

**Integrating a web-based GIS in the optimization of the customer
connection process for utility company: A case of Kenya Power &
Lighting Company, Ltd.**

By

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MNYMAR022

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DEDICATION

I would like to dedicate this project to the Almighty God for His guidance and favour throughout my research. I would also like to dedicate it to my children, parents, siblings and the entire UCT community.

ACKNOWLEDGEMENT

I would first like to thank God for his grace and favour throughout this dissertation writing. He has been merciful and gracious to me throughout my studies especially now when the world is experiencing a global pandemic.

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MAY THE ALMIGHTY GOD BLESS YOU ALL ABUNDANTLY!!!

ABSTRACT

Great strides have been made world over in the use of GIS as a tool for the management of resources and decision making in the utilities. Utilities are now integrating GIS with other company systems in a bid to reduce operational costs, maximize revenue as well as improve efficiency and care to customers. However, this use has been confined to ensuring optimised service delivery to existing customers and overlooks new prospective customers. With privatization and deregulations, utility companies are now faced with a new challenge to strive for the market share in the most efficient and cost-effective ways. This research sought to develop a complementary web-based GIS application that can be integrated with existing utility company systems to improve efficiency in the new customer connection process.

Waterfall System Development Methodology (SDM) was adopted in this research. Its simplicity and straightforwardness gave it a niche over other SDMs in-terms of implementation as one only moved to the next stage once the previous stage had been fully completed and tested. Digital online map, counties information data, enquiry for supply forms as well as the supply contract forms were used as the main datasets in the study.

The objectives of this research were achieved by the development of a geodatabase to record, store and retrieve customer information; and a web-based GIS application to facilitate recording and upload of this information. It is possible to develop a web-based GIS application that can be integrated with existing company's systems. Through integration, the system will automate and augment most of the manual processes in the new connection work-flow. This development would greatly improve new customer connection efficiency, maximize revenue collection for the utility and elevate the customers' socio-economic statuses. The system would also provide a platform for the monitoring and analysis of the infrastructure development geared towards the achievement of Kenya's Vision 2030.

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List of Abbreviations

ADMD	After Diversity Maximum Demand
AM/FM	Automated mapping/Facilities Management
CAD	Computer Aided Design/Drafting
CAK	Communications Authority of Kenya
CRUD	Create, Retrieve, Update and Delete
CSS	Cascade Styling Sheets
DBMS	Database Management System
ECG	Electricity Company of Ghana
ERD	Entity Relationship Diagram
ESRI	Environmental System Research Institute
GDC	Geothermal Development Company
GI	Geographic Information
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HTML	Hypertext Mark-up Language
HTTP	Hypertext Transfer Protocol
IPP	Independent Power Producers
IRENA	International Renewable Energy Agency
IT	Information Technology
JSON	JavaScript Object Notation
KENGEN	Kenya Electricity Generating Company
KETRACO	Kenya Electricity Transmission Company Ltd
KNBS	Kenya National Bureau of Statistics
KPLC	Kenya Power and Lighting Company
MoEP	Ministry of Energy and Petroleum
OSM	OpenStreetMap
PDF	Portable Document Format
RDBMS	Relational Database Management System
REREC	Rural Electrification and Renewable Energy Corporation
SDLC	System Development Life Cycle
SDM	System Development Methodology
SQL	Structured Query Language

UEAG	Union Euro Arab of Geomatics
URL	Uniform Resource Locator
UTM	Universal Transverse Mercator
VGI	Volunteered Geographic Information
XML	Extensible Mark-up Language
KRA	Kenya Revenue Authority
P.I.N	Personal Identification Number

CHAPTER 1: INTRODUCTION

1.1 Background

Utilities throughout the world are facing a myriad of challenges that have necessitated them to adopt to new ways of doing business. Increased territorial deregulation, mergers and acquisitions, utilities' privatization, competition for customers coupled by increased consumer awareness on service options has left utilities scrambling to maintain their market share. Thus, there is need for these capital-intensive companies to employ new tools and strategies in order to stay competitive in the marketplace (Meyers, 1999).

The number of worldwide mobile cellular internet subscriptions has increased significantly and Kenya has not been left behind. A gradual growth in internet subscriptions in Kenya has been witnessed over the years with the statistics standing at 52 million subscribers by the end of September 2019. This growth has been influenced by the increased 3G/4G coverage, availability of affordable smartphones and data plans as well as an increase in the consumption of e-commerce, e-government, social media and other online content (Communications Authority of Kenya [CAK], 2019).

With an ever-changing world, institutions have found it difficult to maintain up-to-date spatial data by use of the traditional spatial data gathering techniques such as photogrammetry, remote sensing and land survey. To overcome this challenge, institutions have innovatively come up with a cost-effective solution that quickly avails the required spatial data. Citizens are voluntarily engaging in the process of collecting, assembling, modifying and sharing geographic data, a phenomenon known as Volunteered Geographic Information (VGI). VGI has particularly been fuelled by the growing ability of citizens to interact with the web and web-based technologies. VGI engagement is evolving as a critical source of spatial data and has the potential of altering the traditional GIS landscape significantly.

Geospatial data, information and technologies are becoming common tools that improve and support government and private-sector decision making (Mapping science committee: National research council of the national academies, 2007). Geographical Information System (GIS) is an automated information system that is able to compile, store, retrieve, analyze and display mapped data (Longley *et al*,

2011). “Visualization and geographic analysis of data distinguish GIS from other information systems, making it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies” (Union Euro Arab of geomatics [UEAG], 2012).

Geospatial data, information and technologies are becoming common tools that improve and support government and private-sector decision making (Mapping science: National research council of the national academies, 2007). A web-based GIS system, which is a relatively new technology, is any system that is able to offer GIS functionalities over the web. Its use is fast gaining momentum and has since established a niche over the traditional desktop GIS system. Organizations and companies, both in equal measure, are leveraging on the low cost of set-up and maintenance of web-based GIS, as well as its ability to be used concurrently by large number of users who do not require any prior professional GIS expertise. Web-based GIS systems are being used by utility companies to carry out utility audits, asset management, network analysis and customer management.

This study seeks to take advantage of the technological advancements in the GIS world, positive willingness by prospective consumers to volunteer information as well as the rapid growth in the mobile internet subscriptions. The research will embrace these three aspects to develop a complementary web-based GIS application aimed at enhancing efficiency in the new customer connections process at the utilities.

