected links - Sewer network (left), Water network (Right) (by author, 2020)

4.2.4 Creation of Maps

A new map was produced with all the existing features, as well as the sewer and water networks produced with the updated shapefiles from the field survey. With the appropriate codes and name tags and other information in the attribute tables. Figure 25 shows the layout of the water system while figure 26 shows the map of the layout of the Sewer system.

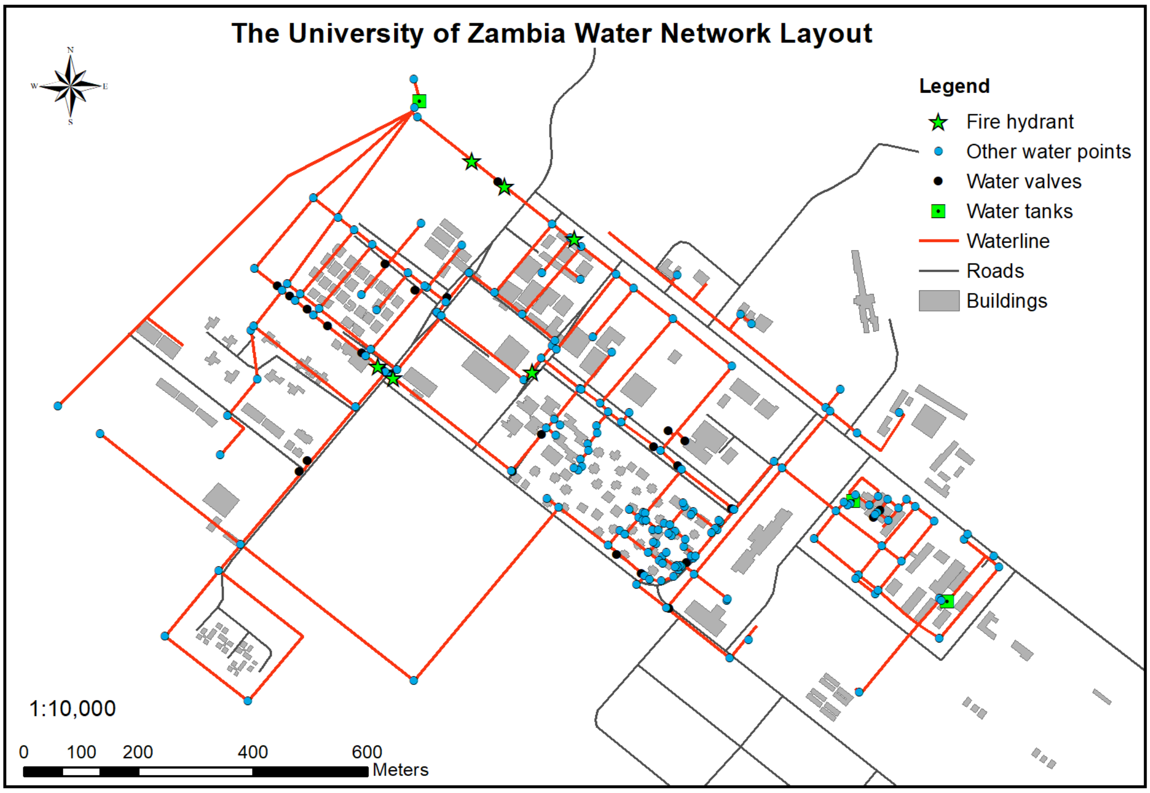


Figure 25: Water Network Layout (by author, 2020)

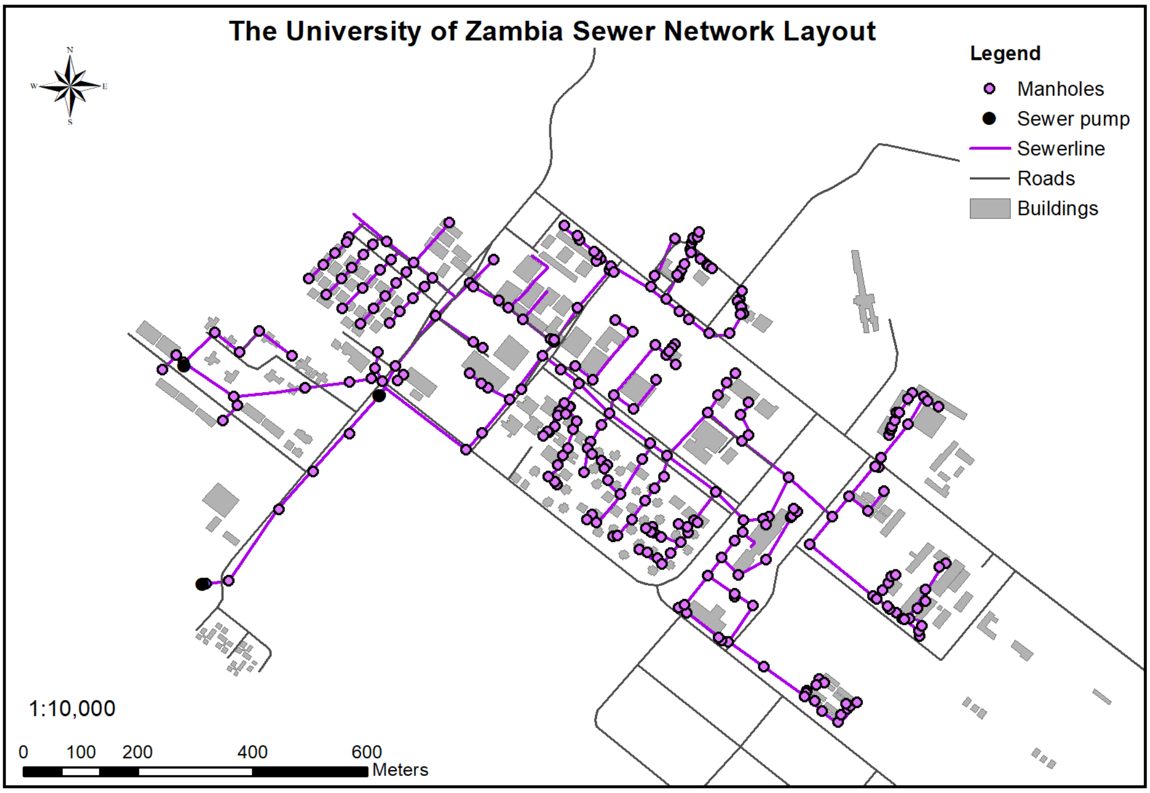


Figure 26: Sewer Network Layout (by author, 2020)

4.3 Naming and Tagging System

Naming of the features in this project was done in preparation for tagging after the shapefiles were created for each feature. There were basically two types of features i.e. nodes and vertices. Nodes included point data like manholes, water tanks, water valves, fire hydrants. Vertices included line features which were sewer lines and water lines. Each feature was given a unique code, line segments were also given a tag including their starting point and finishing point. The tagging system that was used had 15-digit code e.g. for a manhole **RE01MHS10000001**;

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	E	0	1	M	H	S	1	0	0	0	0	0	0	1

1 and 2 – Resident Engineer's Department RE

3 and 4 – Type of system, 01 is Sewer system, 02 is Water System

5 and 6 - Representing the structure type…. MH is manhole. WL is Water Line, SL is Sewer Line etc.

7 and 8 - Represents the area where the structure is. The areas in UNZA have been divided into four parts hence the third digit ranges between S1 and S4, see figure 27.

9 to 15 – The actual number of the structure e.g. 0000001 is number one.

Figure 28 shows the areas of unza and attribute table with the generated 15-digit code. It also shows the layout of connected network.

Figure 27: The four sub areas of UNZA (by author, 2020)

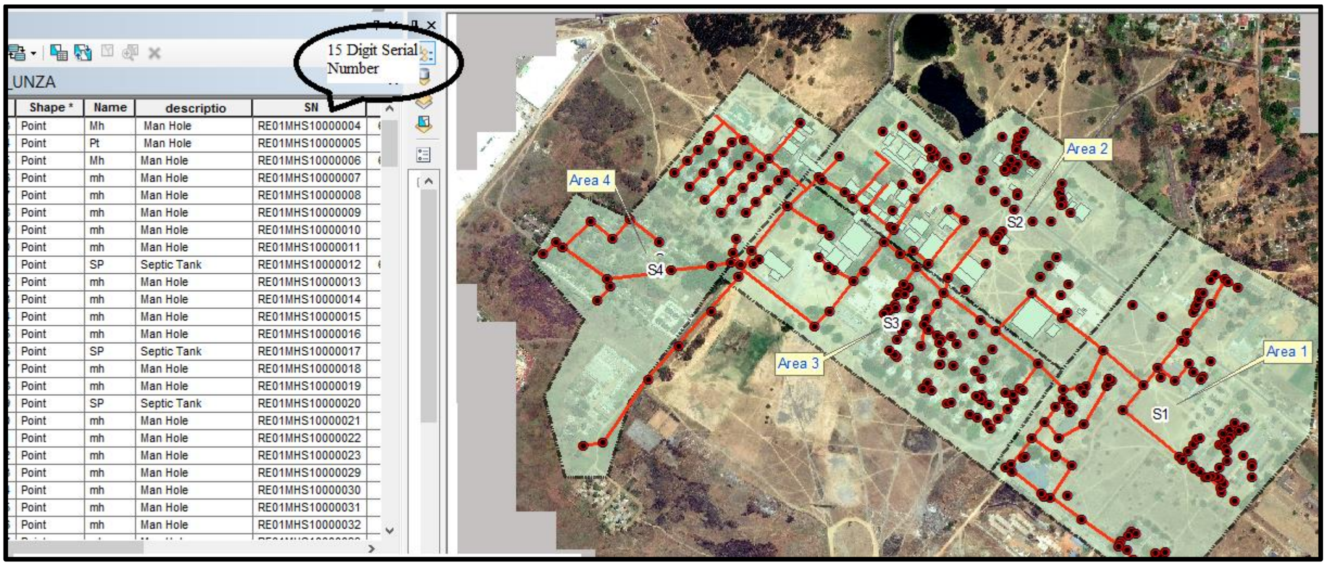


Figure 28: Attribute table and layout of connected network (by author, 2020)

Table 6 is summary of the possible codes of the various features (manholes, water tanks, water valves, fire hydrants, water pipes, sewer lines (pipes). Table 7 shows the details of the completed shapefile's attribute table.

Table 6: Codes for Features of the Water and Sewer Network (by author, 2020)

Digit	**1 and 2**	**3 and 4**	**5 and 6**	**7 and 8**	**9 to 15**
Name	Department	Type of System	Structure	Area code from figure 13	Actual number of the structure
Possible Codes	RE – Resident Engineer	01 – Sewer System, 02 – Water System, 03 - Storm Water	SL – Sewer Line, MH – Man Hole, WL – Water Line, WT – Water Tank, FH – Fire Hydrant, BH – Bore Hole, SP – Septic Tank WV – Water Valve	S1, S2, S3 and S4	000001 to 999999

Table 7: Attribute table of shapefile after coding (by author, 2020)

FID	Shape *	Name	descriptio	timestamp	Serial Number	POINT_X	POINT_Y
3	Point	mh	Service	2018/10/06 08:17:13.000	RE01MHS10000003	28.33027	-15.390825
4	Point	Mh	Man Hole	2018/10/06 08:18:23.000	RE01MHS10000004	28.330313	-15.390925
5	Point	Pt	Man Hole	2018/10/06 08:26:10.000	RE01MHS10000005	28.331276	-15.39039
6	Point	Mh	Man Hole	2018/10/06 08:27:20.000	RE01MHS10000006	28.331516	-15.390563
7	Point	mh	Man Hole	2018/10/06 08:28:02.000	RE01MHS10000007	28.331535	-15.390468
8	Point	mh	Man Hole	2018/10/06 08:28:19.000	RE01MHS10000008	28.331553	-15.390405
9	Point	mh	Man Hole	2018/10/06 08:29:07.000	RE01MHS10000009	28.331572	-15.390396
10	Point	mh	Man Hole	2018/10/06 08:29:17.000	RE01MHS10000010	28.331553	-15.390396
11	Point	mh	Man Hole	2018/10/06 08:29:28.000	RE01MHS10000011	28.331553	-15.390387
12	Point	SP	Septic Tank	2018/10/06 08:29:47.000	RE01MHS10000012	28.331621	-15.390369
13	Point	mh	Man Hole	2018/10/06 08:30:57.000	RE01MHS10000013	28.331646	-15.390296
14	Point	mh	Man Hole	2018/10/06 08:33:31.000	RE01MHS10000014	28.331527	-15.390613
15	Point	mh	Man Hole	2018/10/06 08:33:55.000	RE01MHS10000015	28.331667	-15.390712

4.4 QR Code Generation

The QR codes were automatically generated from the system using the JavaScript QR Code Library. The images produced for some sample structures are as shown in figure 29. The QR codes stored the unique ids for each node that in turn would have a link to the web map once a user clicks it.

Manhole

Borehole

Water Valve

Fire Hydrant

Figure 29: Sample of QR Codes for some structures (by author, 2020)

The codes would be tagged to each structure at an appropriate location to ensure they are safely fixed.

4.5 Webmap Development

Based on the compiled data, database design was initiated. Database design, Development and implementation were the phases carried out in the process of ensuring that the resulting database met user requirements, had efficient data structures and retrieval mechanisms, normalization principles, support for data sharing, multi-user access through the WebGIS portal, easy editing, update, and maintenance.

The GIS based decision support tool was built around OGC compliant software identified from the literature reviewed. The focus of the analysis was on PostgreSQL and Geoserver which formed the core phases of the development of the GIS based decision support tool presented below.

4.5.1 Spatial Database Design

This section covered the development of conceptual models i.e. Entity Relationship diagrams (ERD) which would later be distilled into relational schema. The steps taken are outlined below:

4.5.2 Entity Identification

An entity is an object that exists. It doesn't have to do anything; it just has to exist. In database administration, an entity can be a single thing, person, place, or object. Data can be stored about such entities. A design tool that allows database administrators to view the relationships between several entities is called the entity relationship diagram (ERD**)** (Study.com 2020).

In database administration, only those things about which data will be captured or stored is considered an entity. If you are not going to capture data about something, there is no point in creating an entity in a database. Based on this the table 8 shows the list of entities that were identified for the database.

Table 8: list of entities identified (by author, 2020)

	Entity	Description
1	Admin	The system administrator model.
2	Other users	The client user of the system accessing via the web and mobile app
3	Application	Service requests received from the mobile app
4	Notification	Messages sent to the users

4.5.6 Entity Relationship Diagram (ERD)

An *entity relationship model*, also called an *entity-relationship (ER) diagram*, is a graphical representation of entities and their relationships to each other, typically used in computing in regard to the organization of data within databases or information systems. *An entity is a piece of data-an object or concept about which data is stored* (Webopedia 2020). Figure 30 shows the Entity Relationship Diagram developed for the system developed in the study.

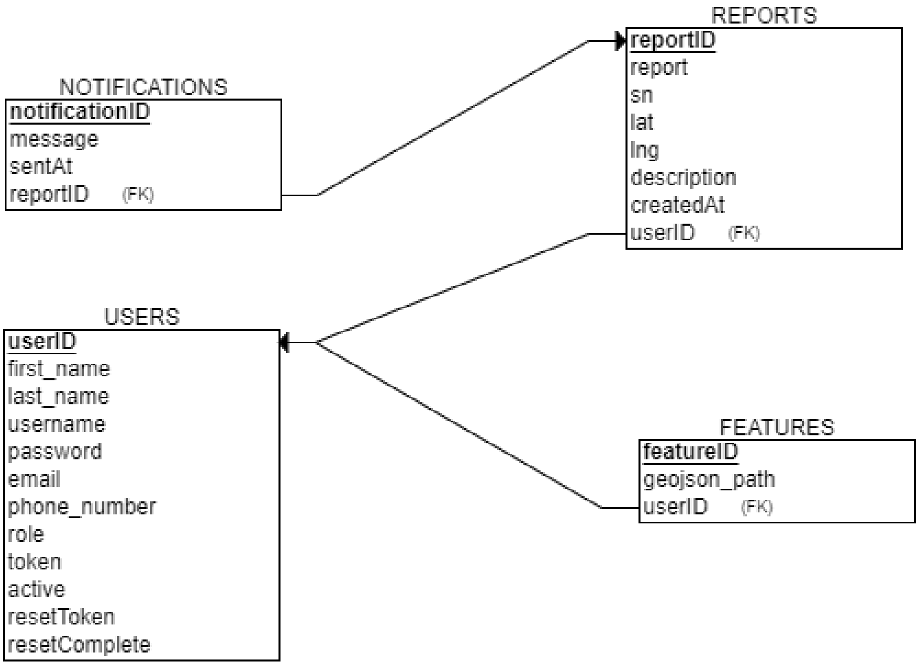


Figure 30: Entity Relationship Diagram (ERD) (by author, 2020)

4.6 Spatial Database Development

PostgreSQL was selected as the open-source database server to support geographic objects and functions such as coordinate systems, projections, etc. Shapefiles were exported to the PostgreSQL/PostGIS database. The default PostgreSQL installation is not capable of supporting operations on spatial data. It manages data in an object-relational database management system.

PostGIS, an extension, provided the added functionality to handle spatial queries and operations after running the command 'CREATE EXTENSION postgis' in SQL Editor. This was used to import all the shapefiles for the water and sewer lines, water network valves, fire hydrants, manholes, water meters, buildings, roads, streams, reservoirs, boreholes etc. QGIS was used for displaying, querying, updating and analysing data directly from the database in Postgres/PostGIS.

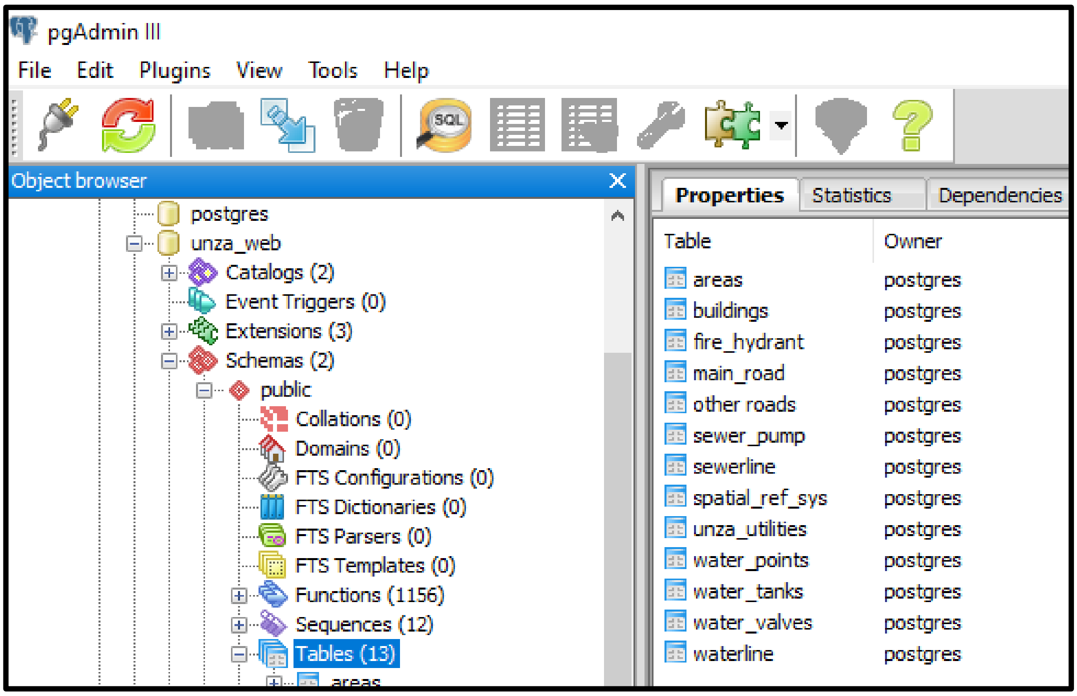


Figure 31: PostgreSQL loaded shapefilles (by author, 2020)

The coordinate system was then manually assigned for all the imported shapefiles. Client application access to the spatial database was through SQL statements. The Query Tool in SQL Editor was used to execute SQL commands for converting the GIS layers in the PostgreSQL/PostGIS database to GeoJSON, KML and text format. The figure 31 shows the uploaded shapefiles in the database.

4.7 Mapserver

GeoServer was selected as the map and feature server for sharing, analysing and editing geospatial data from the PostgreSQL/PostGIS database. GeoServer supplies geospatial information using standard protocols (WMS, WFS and WCS) established by the Open Geospatial Consortium. These are explained below:

The Web Feature Service (WFS) supports requests for geographical feature data with vector geometry and attributes.

The Web Map Service (WMS) supports requests for map images and other formats generated from geographical data.

The Web Coverage Service (WCS) supports requests for coverage data i.e. rasters.

The default password was used to login into GeoServer from the Google chrome internet browser. A new workspace 'unza_web' was created and a vector data source was added from the PostGIS database. The projection parameters for the GIS layers matching the shapefile coordinate system were input. The figure 32 shows the geoserver layer page and the uploaded vector layers;

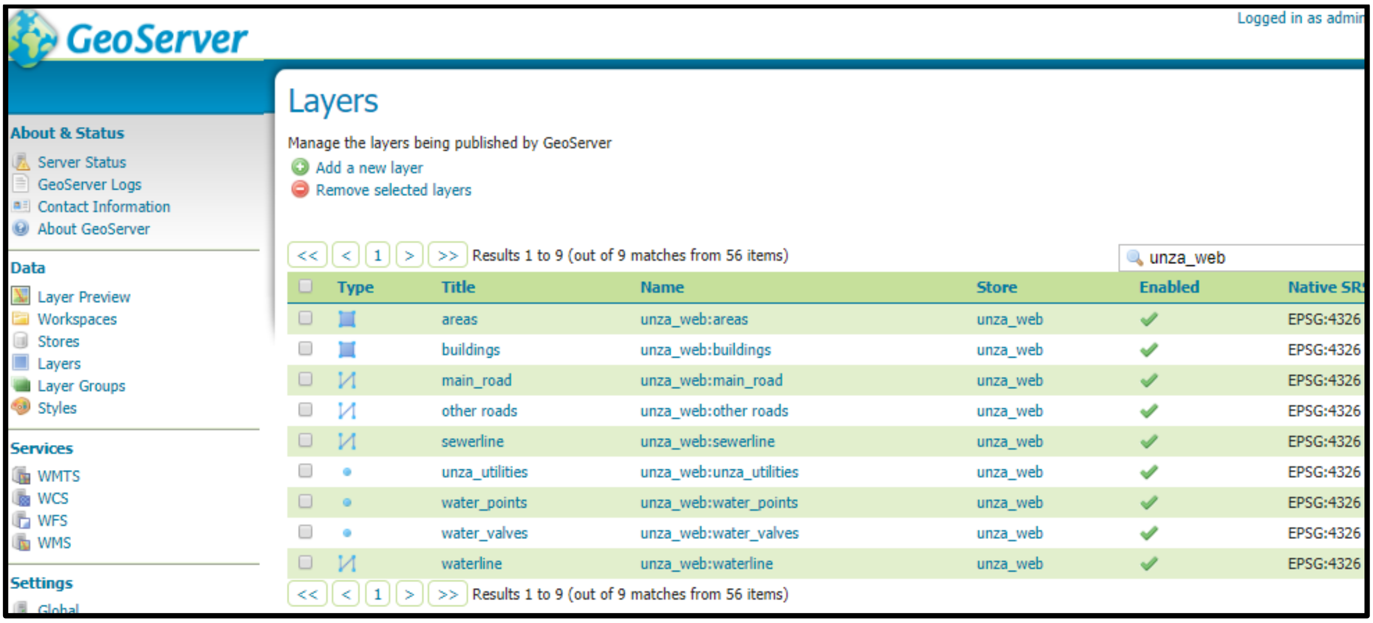


Figure 32: Geoserver platform (by author, 2020)

4.8 Web map Layers

The layers to be published were enabled and then previewed in the Layer Preview Tab which supports a variety of output formats for data sharing. The formats are categorised into three types Applications (Google Earth, OpenLayers, GeoExplorer), WMS format (KML, GeoTiff, JPEG, PDF, etc.), WFS formats (CSV, GeoJSON, GML, JSON, etc.). The figure 33 shows a preview of the layers in open layers while figure 34 shows the layers in Geoexplorer.