1.2 Problem Statement

Adequate energy supply is among the key development enablers for a country. Electricity companies are now relying on GIS as a tool for managing company resources, improving customer service and for decision making. Kenya power and lighting company (KPLC) has been using GIS to manage its network infrastructure, designing for network expansion, tracking and locating existing customers among many other processes. However, the use of GIS has only focused on managing already existing customers with little or no effort made to incorporate new customers applying for supply of this utility. A greater part of the new connection process is manual which result in errors, delays and misinformation. This study seeks to

provide a solution to streamline new customer application process by designing a web-based GIS application to be integrated with the existing KPLC's systems.

1.3 Main Aim of the study

The objective of this study is to develop a complementary web-GIS application to enhance customer power applications by improving the efficiency in new customer connections process.

1.4 Specific Objectives of the study

1. Develop a geodatabase for recording and sharing customer connection data.
2. Develop a web-based GIS application through which customer connection data can be uploaded and retrieved.
3. Publish, share and test the application on an online platform.

1.5 Research Questions

This study intends to address the following research questions:

1. What geodatabase specifications would support self-recording, storage and sharing of customer's connection and location data?
2. Can a web-based GIS application facilitate new customer connection data upload and retrieval?
3. Can a web-based GIS application facilitate an online registration process for power connection of new electricity users?

1.6 Significance of the study

This study is aimed at demonstrating how a web-based GIS system can be used by the utility company to improve efficiency in the new customer connection process. Its integration with the existing utility company systems offers an alternative to the normally manual/semi-manual processes within the new customers connection framework. Its adoption will not only be beneficial to the electricity utility, but also the government administration as a proxy for the assessment of trends in infrastructure development in the country.

1.7 Scope and Limitations of the Study

This research is limited at developing a complementary web-based GIS application for integration with the existing systems to improve efficiency in the new

connections work-flow. The developed web-based GIS application will be for use by prospective customers to record and share information on enquiry for supply of power, as well as the utility company personnel for automation of the manual processes in the new connection work-flow.

The web-based GIS application will be aimed at supporting customers with smart devices as it will be highly interactive. It is also restricted to users with access to good internet reception, as the application is web-based. The target study area is Mombasa county, which comprises of urban, semi-urban and rural landscape which provides a good platform for performance testing of the application. Testing will be evenly distributed within the study area by considering infrastructural development spread.

1.8 Organization of the Study

This research is organized into six chapters with each having several sub-topics as outlined in the table of content. Chapter one entails the background to the research, the gap the study seeks to address under the problem statement, objectives, significance, scope, and limitations. Chapter two gives a brief breakdown of the energy sector in Kenya and brings the readers into speed with the current state in new electricity application process in the country. Chapter three reviews the literature that is significant to the study while, chapter four generally presents the methodology to be used during the research. Chapter five outlines the results obtained from the study and a discussion of their relevance in the research. Chapter six concludes the research by reviewing whether the research objectives have been met as well as outlining any challenges experienced during the study and any further recommendations.

CHAPTER 2: ELECTRICITY UTILITY IN KENYA

This chapter seeks to discuss the Kenya's electricity utility industry players and the existing technologies in use, and is divided into five sections. The first section provides a brief background on the Kenya's vision 2030 and the role of the energy sector in its achievement. The second section outlines the structure of the Kenya's energy sector, while the third section discusses the Electricity sub-sector outlining each player in the sector. The fourth section tackles the Kenya Power and Lighting Company which is currently the sole distributor and retailer of electricity in Kenya. Section five describes the study area used in this research.

2.1 Kenya's Vision 2030

Kenya's Vision 2030 is the country's new development blueprint for the period between 2008-2030. It was developed as a result of an interactive participation and contribution from both the local and international experts and the general public. Its aim is to transform Kenya into a newly industrializing, middle-income country that provides high quality life to its citizens. The vision is anchored on three pillars namely social, economic and political pillars.

Adequate energy supply is one of the most important elements that enables a country to realize major strides in development. Kenya's development agenda under the Vision 2030 umbrella identified energy as one of the key infrastructural enablers for development and its demand was projected to rise in order to meet the supply requirements of the new developments (MoEP, 2020). However, it was noted that Kenya's energy prices were considerably higher than her competitors and thus it was important that the country generates more energy at a lower cost as well as increase efficiency in energy consumption. In order to achieve these, the government committed to carrying out institutional reforms (Government of the Republic of Kenya, 2007). These reforms included having a strong regulatory framework, encouraging more private generators of power and separating generation from distribution of energy.

2.2 Kenya's Energy Sector

A typical energy sector comprises of all stakeholders that play vital roles in energy generation/production, transmission, distribution and sale of different forms of

energy to the final user. These include oil and gas industries, hydroelectric power generators and distributors, coal mining and usage, wind and solar energy harnessing and distribution, geothermal energy extraction and distribution, biofuel industry, wave and tide energy harnessing, and nuclear energy among others. In the Kenyan commercial energy sector, petroleum and electricity provides for the modern economy energy needs while wood fuel provides for the traditional economy energy needs. However, due to its versatility in application, electricity remains the most sought-after energy source with its access being associated with a rise in quality of life (Ministry of Energy, 2004).

The Ministry of Energy and Petroleum (MoEP) is at the helm of Kenya's energy sector. "Its main responsibility is the development and implementation of policies that create an enabling environment, for efficient operation and growth of Kenya's energy sector" (MoEP, 2020). It is governed by the energy act (2019) whose enactment sought to consolidate all laws related to all forms of energy. This was in order to streamline the exploitation, production and distribution of all forms of energy. It properly delineated the role played by both the National and devolved governments on energy matters (Rold and Partner, 2019).

Unfortunately, in Kenya like the rest of the world most sources of energy are diminishing in nature, necessitating the development of sustainable energy plans. According to Murphy (2018) a sustainable energy plan is one that meets our energy needs today without risking the depletion of future energy sources. To enable sustainable energy efforts, GIS has become a critical planning and management tool (Altaweel, 2016). GIS is widely being used in all semi-autonomous agencies under the ministry to manage all sources of energy and for future planning of operations in those agencies.