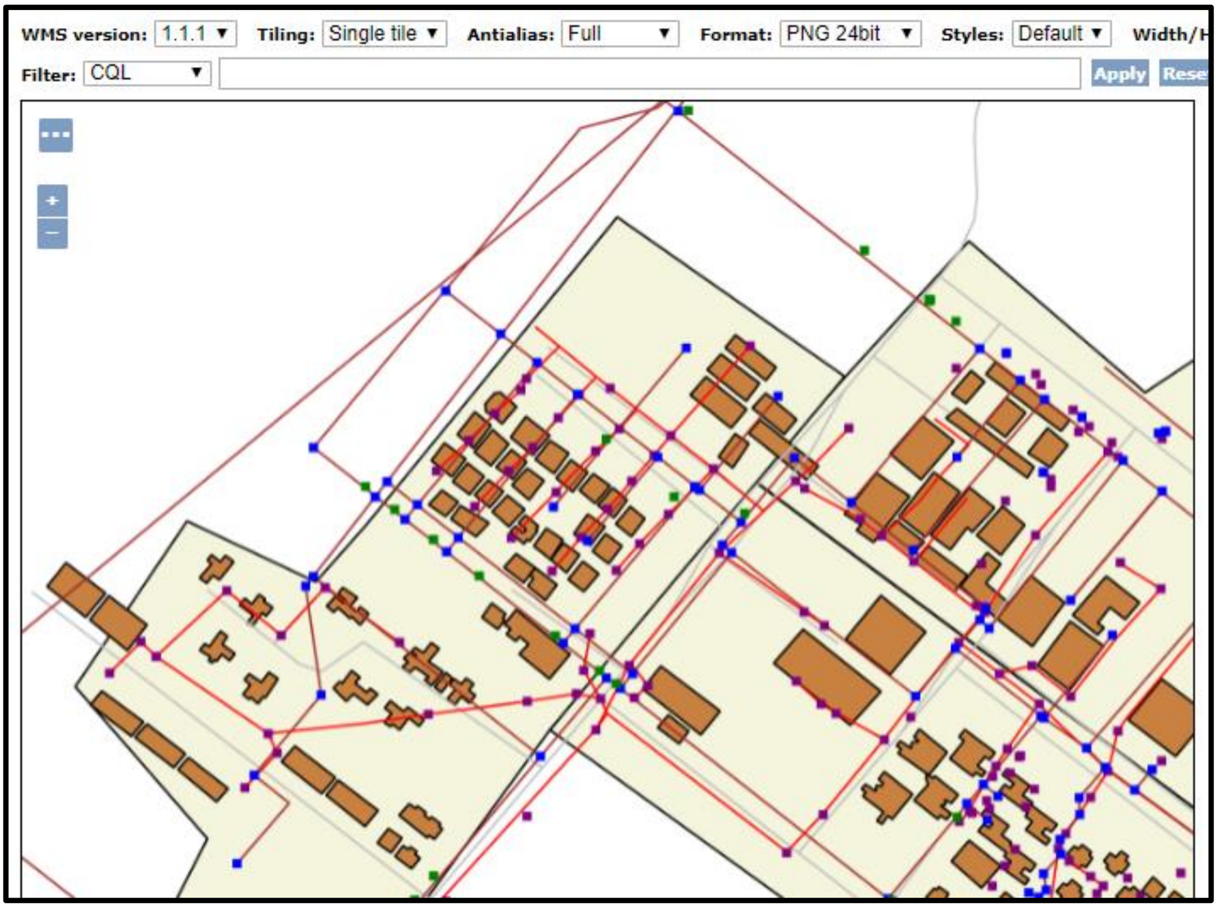


Figure 33: The UNZA Water Utilities in Openlayers (by author, 2020)

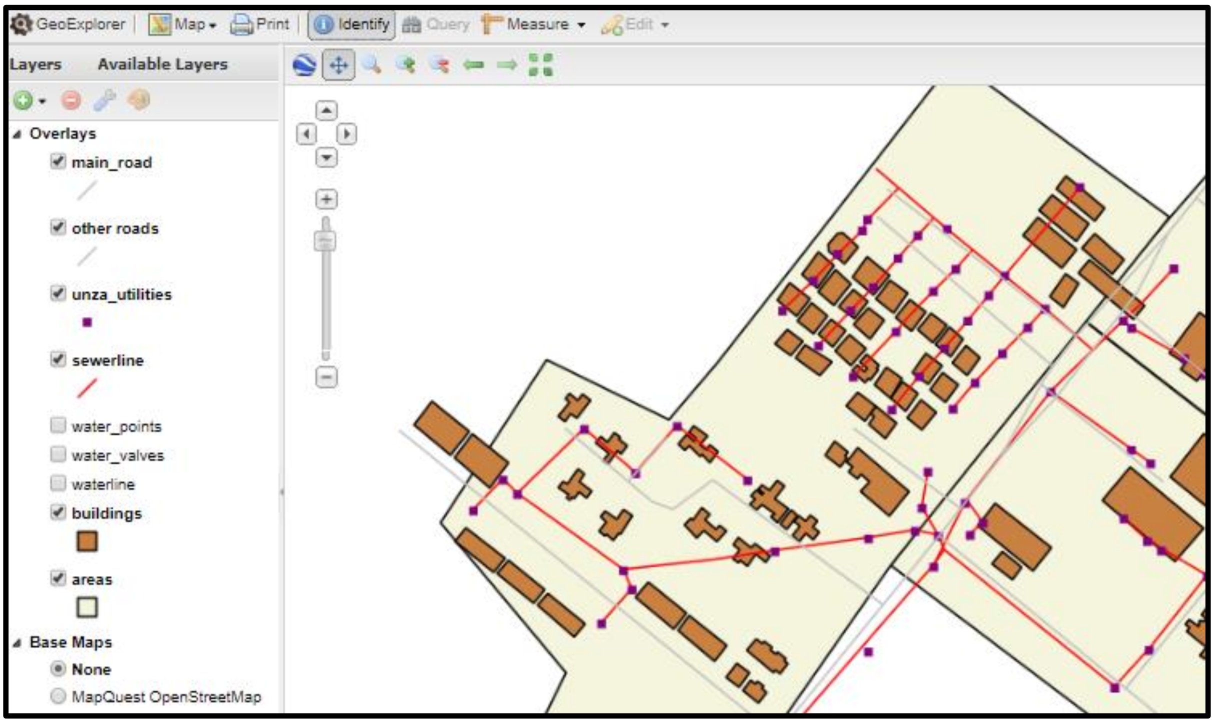


Figure 34: The UNZA Water Utilities in GeoExplorer (by author, 2020)

4.9 The web application System

The web-based GIS application provided viewing of the water and sewer networks via the web using a web browser. The website could be accessed through any browser using login page. Login details for the web app required the user's name and password. The user could input their details in the login page as shown in figure 35. The user could see the map and the data layers once they were logged in. The user could also reset the password if it had been forgotten. The user password reset was sent to the registered email address and a new password could be regenerated.

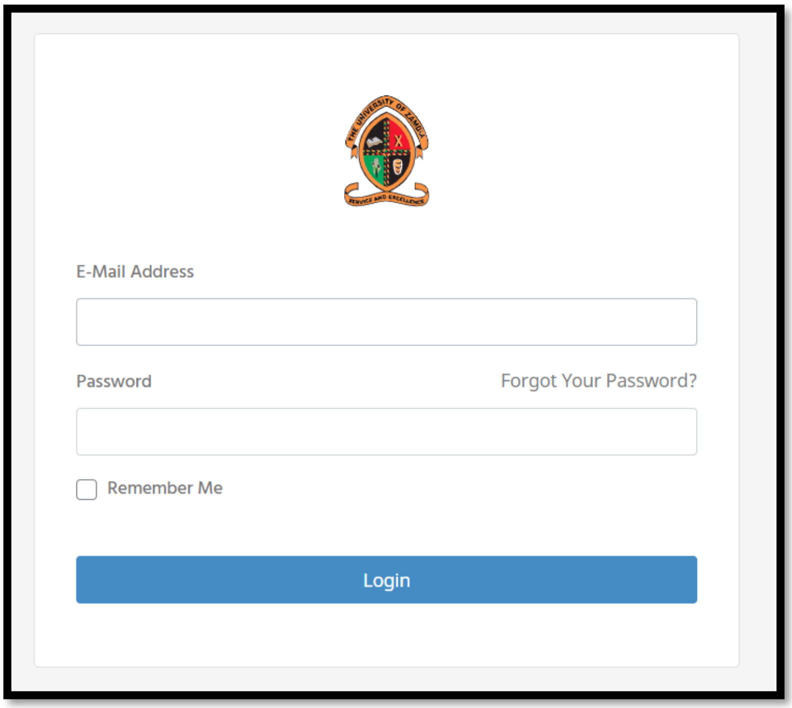


Figure 35: Login details page (by author, 2021)

The welcome first page had the home page which contained sections for *about, assets, contacts* buttons and *username* dropdown with a *dashboard*. The home page is shown in figure 36. It further had a section to *search* for an asset by id, see figure 37. This was accessed to view the list of assets but the main functions of the systems could be accessed once someone was logged in. The main map could also be directly accessed on the main page and in the system dashboard, see figure 38. The last section was the contacts, see figure 39. The table 9 shows the summary of the tools that could be accessed on the home page of the website. Table 10 describes all the items that could be accessed on the dashboard.

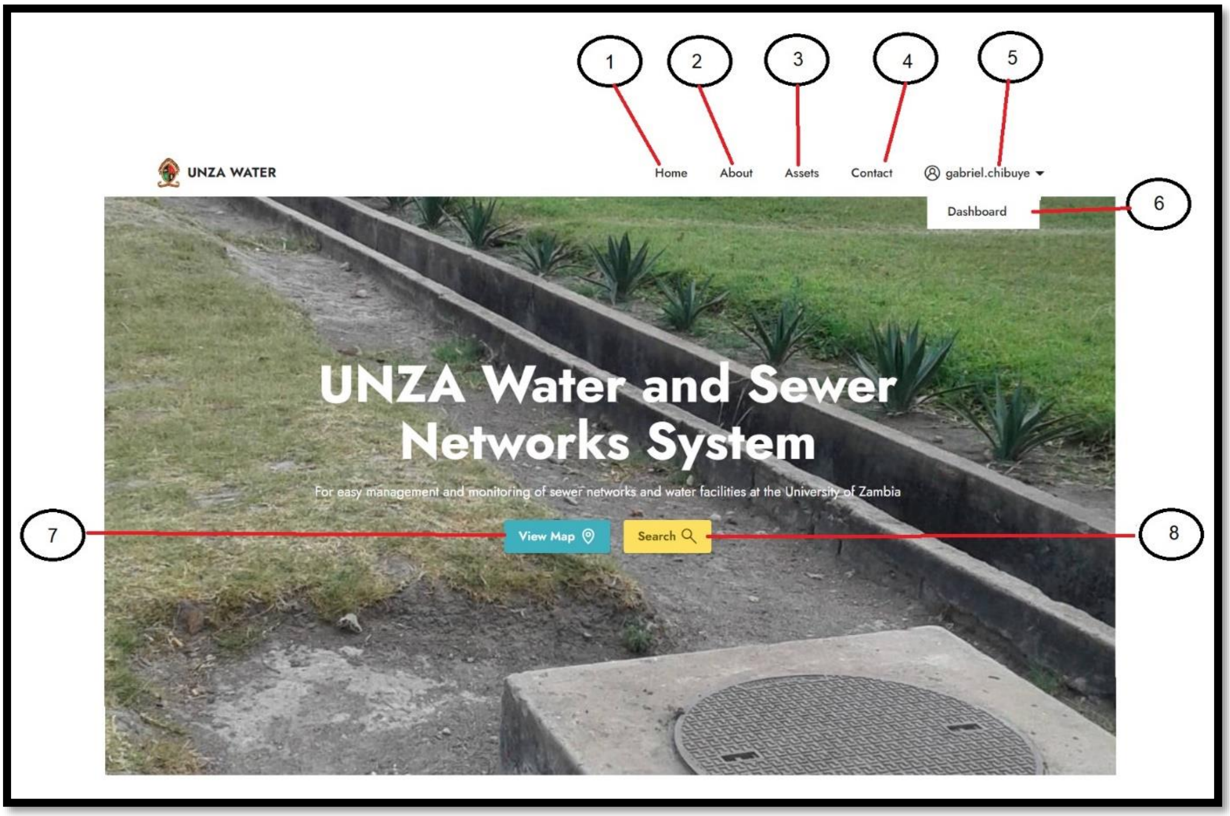


Figure 36: First page of the Home page (by author, 2021)

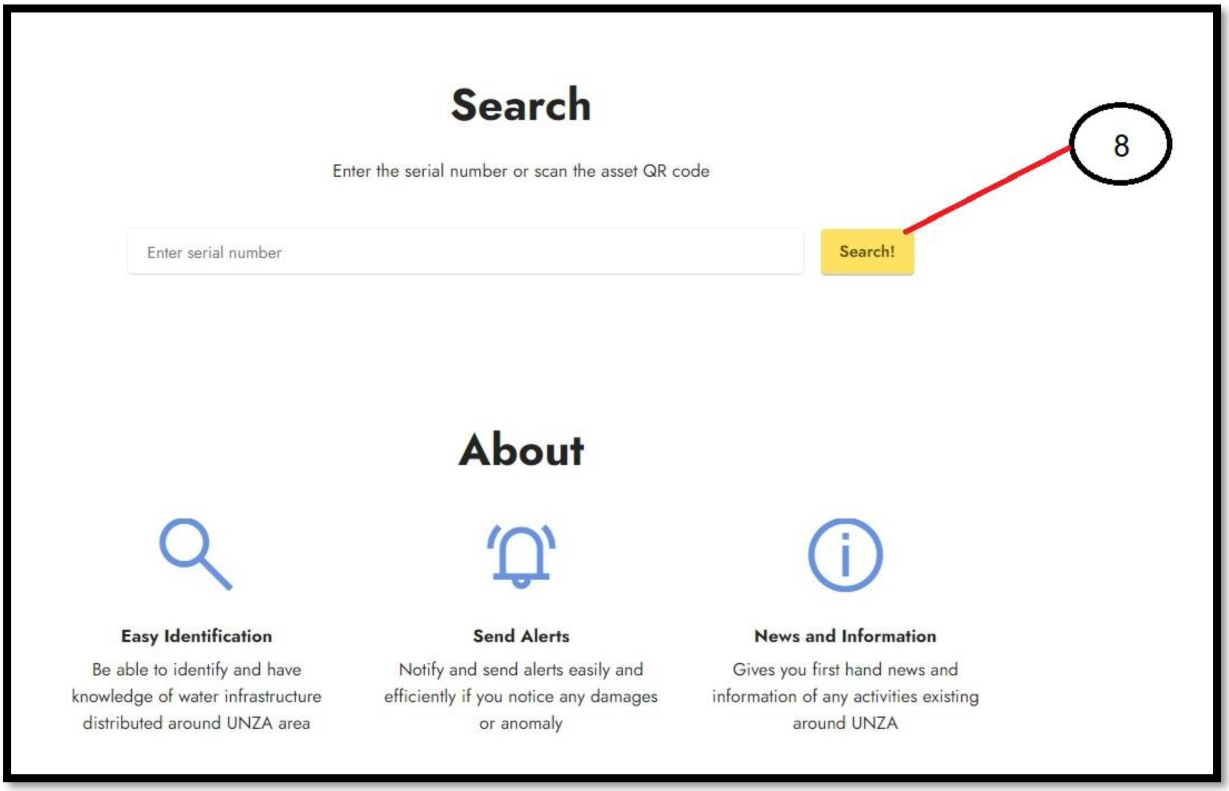


Figure 37: Search and About section (by author, 2021)

Figure 38: Map section (by author, 2021)

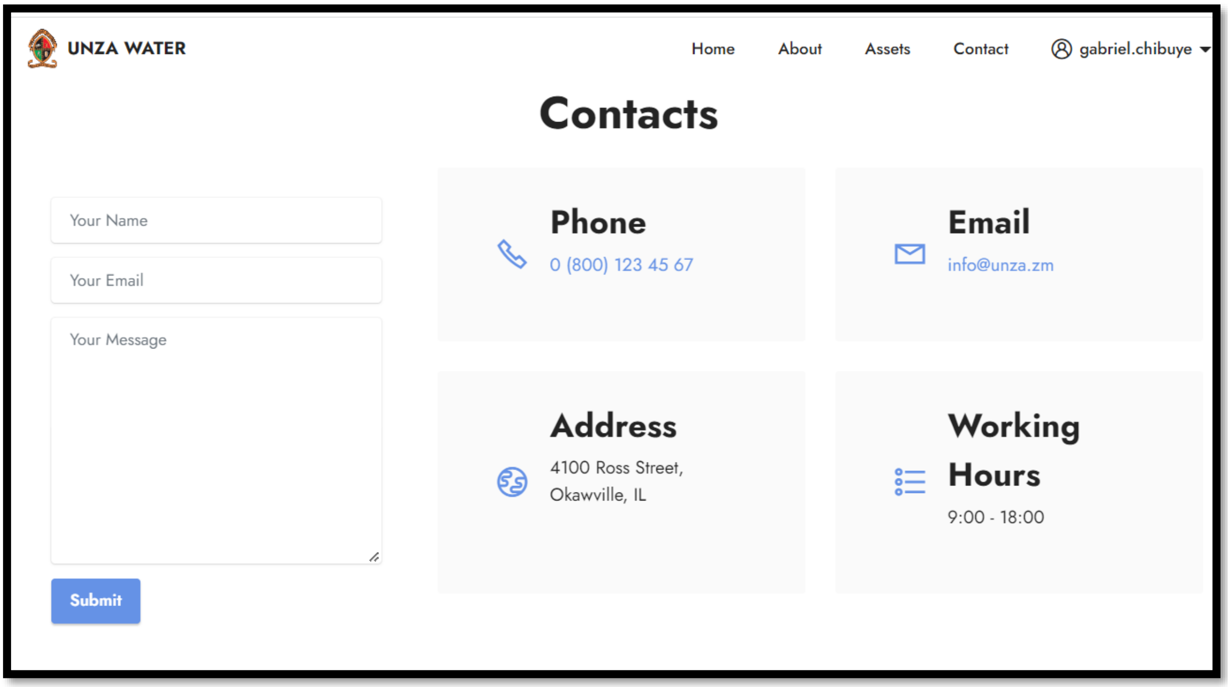


Figure 39: Contacts section (by author, 2021)

Table 9: The web app system home page item description (by author, 2021)

Item No.	Item Name	Item Description
1	Home	Home screen or main page of the website
2	About	has information about the site
3	Assets	has the list of assets and takes the user directly to the dashboard
4	Contacts	Has the contact information of the organisation
5	Login	This the login section to access the dashboard once the user signs in
6	Dashboard	This the main dashboard access button
7	View Map	This is the quick button to get to the map
8	Search	Users can search for an asset or if they a using a mobile device, they can scan the QR code
9	Map	This is the main map for viewing the assets on the website
10	Zoom button	Controls zoom level of the map
11	Layer Control	Displays basemap and overlay layers

4.9.1. The system Dashboard

Figure 40: An overview of the System Dashboard for the web Application and with a popup (8) (by author, 2021)

Table 10: Dashboard details (by author, 2021)

Item No.	Item Name	Item Description
1	Three line menu	Accesses the side bar navigation panel of the dashboard
2	Navigation	Houses the side bar tools
3	Enquiry messages	Shows the messages sent as enquiries to the system from either the mobile access or using the web
4	Notifications	Shows any activities from different users, see figure 41
5	Administration	Accesses the administration management panel
6	Assets	Accesses the assets management panel
7	Website	This takes the user back to the home page
8	Popup window	Gives a brief description of the asset on the map.
9	Users	Shows the total number of users registered in the system
10	Total Enquiry Messages	Shows the total number of enquiries submitted to the system by anyone who visits the website
11	Total Alerts	Shows the total number of alerts sent to the system by the users
12	Notification alert	Gives a summary of all the enquiries and alerts sent to the system. See figure 56 for the alert details
13	User access	Accesses the user's profile management page and logout
14	Total Assets	Shows all the assets in the system

Enquiry messages – When a user accessed the system and had queries, the message sent from figure 39 would be sent to the enquiry message page in the system. The details of the message page are shown in figure 41. The detailed message is as shown in figure 42.

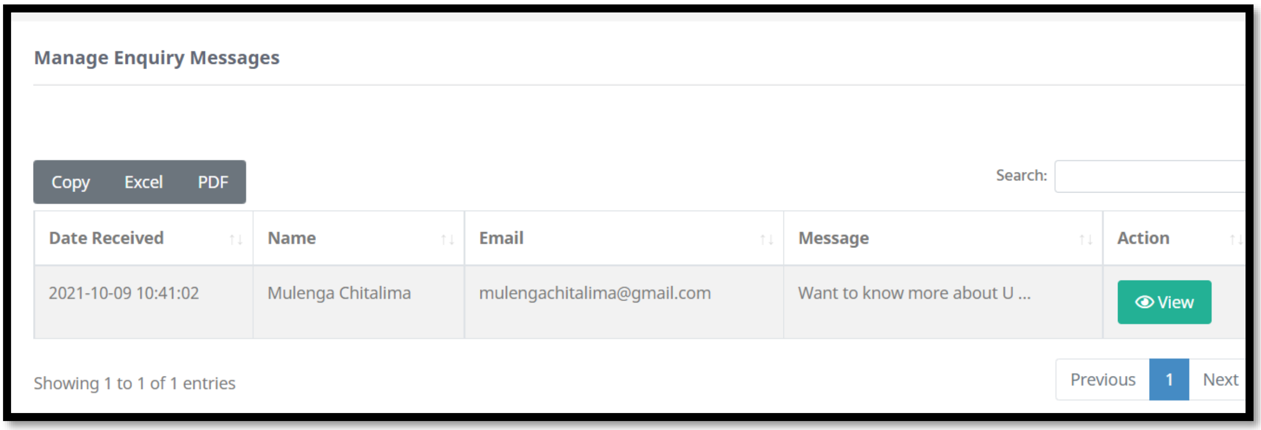


Figure 41: enquiry message page (by author, 2021)

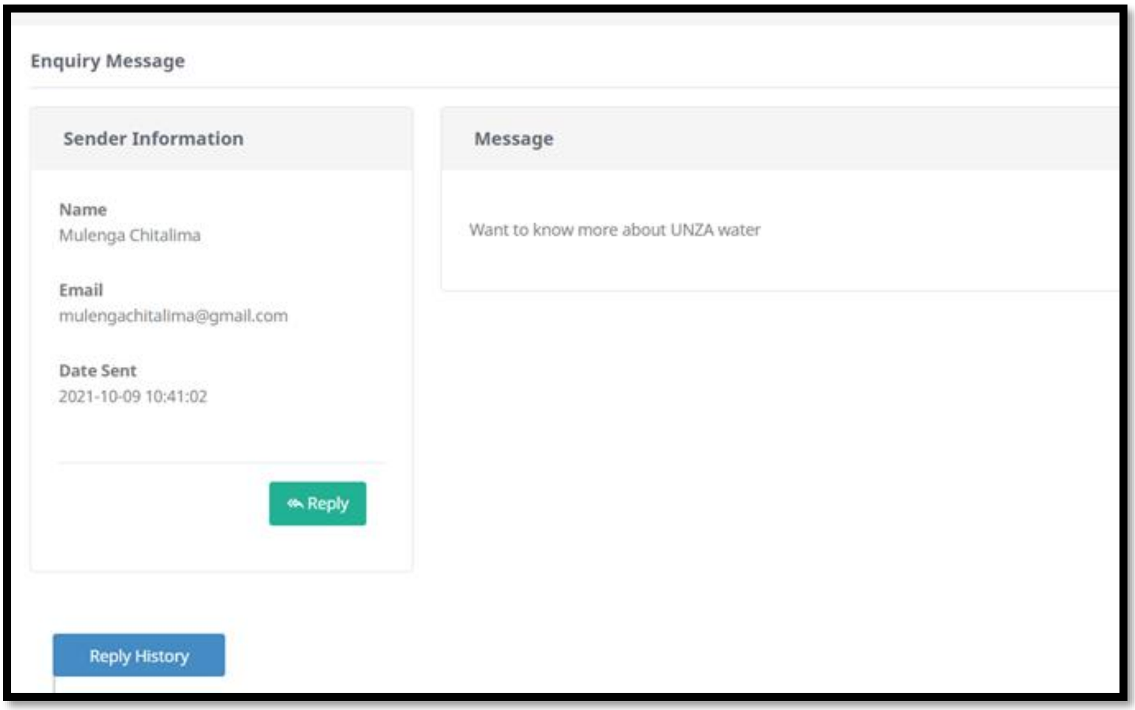


Figure 42: Example of enquiry message details (by author, 2021)

Notifications – Notification from the users of the system could be received as an alert via the notification panel, see figure 43.

Figure 43: Notification page (by author, 2021)

Administration Management panel - could only be accessed by the administrator. It had three pages.