2.3 Kenya's Electricity Subsector

The Electricity sub-sector in Kenya is one of the semi-autonomous agencies under the MoEP. It is comprised of several bodies responsible for the generation, transmission and distribution of electric power as well as other regulatory functions. Kenya Electricity Generating Company Limited (KenGen), Geothermal Development company Limited (GDC), Independent Power Producers (IPP's), Kenya Electricity Transmission Company Limited (KETRACO), Rural

Electrification and Renewable Energy Corporation (REREC) and Kenya Power and Lighting Company Limited (KPLC) are involved in the generation, transmission and distribution of electricity (Kenya power, 2013).

KenGen, GDC and IPP's are responsible for the generation of electricity at 415v which is then stepped up to either 132/220kV and fed into the electricity GRID for transmission. KETRACO is involved in the construction of transmission substations and transmission lines i.e., 400kV, 220kV and 132kV lines. REREC is involved in the design and construction of high and low voltage power lines i.e., 33kV, 11kV, 415v and 240v to supply public institutions and market centres in the rural areas. "KPLC is a state corporation responsible for electricity transmission, distribution and retail sales" (MoEP, 2020).

Kenya's electricity network is divided into two categories namely, the transmission network and the distribution network. The transmission network refers to all equipment and infrastructure that carries and transmits electricity at either 400kV, 220kV, 132kV or 66kV. On the other hand, the distribution network refers to all equipment and infrastructure that carries and transmits electricity at voltages of 33kV, 11kV, 415v or 240v (Lahmeyer International, 2016). However, the 33kV lines are categorized either under transmission network or distribution network depending on whether or not they are supplying primary substations. The 66kV lines are only found in Nairobi where they supply primary substations and large power customers like cement mining companies, steel rolling companies among others.

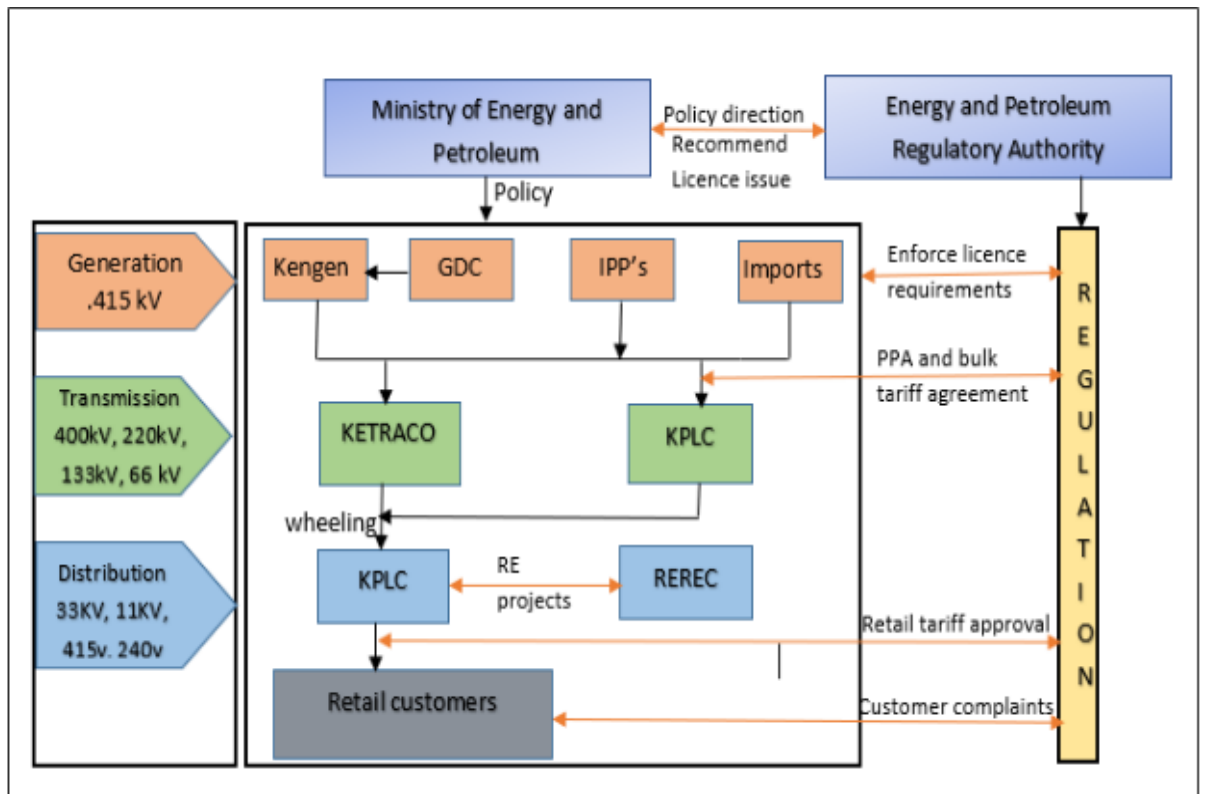


Figure 2.1: Kenya's electricity sub-sector. (Adapted from the KETRACO website)

2.4 Kenya Power and Lighting Company Ltd

As stated in its mandate, KPLC plans for sufficient electricity generation and transmission capacity to meet demand, builds and maintains the power distribution and transmission network and retails electricity to its customers. (Kenya Power, 2020). Currently, KPLC enjoys a monopoly as the sole distributor and retailer of electricity in Kenya. 'It operates Kenya's interconnected grid, as well as several off-grid stations in the northern regions of the country' (Power Africa, 2016).

2.4.1 KPLC network Hierarchy

KPLC's transmission and distribution network is operated in eight distinct regions namely; Nairobi, Mt. Kenya, North Eastern, Coast, West Kenya, North rift, Central rift and South Nyanza region (KPLC, 2020). The extent of the grid covers the main population centres in all the regions with extensions having been made by REREC to all public schools and health centres in rural areas (Parsons Brincker, 2013).

Nairobi region

This region receives its bulk supply of electricity via 220kV and 132kV transmission lines which terminate at 220/66kV and 132/66kV transmission substations respectively. Each transmission substation yields several 66kV feeders, with each feeder supplying one or more 66/11kV primary substations (Parsons Brincker, 2013). Each primary substation steps down the voltage to 11kV and yields feeders which in turn supply 11/.415kV secondary substations (distribution transformers). Low voltage lines which are either three phase (415v) or single phase (240v) emanate from the distribution transformers and supply customers according to their load demand.