1. Manage Staff page – the administrator would be able to add and remove users, see figures 44, 45 and 46.

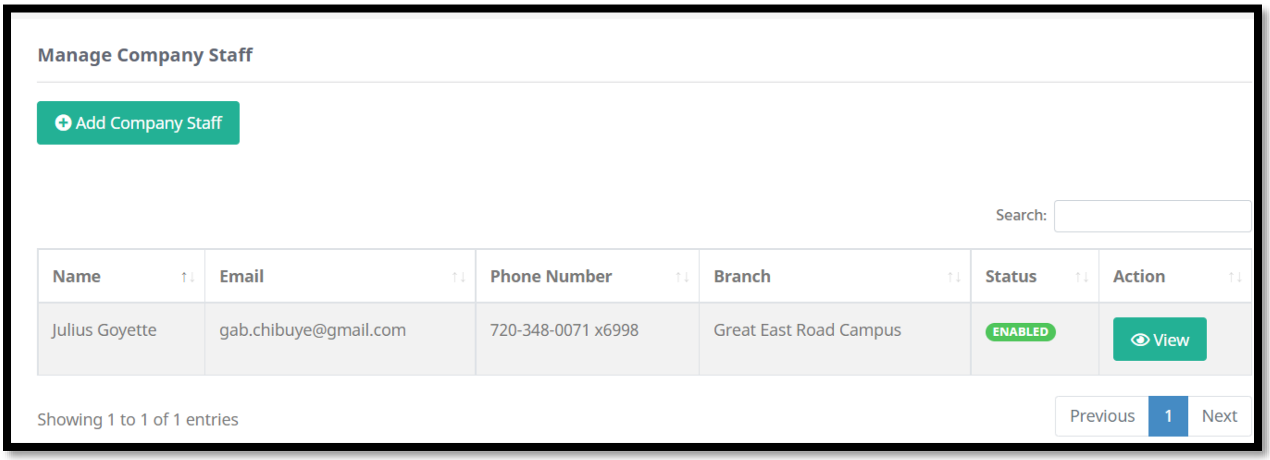


Figure 44: Manage staff page (by author, 2021)

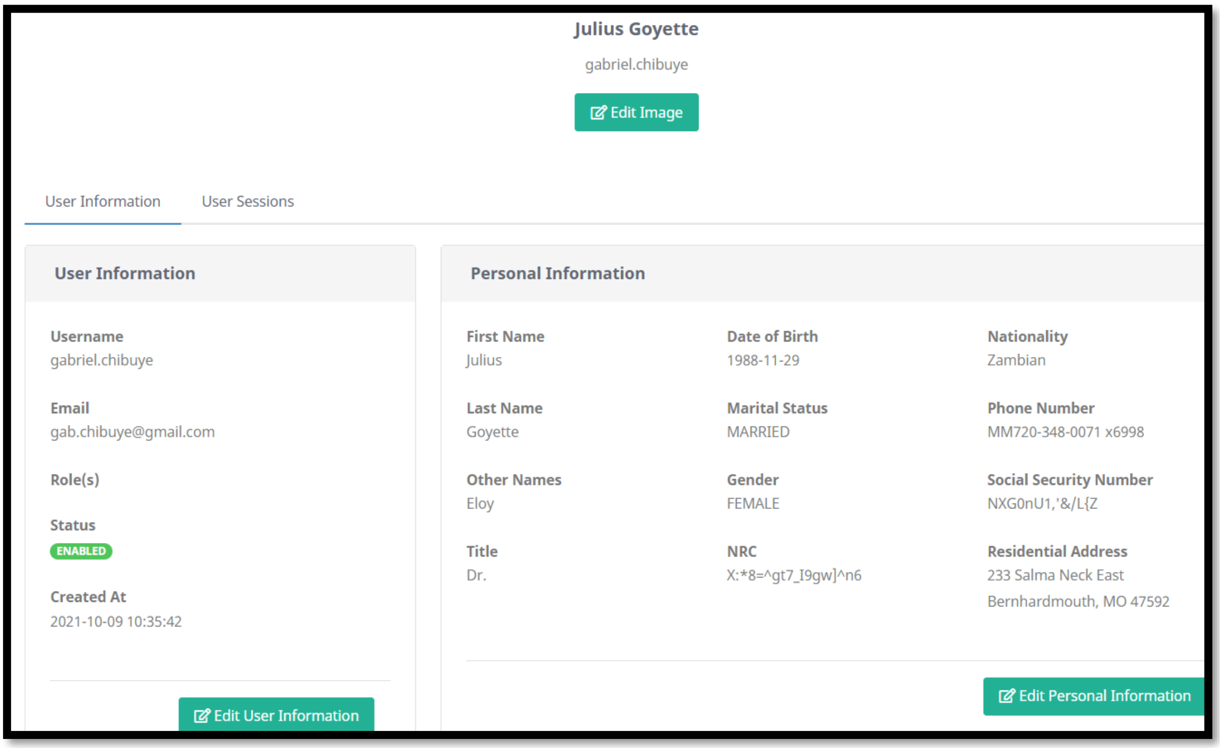


Figure 45: staff details (by author, 2021)

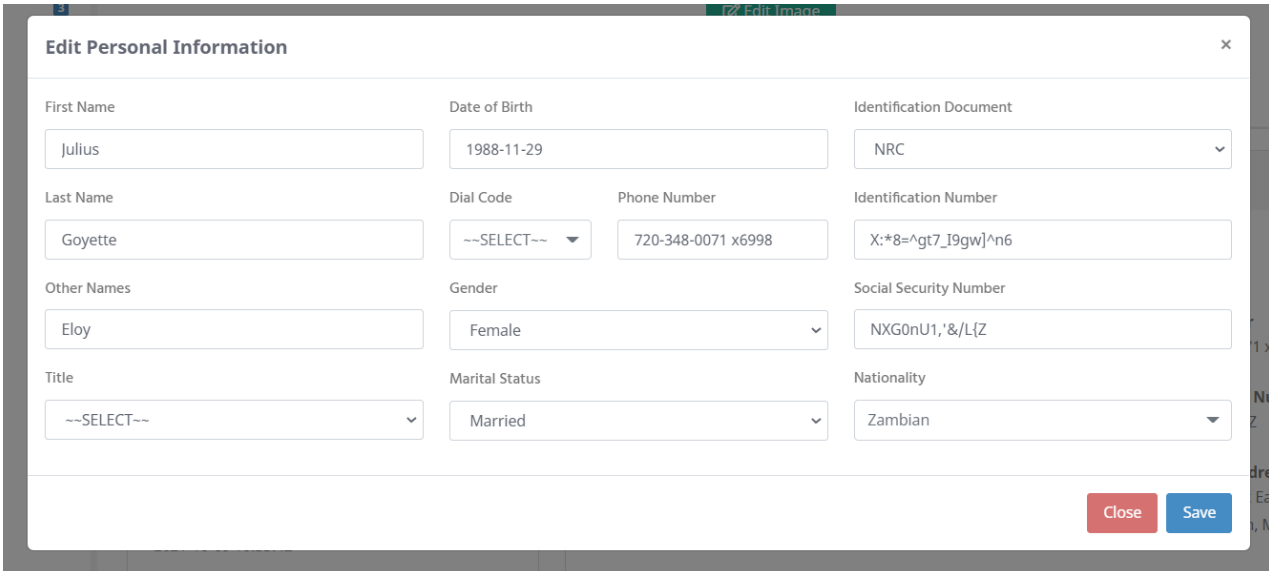


Figure 46: Adding/ editing user details (by author, 2021)

2. Manage Branches – the administrator would be able to add and remove branches or departments see figures 47, 48 and 49.

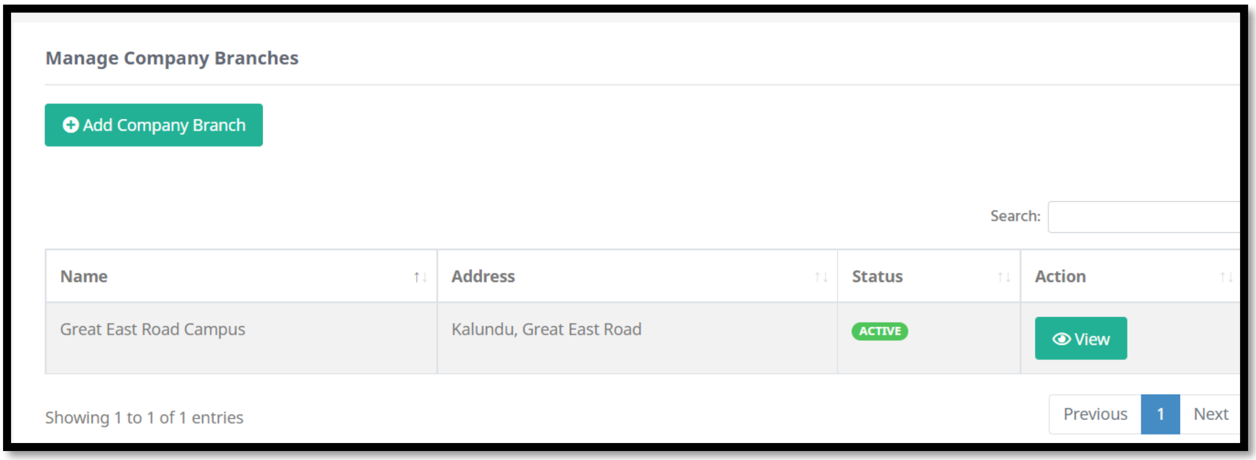


Figure 47: Manage Company Branches page (by author, 2021)

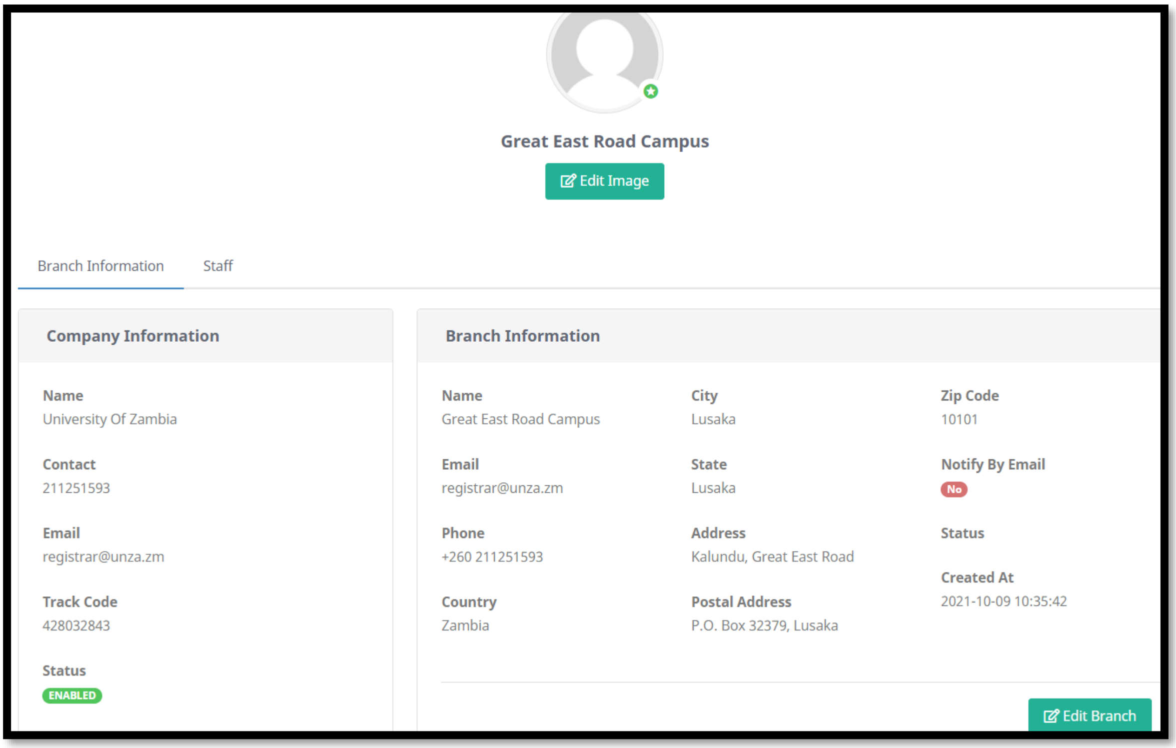


Figure 48: Example of company branch details (by author, 2021)

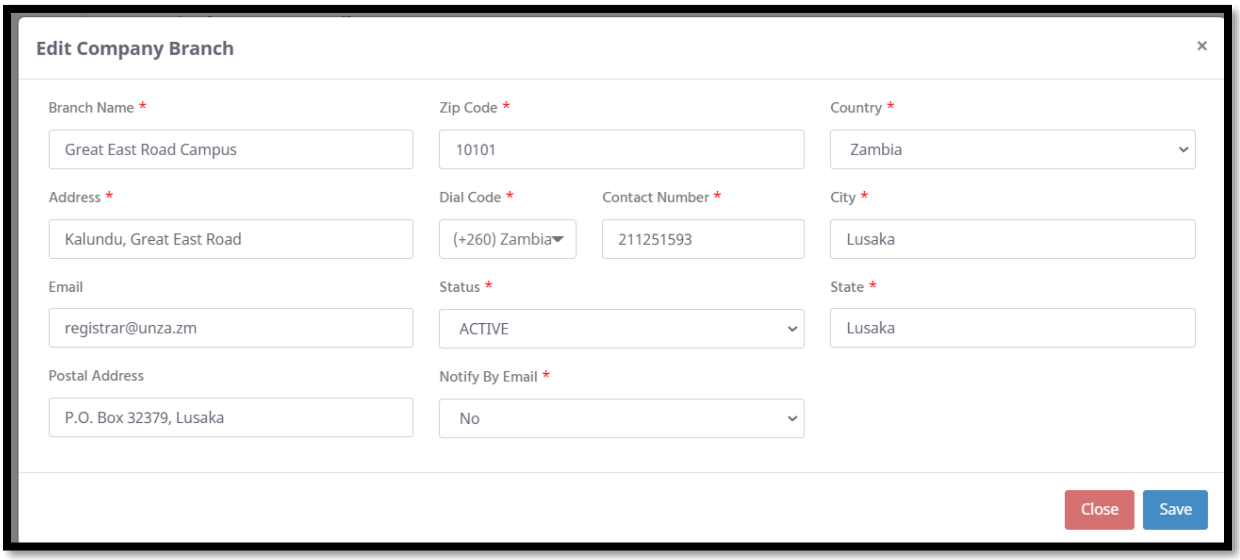


Figure 49: Adding/ editing branch details (by author, 2021)

3. Manage User Sessions – the administrator would be able to monitor all user activities on this section, see figures 50 and 51.