Other regions

The distribution network in all the other regions receives its bulk supply of electricity from 220/33kV and 132/33kV transmission substations. The voltage on these transmission substations is stepped down and yields several 33kV feeders. Each 33kV feeder supplies one or more 33/11kV primary substations and many 33/.415kV distribution transformers (Parsons Brincker, 2013). Subsequently, 11kV feeders emanate from these primary substations and supply 11/.415kV distribution transformers. As in the case of Nairobi region, low voltage lines emanate from these distribution transformers and supply customers with electricity.

In the urban centres for all regions, the network is interconnected with normal open points that provide for alternative power supply in case of a fault or scheduled maintenance of particular feeders/equipment. Large power customers that require bulk supply of energy are supplied using either 11kV/33kV or 66kV feeders depending on their energy requirements. With increasing industrialization coupled with the government initiative to achieve vision 2030 which has electricity as one of its key enablers for development, KPLC has seen a tremendous growth of its customer base from about 2.4 million in 2014 to 7.2 million customers by June 2019 (KPLC, 2020).

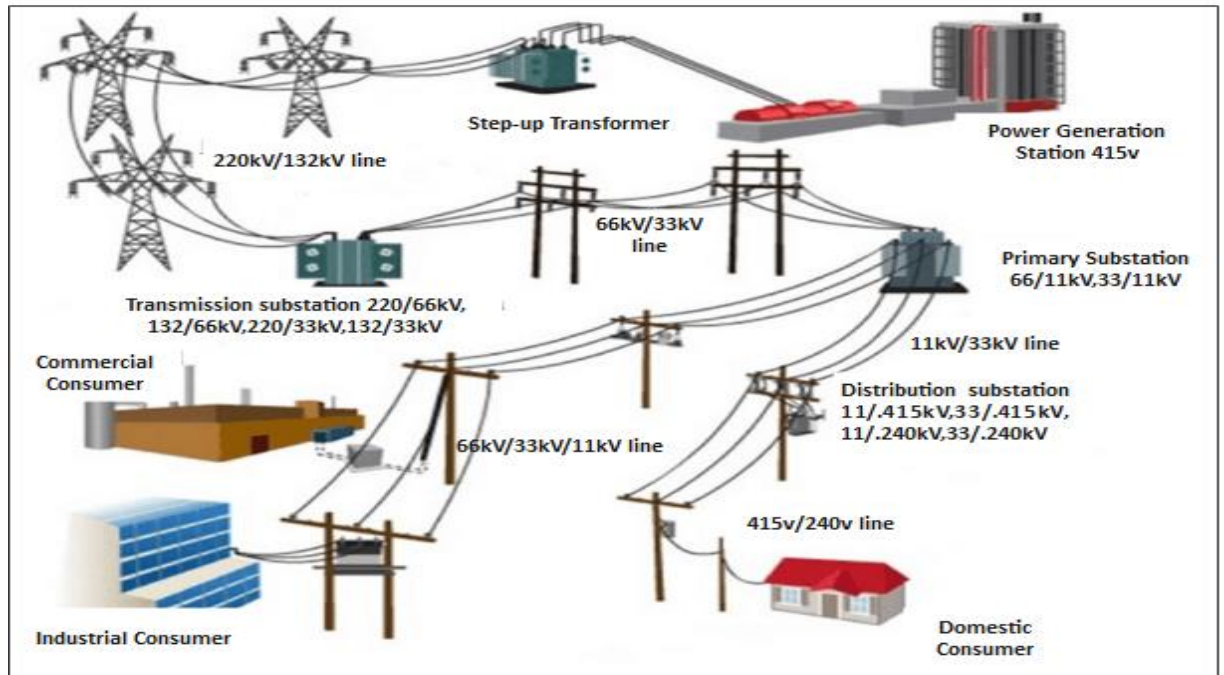


Figure 2.2: Typical Transmission & Distribution network hierarchy in KPLC (Adapted from Hussain *et al*, 2016)

REREC has been one of the contributors for this growth in the electricity customer base. As at 2015, REREC had helped move rural electrification from 4% to 32% of rural households, largely through its efforts to connect 60,000 public hospitals, primary and secondary schools around the country and all household consumers within 600 meters of those facilities (Power Africa, 2016). This growth has been witnessed both in rural and urban set-ups and has seen the company extend its grid network by hundreds of kilometres.

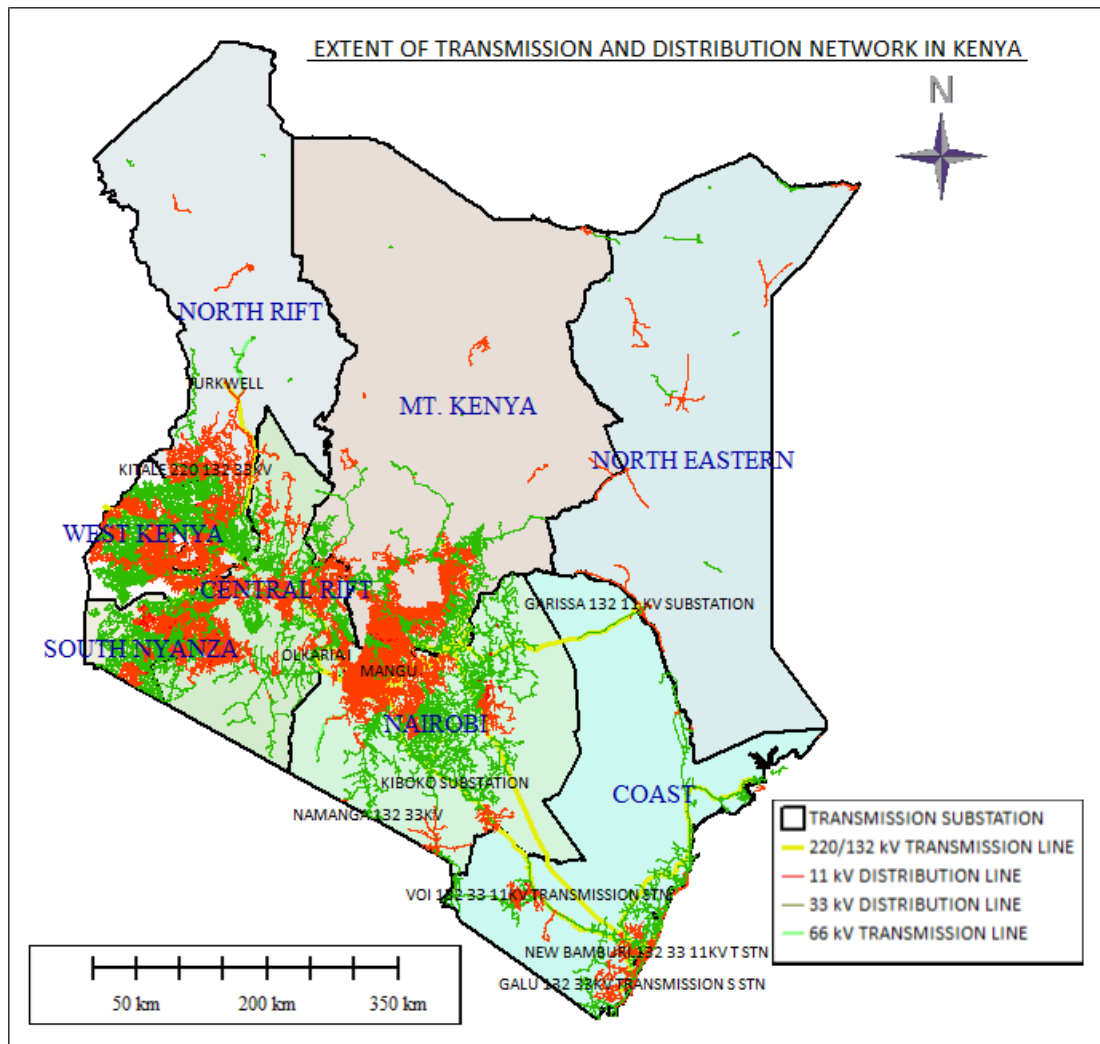
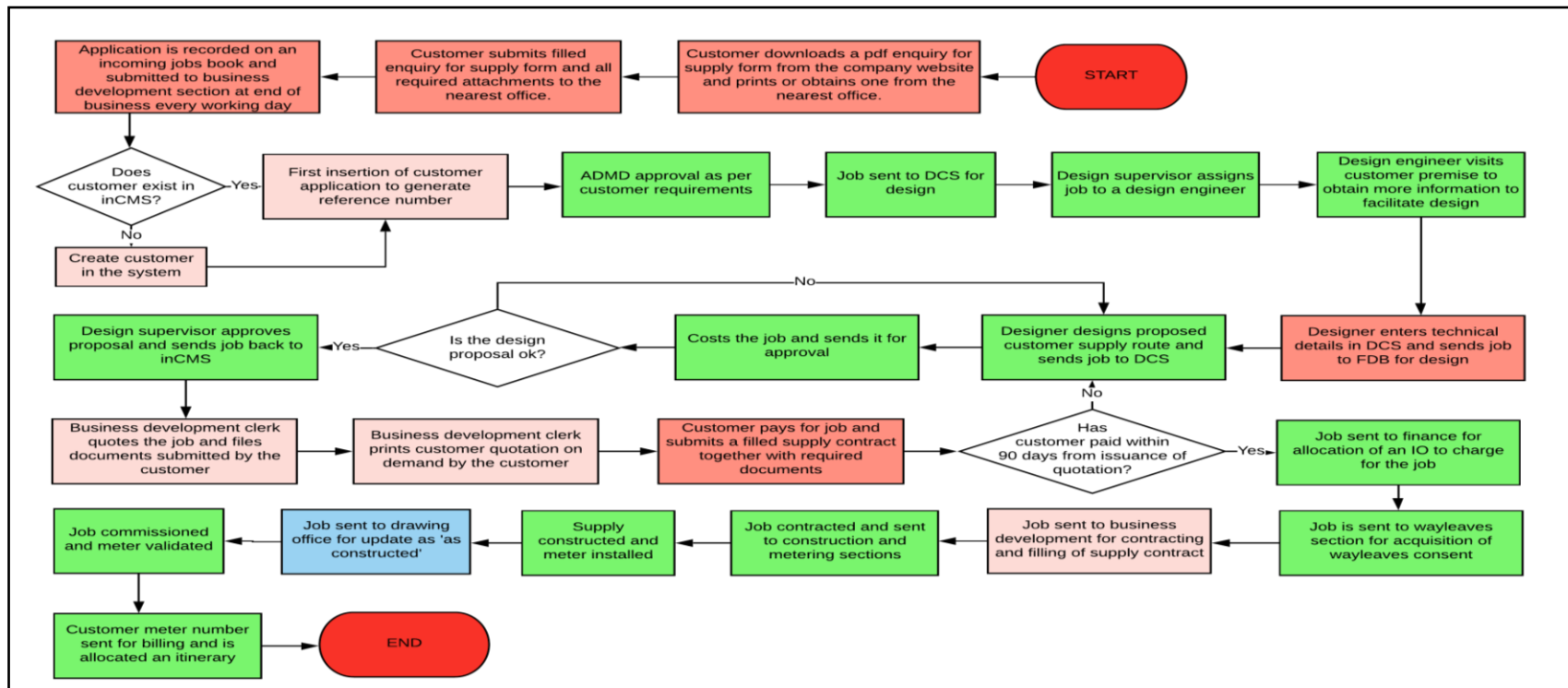


Figure 2.3: Extent of electricity distribution and transmission network in Kenya. (Adapted from the Facilities database (FDB) system at KPLC as at Jan, 2020)

2.4.2 New customer connection business structure at KPLC

Design & Construction (D&C) is one of the core departments at KPLC which is tasked with the receipt of new customer applications, the design of a suitable route for supplying the customer and actual construction of the supply as per the proposed design. The department is composed of five sections namely; business development, design, wayleaves, construction and FDB/GIS section, which are expected to work seamlessly to ensure that the customer has been connected with power supply within a period of 21 days. Figure 2.4 shows a step-by-step work-flow in the new connection business process.