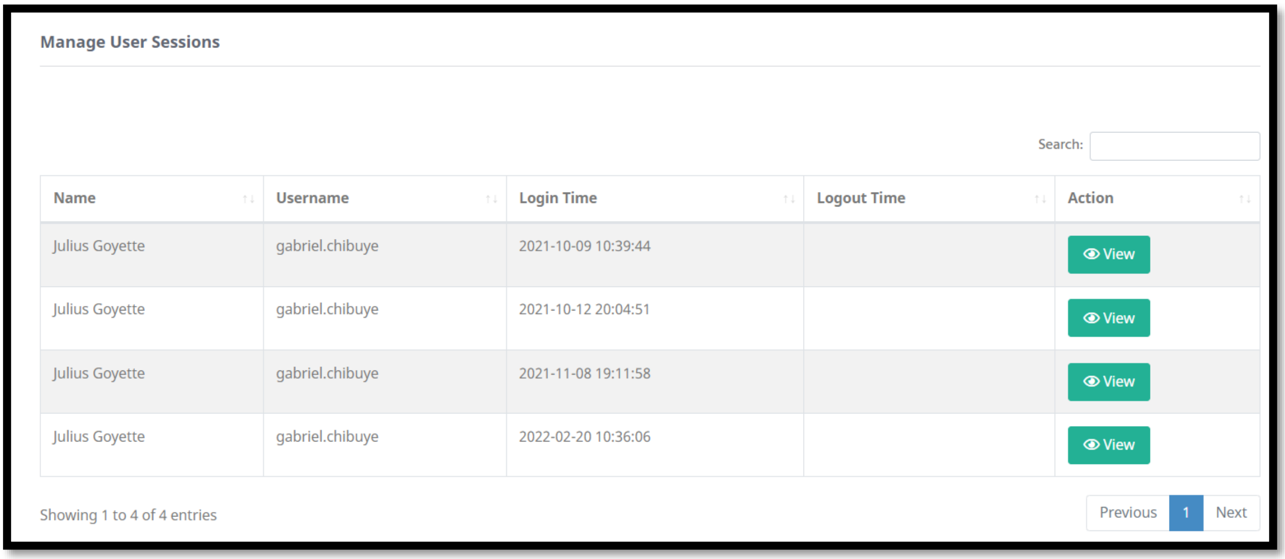


Figure 50: User sessions (by author, 2021)

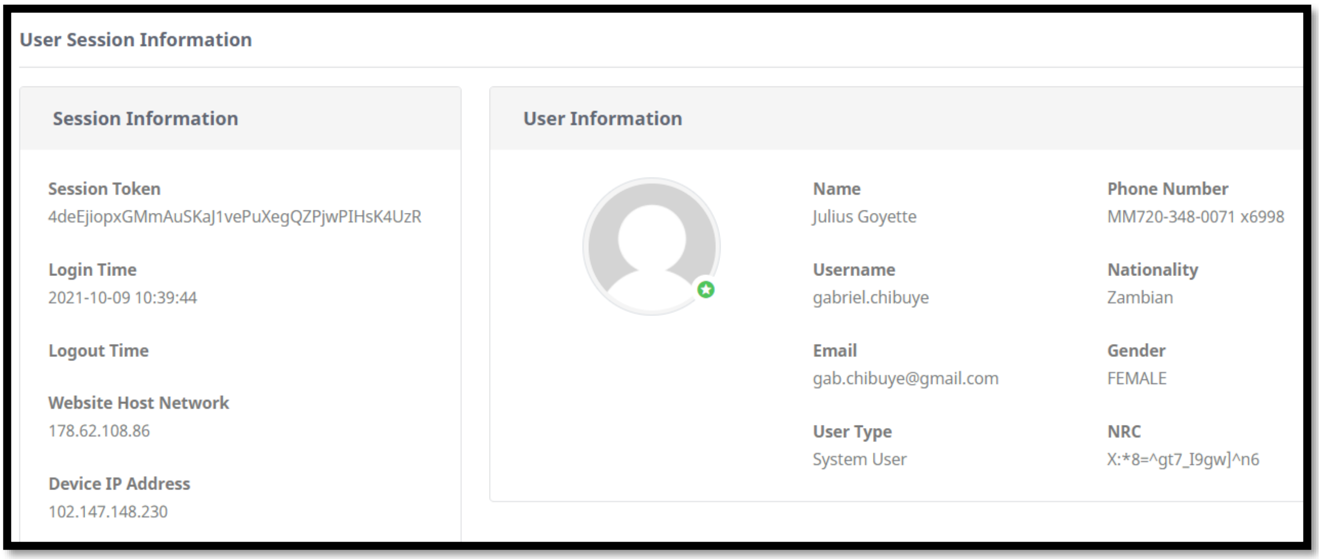


Figure 51: user session details (by author, 2021)

Asset Management Panel - The asset management panel could only be accessed by the administrator as well as any user with access rights. It had two pages;

1. The asset management page showed the list of all the assets in the system, see figure 52. The user could add or delete an asset. When a user viewed an asset, the details could be edited, see figure 53. The QR code was also generated from here, see figure 54 for an example of the QR code generated after adding an asset. The asset list could be copied to clipboard, exported to excel or pdf.

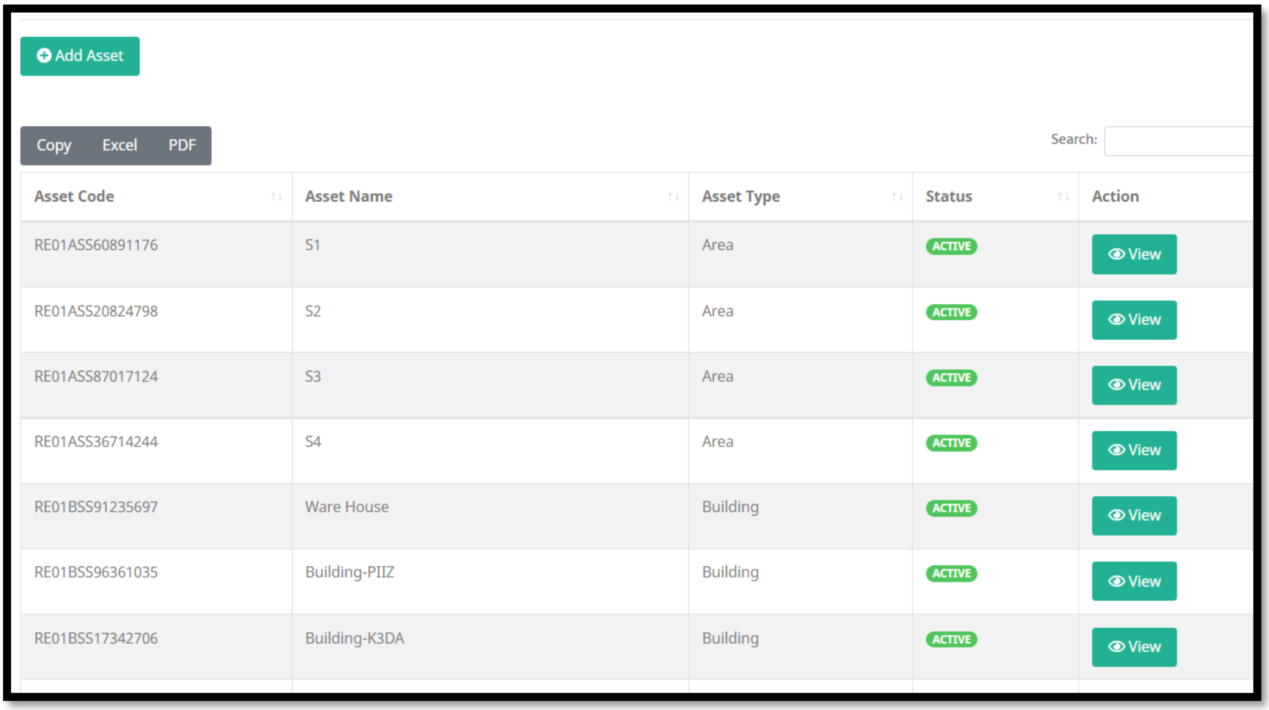


Figure 52: Asset management page (by author, 2021)

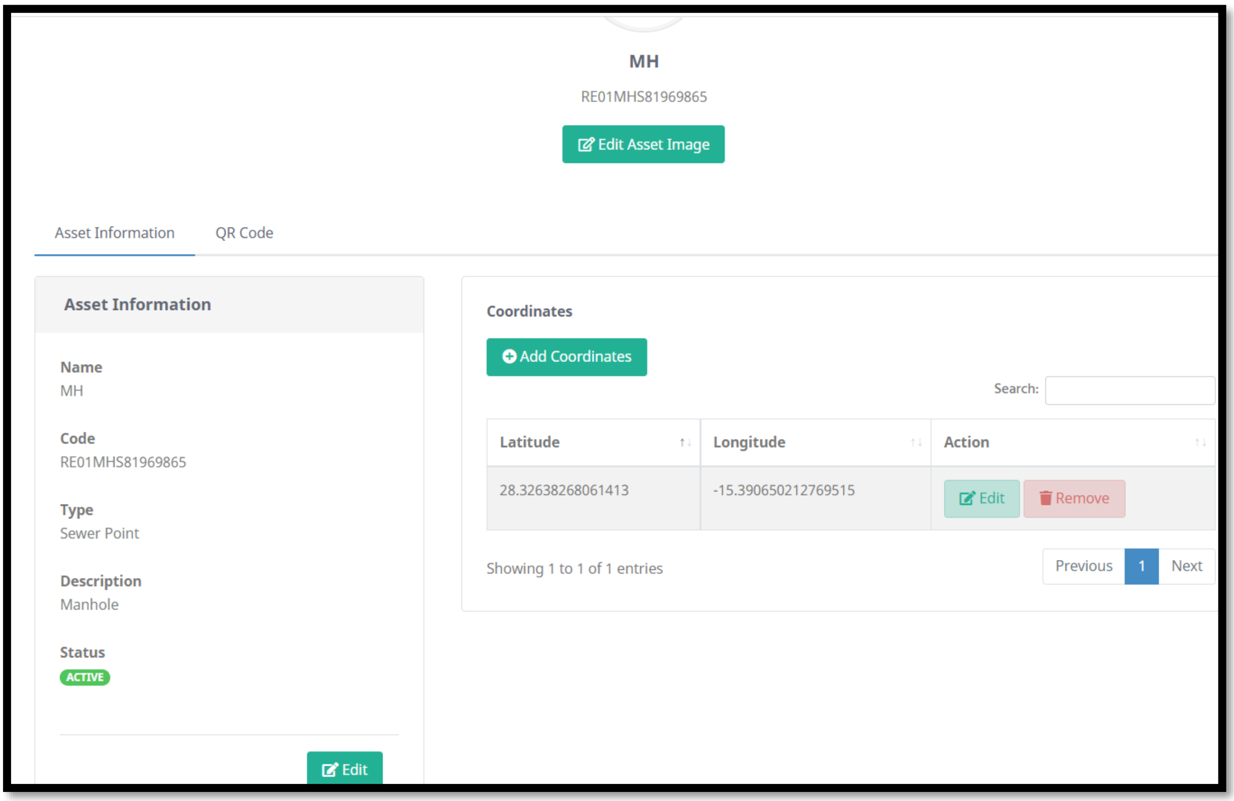
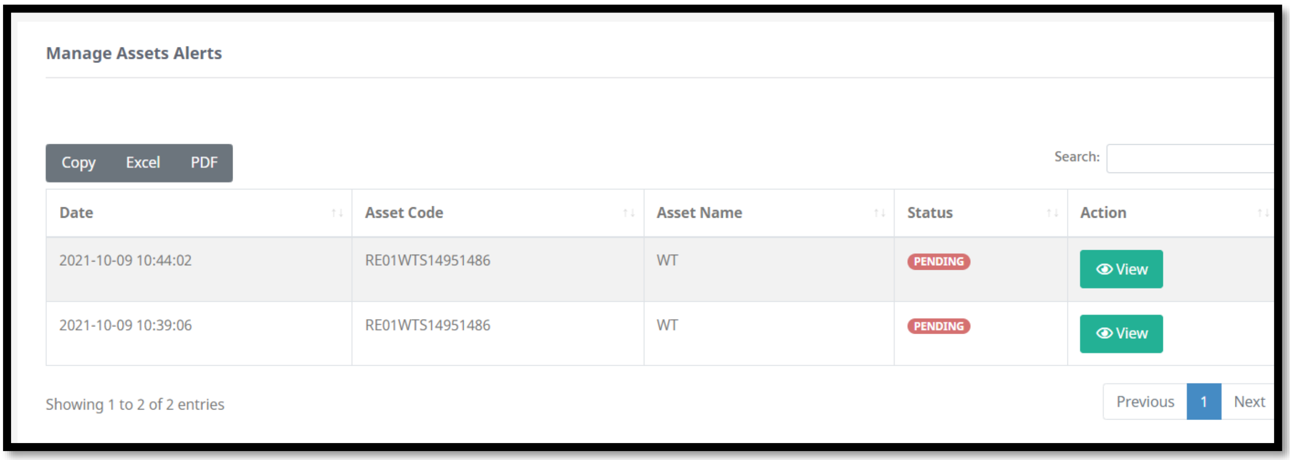