**** KEY**

inCMS-Integrated customer information system ADMD-After Diversity Maximum Demand DCS-Design and Construction System

FDB-Facilities Database (a GIS system for KPLC) IO-Internal Order

Manual process

Semi-manual process

Digital subject to upgrade

Automated process

Figure 2.4: New customer connection work-flow diagram (adapted from Mage, personal communication 2020, February 18)

i. Business development section

This section is responsible for the receipt of customer application documents, creation of customer job in the inCMS system, job progress to the design section, generation of customer quotation, job progress to finance for IO allocation, job progress to wayleaves to obtain wayleaves consent, job contracting and progress to the construction team. Most of its functions are carried out manually or semi-manually.

ii. Design section

The designer's role is to visit customer site to collect all the relevant information necessary for proposing a supply route to the customer to link them to the grid, proposal of a suitable route for connecting the customer supply and costing of all materials and tools required for the connection.

iii. FDB/GIS section

The FDB/GIS section comprises of the drawing office team, survey team and the GIS team. It is tasked with preparation and printing of design proposal on demand by the construction engineer or any other stakeholder, provision of survey and GIS services to the design and construction teams and update of changes made to the design proposal during construction of the customer supply.

iv. Wayleaves section

This section is responsible for obtaining wayleaves consent to pave way for the construction of the supply line to the customer premise.

v. Construction section

The role of the construction engineer is to book all the required materials and tools from the store, construct supply line to the customer premise, advise the FDB team on changes made on the proposed supply route and commissioning of the customer supply.

2.5 The Study Area

Mombasa County is located along the coastal region of Kenya. It covers a land area of 229.86Km² and a water mass of 65Km². The county is divided into six constituencies namely Changanwe, Jomvu, Kisauni, Nyali, Likoni and Mvita. The county borders Kilifi County to the North, the Indian Ocean to the East, Kwale County to the South and Kilifi and Kwale Counties to the West. The 2019 census estimated Mombasa population to be at 1,208,303 persons (Kenya National Bureau of Statistics [KNBS],2019). The County lies between latitudes 3° 56' and 4° 10' South of the Equator and between longitudes 39° 34' and 39° 46' East of Greenwich Meridian.

Mombasa County hosts quite a number of industries spread across all sectors of the economy, which have provided employment opportunities and enhanced the spread of infrastructural connectivity within the county. However, some parts of the county have been facing short supply of water, electricity and sanitation due to poor planning brought about by poor land administrative laws in operation. With devolution, this trend has slowly started to fade as the county is now experiencing a major increase in the number of modern structures being constructed (Murathe, 2018). This change has been brought about by the new land policy passed by the county assembly in 2017, that attempted to solve land ownership issues that hindered proper infrastructural development. It being an important tourist and port city in East Africa, Mombasa has attracted a lot of migrant workers from different parts of Kenya and other countries.

Majority of its population have access to internet enabled smart mobile phones and are literate hence will easily understand how to navigate on the web application. The area is currently experiencing a major growth in formal housing, with majority of the old Swahili houses being replaced with modern structures that require electricity connection. The existing electricity network infrastructure is well mapped and is up-to-date in the company's GIS system. This is an added advantage to the study in that it would not be necessary to map and include it in the geodatabase. The friendliness of its inhabitants coupled with the confidence of previously having given a good feedback to KPLC on services offered to them gives hope of good uptake of VGI.

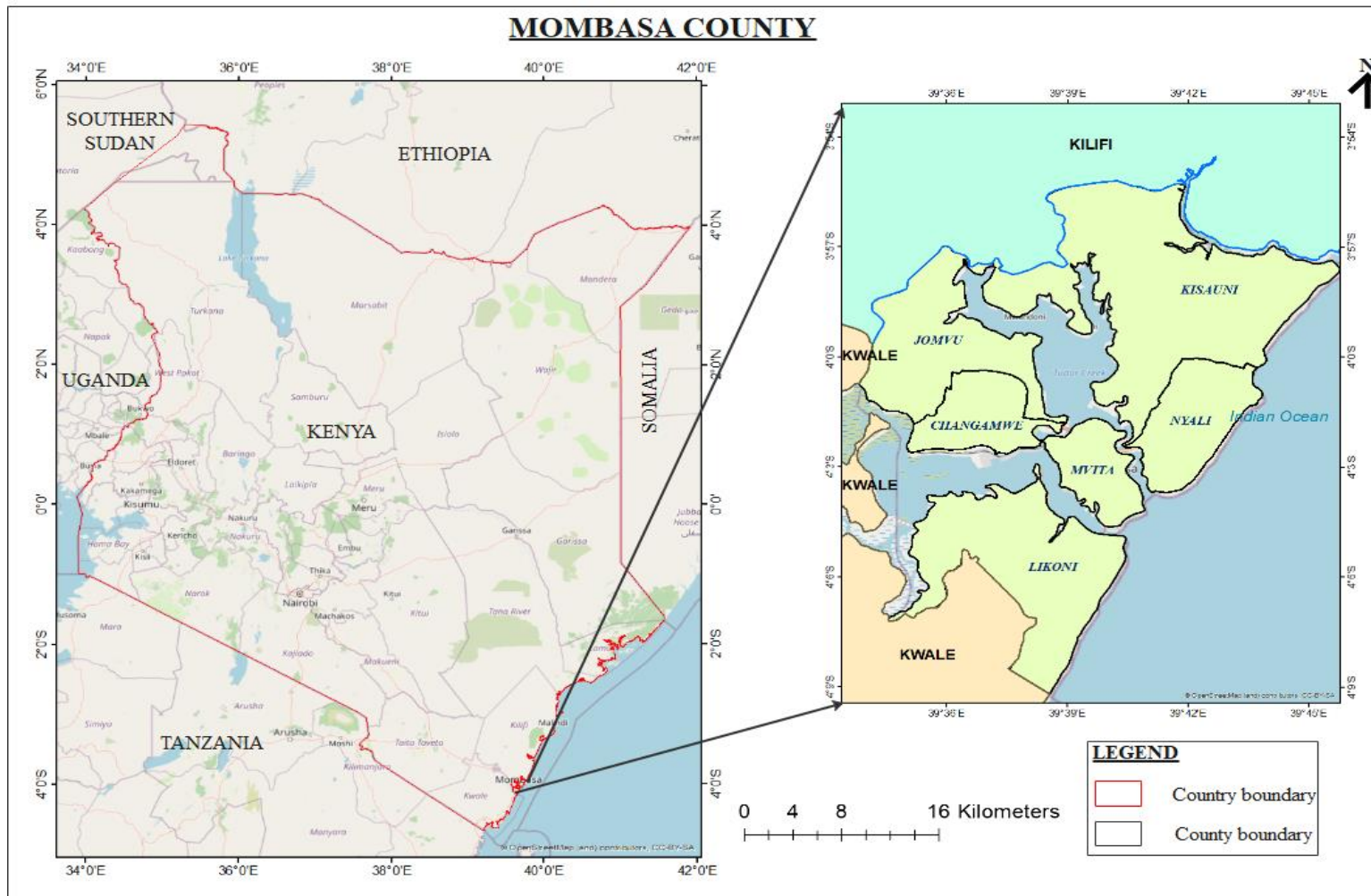


Figure 2.5: Mombasa County

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

This chapter seeks to discuss the strides made in the use of GIS and web-based GIS technology in the utilities and is organized into four sections. The first section is the introduction to the chapter section. The second section provides an in-depth discussion of what GIS and web-based GIS are, and the new emerging trend in GIS where the public is actively involved in data acquisition for the GIS. The third section discusses the major strides made in the use of GIS by utilities and the major research gaps arising from its utilization. Finally, the fourth section provides a summary of the literature review.

3.2 Geographic Information System (GIS) and Web-based GIS

GIS refers to a system of hardware, software and procedures that capture, store, edit, manipulate, manage, analyze, share and visualize georeferenced data (Fu & Sun, 2011). GIS technology integrates common database operations such as query and statistical analysis, with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems making it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies (UEAG, 2012).

Web-based GIS on the other hand, “is any GIS that uses web technology to communicate between components” (Fu and Sun, 2011:13). It is any GIS system that enables clients to retrieve information from a GIS server over the web by use of the internet. To date web-based GIS is widely being used to solve day to day challenges such as finding a place near you (e.g., hotels, ATM’s, schools, recreational parks etc.), getting locations, creating navigation paths to places; mapping of transmission of infectious diseases, real time earthquakes and wildfire disasters online to keep members of the public healthy and safe among others.

3.2.1 History of GIS

In 1960, Dr Roger Tomlinson developed the first ever GIS system. Its first iteration was designed to store, collate and analyse data on land usage in Canada (Tate, 2018). Later in the late 1960’s, the internet was developed and this allowed sharing of information from one computer (server) to another with ease. Early 1990’s saw the development of the World Wide Web (www) which led to the development of the

first mapping web page in 1993. With the advent of the web, the GIS potential was greatly unlocked and the horizon of its applications broadened tremendously (Fu and Sun, 2011).

Traditionally the collection, collation, manipulation and sharing of Geographic Information (GI) in institutions was solely in the domain of experts trained to carry out the tasks. These were cartographers, surveyors, photogrammetrists and GIS experts. However, with time GI needs expanded together with constrained financial support making it impossible for institutions to keep up the pace of data acquisition. This necessitated these institutions to come up with other ways of information gathering that were more time and revenue efficient. A new trend in the GIS world where the general public is voluntarily involved in data acquisition was born. This trend is known as VGI.

Goodchild (2007b) terms VGI as information collected by many volunteer participants that is collated in a central database, and distributed in multiple digital formats through the internet. VGI platforms provide a general base map information and allow users to create their own content by marking locations where various events occurred or certain features exist but are not already shown on the base map. It provides a platform for both experts and non-professionals to create and share location-based information related to a particular subject.

“With the increase in the adoption of mobile phones for communication and micro computing, the ease of positioning features through mobile phones and the ability to create and share online maps and georeferenced photographs, there has been increased VGI” (Goodchild, 2007a:215). Examples of VGI are: OpenStreetMap (OSM), Tracks4Africa, The Southern African Bird Atlas, Wikimapia, Flickr, Ushahidi and Google Map.

3.2.2 Benefits of a web-based GIS over traditional desktop GIS

Over the years, both government and privately owned institutions have been shifting focus from the use of traditional desktop GIS towards web-based GIS. This move has greatly been fueled by the steady growth in internet speeds and its availability as well as the availability of the web. Sharing of data and information between individuals and institutions has been made very easy, irrespective of the physical distance

between them. Listed below are some of the benefits reaped from the use of web-based GIS.

i. The easy-to-use nature of a Web-based GIS

Desktop GIS are normally sophisticated kind of applications that require users to acquire some training in order to interact and manipulate data. With web-based GIS, it is not required that a user be a GIS expert in order to benefit from web mapping services, as they can access the mapping functionalities via a regular web browser and an integrated Viewer with a simple, user-friendly interface (Fu & Sun, 2011).

ii. Low installation and running cost

Most desktop GIS software are proprietary in nature and requires organizations/institutions to pay an initial purchase price with subsequent payment of annual licence fees to remain operational. This fee is dependent on the number of licences obtained and tends to go higher with every additional user. With web-based GIS the cost of development and maintenance in relation to the number of users translates to very minimal fees that are affordable to the organisation (Hyndman, 2016).

iii. Cross-platform collaboration

Users of desktop GIS can only view, edit, analyze and manipulate data that's available on their machine as the software is hosted locally. This hinders real-time data sharing between different users. With web-based GIS there is ease of data sharing across platforms which make it possible for users to share ideas, produce shared maps and present results in different formats to different stakeholders with ease (Fu & Sun, 2011).

iv. Supports multiple users at a time

Desktop GIS is available for use by one user or a limited number of users depending on the number of licenses acquired. With web-based GIS, multiples users on different geographical locations are able to access and manipulate data on the system concurrently without affecting the software' performance (Fu & Sun, 2011).

3.2.3 Components of a Web-based GIS

A Web-based GIS comprises of the following key components which are essential to its proper operation.

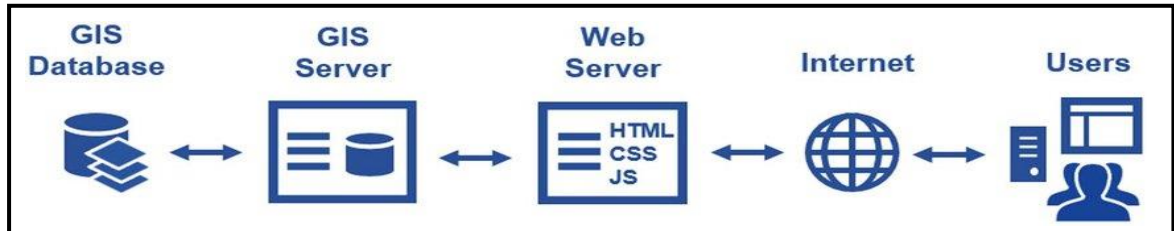


Figure 3.1: Components of a Web-based GIS (Adapted from Javadnejad et.al. ,2017)

User/client

A user (client) is any internet browser such as Microsoft edge, google chrome, Mozilla Firefox etc., a desktop application or a mobile application. The client uses the internet connection to connect to the web server (Chathura, 2013).