Figure 53: Asset details and editing (by author, 2021)

Figure 54: Generated asset QR code (by author, 2021)

2. Manage Assets Alerts – Alerts sent for any assets was viewed and resolved on this page. Issues could be resolved here or pending issues could be tracked from this page, See figures 55, 56 and 57



Date	Asset Code	Asset Name	Status	Action
2021-10-09 10:44:02	RE01WTS14951486	WT	PENDING	View
2021-10-09 10:39:06	RE01WTS14951486	WT	PENDING	View

Figure 55: manage asset alert (by author, 2021)

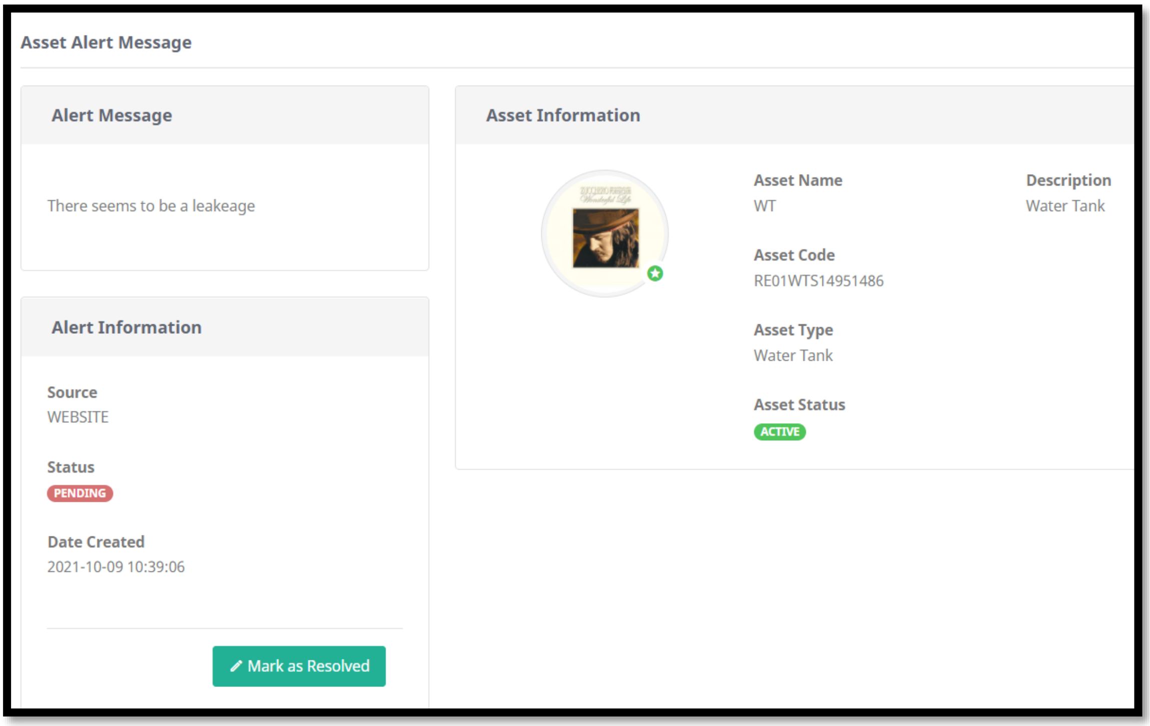


Figure 56: Manage asset details (by author, 2021)

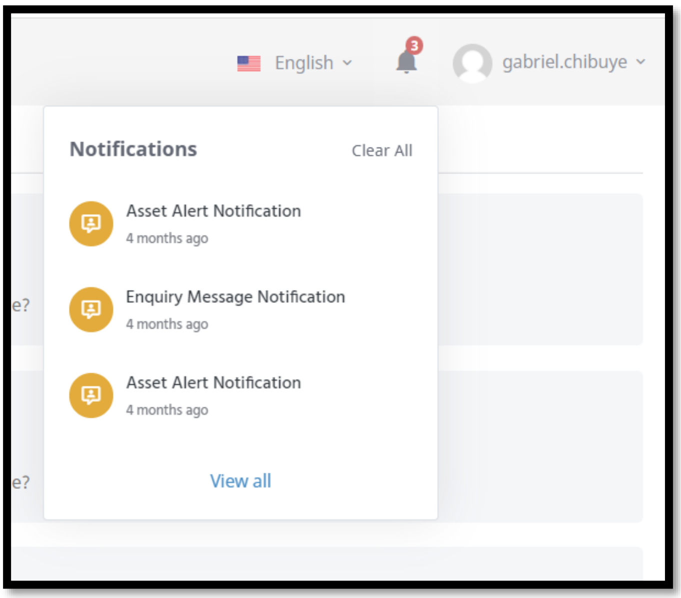


Figure 57: Alert notification (by author, 2021)

4.9 Mobile App Development

The mobile app users could access the system directly using their mobile phones or other handheld gadgets by scanning the QR Code. The QR Code takes the user the home page were the user can view and report any issues that they may have noticed. The mobile access of the system was made compatible with android 4.4.4 and higher.

In the example of the asset's QR code in figure 54, when scanned from an android phone, the QR code had a link would take the user to the system. The app opened into the asset information about the scanned asset, see figure 58. On the same page, users could send alerts to the system to report any malfunctioning structure. The user could view the asset details as shown in figure 59. The user could access the home screen by clicking on the three-line menu on the top right corner, see figure 60. The other functions like search, contacts, asset list could be accessed from the home screen in figure 61.

The user could also login using their details and could access all the features just as in the main desktop web app.

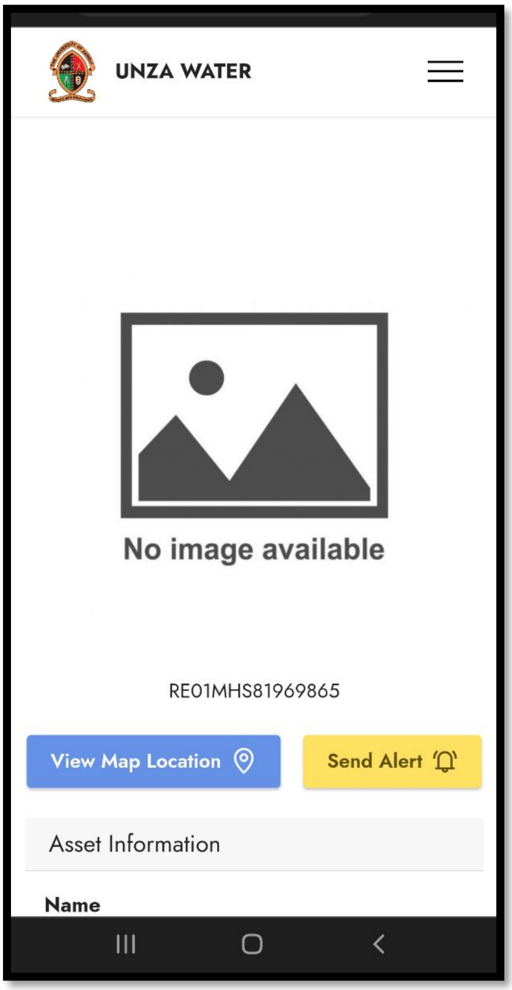


Figure 58: Mobile web browser accessed via the QR code link (by author, 2021)

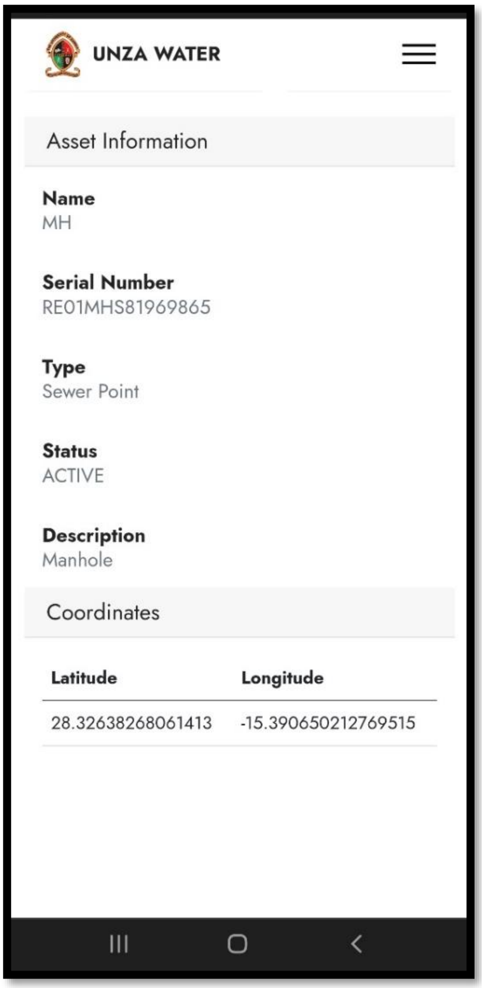


Figure 59: Asset details (by author, 2021)

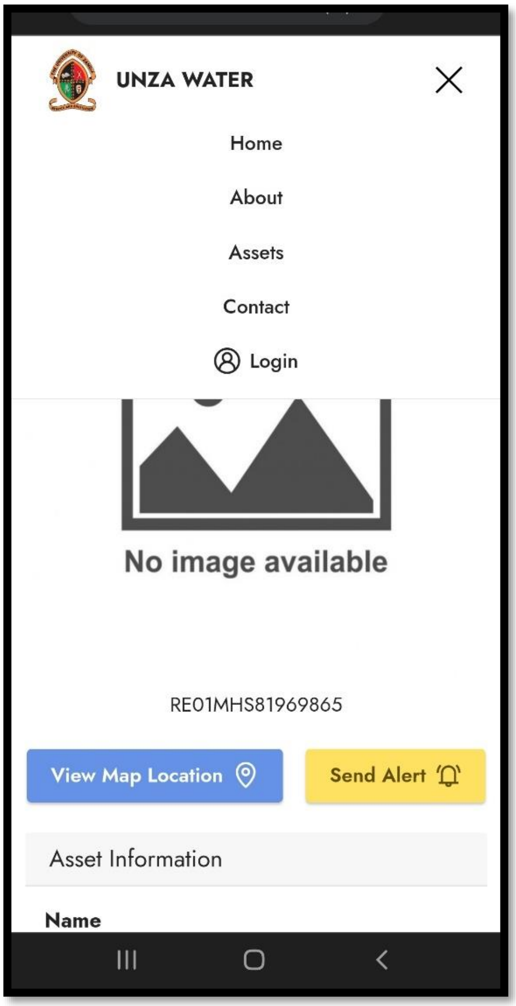


Figure 60: Opening the three lined menu (by author, 2021)

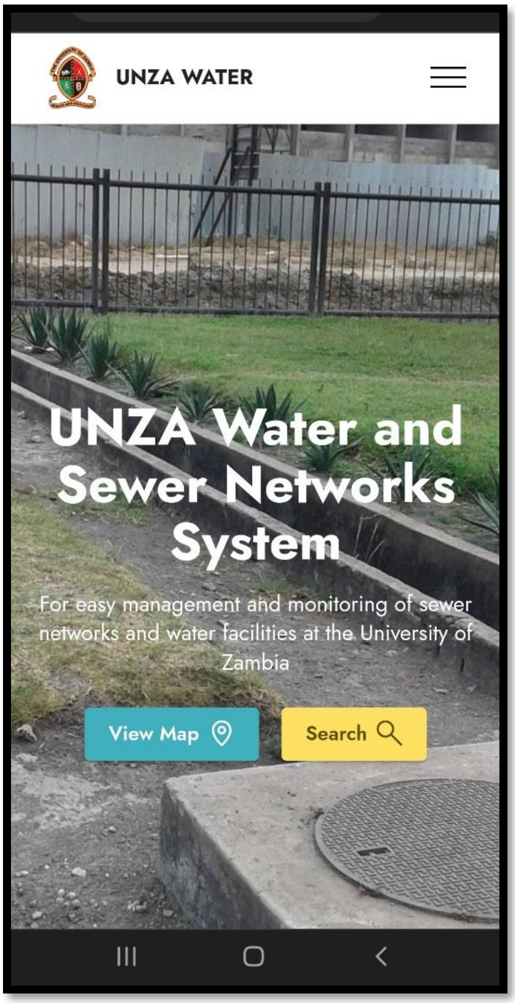


Figure 61: Home page on mobile web (by author, 2021)

4.10 Site QR Code Tagging

Tagging was intended to be done for each node, using the QR codes generated for each structure in the system. The tags would be stuck on manholes such that they could easily be seen and read. The tags would be labelled with the QR Code matching each structures unique id.

4.11 Sensor installation and Configuration

The proposed sensors are water level sensor's that could detect water level for the blocked sewer manhole. These would give an alert with the details and location of the affected manhole.

The water level sensors would be installed on a few manholes and using Arduino Development Kit and internet of things and connected to the web app. The physical prototype connection of the sensor to the arduino is shown in figure 62.

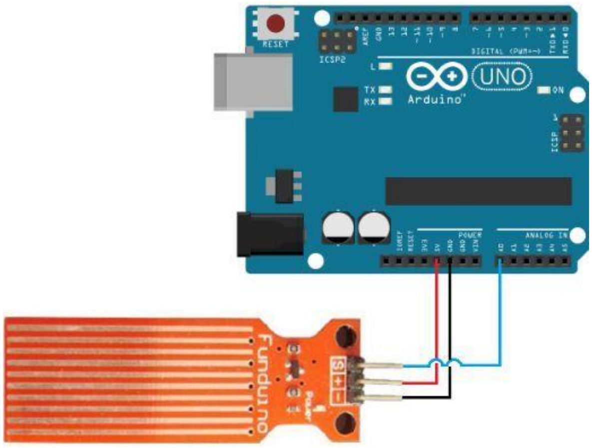


Figure 62: the water level sensor and Arduino board (by author, 2021)

After hardware connection, the sample sketch was inserted into the Arduino IDE. Using a USB cable, connected the ports from the Arduino to the computer. Uploaded the program. The results could be seen in the serial monitor.

Result: More and more you dip the board in water the value on serial monitor kept on increasing.

The series of sensor network could be connected to a personal area network and an aggregator that had a GSM shield. This GSM shield could support the common mobile network technologies such as GSM, 3G, LTE. The GSM shield was connected to an Arduino aggregator and an operating system was be used to communicate with the shield and upload data to the remote server. The Mosquito server was used to gather all the information from the remote sensor.

The sensor could send notification to the web app and the user can tell which manhole was affected prior to going to the field. The users can log in and view any information required for each structure. Administrator rights were also included to allow top management to be able to edit, update and manipulate the data as required. The users could log in and view any information required for each structure.

4.12 Chapter Summary

This chapter discussed the results and finds from the steps and methods used in chapter three. The user assessment needs were analysed and data collected was used to create more shapefiles which were used to create maps. The shapefiles produced were the main data inputs into web map. The components developed and the installations in the system were also discussed.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This chapter will discuss the findings of the study in the conclusion and give some recommendations based on the experience and limitations of this study.

5.1 Conclusion

A baseline study was conducted of the existing sewer and water networks. During the baseline, it was found that the resident engineer's office did not have an automated system to plan, manage and monitor the university water and sewer infrastructure. The framework was then developed based on the baseline study. Using the framework, data was collected from various sources, analysed and processed and finally used to build a spatial database using PostGiS and PostgreSQL and web mapping tools. The internet of things was used to integrate sensors into the web-based framework after coding and tagging were done for each feature using QR coding system.

The WebGIS tools were used to build a working prototype of the spatial framework for the University of Zambia. The system could be accessed by both desktop web applications and mobile web applications. Different users' access had been set up and notifications could be sent to the system. It was envisioned the developed prototype would ease operations for the Resident Engineer in terms of maintenance, management, and overall workflows.

5.2 Recommendations

- The study can be implemented by mimicking the processes to make sensor installations in the manholes and tagging for identification. The network system can be improved if accurate elevations of the water and sewer lines are known. At the moment the accurate locations are in the horizontal i.e. X and Y. A topographic survey of the entire corridor of the sewer and water lines could be done, and an accurate digital terrain model can be generated and uploaded to the system hence improving the surface accuracy.
- Scans of the lines of the water and sewer lines can be done using Ground Penetrating Radar (GPR). This would give precise elevations of the top of the pipes which can also be included into the system. Accurate information of the round elevation the pipe elevations can help when making new installations and can prevent damage of pipes as a result of any excavations within the University.

- The study could further be realised by implementing sensor networks that could be manually installed in the pipelines and manholes. The system could be used for any IoT related works and therefore help in making the university of Zambia a smart campus. The methodologies used can also be used in other related studies that need to implement a web GIS app or other location-based technology related studies.

5.3 Chapter Summary

This chapter discussed the findings of the study in the conclusion and proposed some future works that could be done to improve the system developed in the recommendations.

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APPENDICES

List of Publications

1. Journal Publication

   Gabriel Chibuye, Jackson Phiri and Faustin Banda (2020), "A Spatial Framework for Managing Sewer and Water Networks Using Sensor Networks: A Case of the University of Zambia" International Journal of Recent Contributions from Engineering, Science & IT (iJES) – eISSN: 2197-8581, Volume 8, Issue 1.

A Spatial Framework for Managing Sewer and Water Networks Using Sensor Networks: A Case of the University of Zambia

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Abstract—The University of Zambia like any public institution has a lot of infrastructure which require maintenance and management. There's however uncertainty of the utility lines locations and their depths. This causes destruction of water pipes and sewer lines when undertaking new constructions or any excavations. The lack of accurate location of underground and un-updated lines makes maintenance, management and planning of the utilities very difficult. Therefore this study aimed to build a framework for Managing Sewer and Water Networks Using Sensor Networks at the University of Zambia. The Resident Engineer's office only has some old scanned pdf sketches of both sewer and water networks. The field engineers locate most lines and other facilities using memory and experience. The methodology involved understating the existing operations of the Resident engineer's office to ascertain the user needs. These needs formed the basis of the research, the development and design of the prototype of the Webbased Framework. Data Collection tools included Records (old maps) and Secondary Data (satellite images), Field Observations, Interviews and field Surveys. A presurvey (Reconnaissance Survey) was done to have an idea of the existing infrastructure and a more accurate survey was done using GPS GNSS equipment. The raw data was processed and GIS software was used to merge the collected datasets and the existing data. Georeferencing of existing maps and the satellite images was done using the GPS field data in ArcMap. New shapefiles were created from the point data from the survey and from digitising the existing scanned maps. New maps of the water and sewer networks (using the new shapefiles) and satellite imagery were created. A 15 digit coding system was created and was used to assign unique identification numbers and extra attribute information to the water and sewer network shapefiles. A QR code was generated for each node and the serial number recorded. Tagging was done using the QR code for each structure. All the shapefiles were loaded into a PostGreSQL spatial database and were used as input in the Web GIS application. The web application had some tools imbedded in it including; query, measure, add point/vertex, zoom, view, search and identify. Using internet of things (IOT) technology, water level sensors were placed on some critical manholes to help with the monitoring of the sewerage network. The system can therefore be used for identification of any infrastructure by scanning the QR code and a map showing the structure is seen online by the field

2. Conference Paper

Gabriel Chibuye, Jackson Phiri and Faustin Banda (2019), ”A Spatial Framework for Managing Sewer and Water Networks Using Sensor Networks: A Case of the University of Zambia” Proceedings of The International Conference in ICT (ICICT2019) - Lusaka, Zambia (20th - 21st November 2019)

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE IN ICT (ICICT2019) - LUSAKA, ZAMBIA (20TH - 21ST NOVEMBER 2019)

A Spatial Framework for Managing Sewer and Water Networks Using Sensor Networks: A Case of the University of Zambia

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***Abstract*— The University of Zambia lacks accurate up to date locations of manholes, sewer lines and water lines which makes maintenance, management and planning of these utilities very difficult. Therefore this study attempts to build a framework for Managing Sewer and Water Networks Using Sensor Networks. A Web-based GIS or WebGIS application was used to develop the spatial framework. WEBGIS is a powerful mapping and analytical functionality expressed within a web browser. Using internet of things (IOT) technology, water level sensors were placed on some critical manholes to help with the monitoring of the Sewerage network. Utility coding and tagging was done using QR code which hugely helped in the identification of all the infrastructure. The QR codes could be scanned using any QR code reader and could provide attribute data including the location for easy identification for any field personnel.**

Keywords*— GIS, WEBGIS, Sensors, Internet of Things, Coding, Tagging, QR Codes

I. Introduction

The University of Zambia is rapidly expanding as observed from the new developments all around campus [1]. The growth naturally necessitates the acquisition of new properties and development of University infrastructure. One of the key areas of focus for managing the University facilities is optimal use of utility spatial information. In particular, water sewerage utilities are essential for the smooth running of a university. Water provides inevitable sustenance to life and sewerage systems provide a means of discarding waste water. As such, it is essential for water utilities to be managed well.

Most of the water utility spatial information used in managing the University facilities have been primarily paper based maps. These hardcopy maps and documents have become largely inaccurate because they have not been updated in a very long time. The maps have become old and inaccessible over time as most maps are torn and are now lost. These hardcopy maps are no longer appropriate for real time decision making because they are unable to act in response to changing circumstances. The field technicians locate most lines
and other facilities using memory and experience. Consequently, there is need to introduce better systems that are more efficient in spatial data organization, manipulation and visualization.

The aim of the study was therefore to build a spatial framework for managing the existing sewer and water networks at the University of Zambia. There first objective was to conduct a baseline study of the existing sewer and water networks. The second objective was to design a framework for the GIS sewer and water networks integrated with sensors based on the findings in the first objective. The final objective was to develop a prototype based on the framework developed in the second objective using the web, mobile and sensing technologies.

The Research Questions formulated were in line with each objective. For objective one the research question was: Where are the water and sewer networks located and how are they currently identified around the University? In objective two the research question was: Can a framework be designed for the findings in the first objective to monitor, manage and integrate the utility system with sensors? Finally the third objective question was: How can a prototype of the framework designed in the second objective be developed?

A Web-based GIS or WebGIS application was used to develop a spatial framework. WEBGIS is a powerful mapping and analytical functionality expressed within a web browser. The web application had some tools imbedded in it including; query, measure, add point/vertex, zoom, view, search, identify and update. Using internet of things (IOT) technology, water level sensors were placed on some locations to monitor some manholes of the Sewerage network. Utility coding and tagging was done using QR code. The code was used to uniquely identify all the structures.

II. LITERATURE REVIEW

The literature reviewed involved looking at the various geospatial and other relevant technologies that could be of use in water and sewer networks. These included aspects of Land Surveying, Traditional GIS and Mapping, Web Mapping, Spatial Database, QR Code technology and Internet of things technologies.

A. GIS AND OTHER TECHNOLOGIES

Geographical Information Systems (GIS) technology offers combined power of both geography and information systems an ideal solution for effective management of water and sewer utility infrastructure. The effective management of water utility network can be possible by proper

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