Internet connection

An internet connection connects the client to the web server. It handles requests from users and returns a web page. Internet bandwidth determines its speed thus the higher the bandwidth the better the performance and vice versa (Chathura, 2013).

Web server

A web server is a computer program that manages access to centralized resources/service via the web. It handles requests from the user using HyperText Transfer Protocol (HTTP) and returns results on a web page. Its primary function is to store, process and deliver web pages to clients. Examples of web servers include Apache, Microsoft's Internet Information Server (IIS), google Web Server (GWS), Nginx among others (Dizaji & Celik, 2015).

GIS server/map server

A GIS server (map server) is the engine behind the map displayed on a web page. It is usually configured in such a way as to communicate between a web server and a GIS database and assembles data layers from the database into appropriate image. Results are then displayed on a web page in many formats depending on the client's specifications such as HTML (HyperText Mark-up Language), XML (Extensible

Mark-up Language), binary image or JSON (JavaScript Object Notation). Examples include Google maps, Yahoo! Maps, Geoserver etc (Dizaji & Celik, 2015).

GIS Database

A GIS database also known as a geodatabase, is a collection of structured and related data/information containing location that is stored electronically in a computer system. Database Management System (DBMS) is a software that serve as an interface between users and their databases. It allows users to Create, Retrieve, Update and Delete (CRUD) information in a database (Dane, 2018). They ease the management of information by providing for backups, supports concurrency, handles security, supports importation and exportation of data and interacts with software applications. Relational Database Management System (RDBMS) organizes data into tables, while non-RDBMS organizes data into other formats other than tables e.g., key/value pairs, JSON documents etc. depending on the specific requirements (Dane, 2018).

A RDBMS has data organised in one or many tables. Each table is made up of one or more data entries, with each entry comprising of one or more attributes. Attributes are stored in the columns, while the rows store individual data entries. A primary key is used to uniquely define an entry in a table and is made up of one or two attributes. Objects with similar kind of traits/characteristics are stored in one table (Dane, M. 2018). Tables in a database are linked to each other by use of special keys called the foreign keys. Foreign keys allow one to define relationships between tables. A relationship is a representation of the association that entries/objects have with each other in the real world (Dane, 2018).

RDBMS' use Standard Query Language (SQL) as the main language for performing CRUD operation as well as other administrative tasks such as user management, security and back-up. Examples of DBMS' are Oracle, MySQL, IBM DB2, MS SQL Server, MS Access, PostgreSQL, Mongo DB, CouchDB, HBase among others (Dane, 2018).

3.2.4 Developing an efficient web-based GIS system

Web-based GIS applications often range from simply presenting a simple world map, to complex visual analysis of spatial distributions and processes. Just like any system, the development of a web-based GIS system follows a systematic process

with a set of steps and phases regardless of the system development methodology applied. Any system developed is geared towards solving a particular problem, hence the steps followed normally lean towards problem resolution. There are six distinct phases in any system development which are either carried out independently or in combination with each other depending on the methodology adopted. These are: -

i. Planning

This is the most critical part of any system development, as it directly impacts how the system is going to be developed. It involves an in-depth evaluation of the project scope, participants, resources and the approach to be followed (Medeiros, 2009).

ii. Analysis

It is at this stage that the management gets to evaluate the existing system/processes, identification of its shortcomings and how to overcome them. A feasibility study to come up with the most viable solutions to the outlined problems is carried out (Medeiros, 2009). A system requirements document is then drawn, and the project requirements are then sub-divided into functional modules. Each module contains functionalities that are unique to a particular set of users and represents their external view of the system. These modules form what is known as the external model.

iii. Design

At this stage the system developers come up with a concrete solution to the system requirements defined earlier. An elaborate plan of execution is then formulated without considering the hardware and software to be used. The main major segments for a web-based GIS system are the geodatabase development and the application development.

For the geodatabase, its development comprises of a conceptual model and a logical model. Conceptual model involves the design of an Entity Relationship Diagram (ERD) which defines the entities to be stored in the database and the relationship between each other (Medeiros,2009:23). This model is independent of the DBMS or hardware to be used in the project. Once a conceptual model has been put in place, the developers go ahead to design a logical model. A logical model defines how the system should be implemented regardless of the DBMS but considers the structure of the kind of DBMS to be used e.g., Relational, network oriented, hierarchical etc. It is the lower level of a conceptual model. It involves making decision on the data type

and size to be used to store each entity, as well as defining the rules and constraints between entities (Gupta, 2012).

A web application design is concerned with the web application pre-development structure. Web-wireframing provides a visual guide to the website and demonstrates a link between different pages in the website (Adnan *et al*, 2010). It helps in the creation of the final design of the website before actual development, thus saving on time. Design patterns on the other hand, provides a general solution to commonly recurring problems by using a template to clarify the relationship between entities of a web application. They are used to standardize applications according to the problem domain hence tuning the application to work better e.g., Abstract factory, Factory method, Builder, lazy initialization and prototype (Adnan *et al*, 2010).

iv. Development and implementation

This refers to the phase in which the actual system construction takes place. The DBMS is decided on and all the programming languages and software chosen. A physical model of the geodatabase, which describes how the system will be implemented using the specific DBMS system is developed and implemented. All the datasets to be stored on the geodatabase are then prepared and loaded. The application is then developed with reference to the entities described on the wireframe. These two then undergo individual tests for functionality after which they are integrated to form one complete unit. User training is also carried out during this phase. The choice of technology and database platforms influences the performance of a web application (Airbrake, 2015).

v. System testing

At this phase the application is published and is made available to the target environment. It is then tested for functionality and a comparison made against the set system requirements. These tests involve the collection and upload of sample data which is then processed within the various stages to make sure that all components are functioning properly (Airbrake, 2015).

vi. Deployment and maintenance

This is the last step in system development and involves releasing the application to the users. An elaborate plan for maintenance is also put in place at this stage (Airbrake, 2015).

3.2.5 Web-based GIS development methodologies

“Several software development models and methodologies exist for the development of web-based GIS applications. Models and methodologies describe the whole cycle of development stages including achievement of functionality, release and maintenance” (Kuria *et al*, 2019). Table 3.1 describes some of the conventional System Development Methodologies (SDM) in existence.

Table 3.1: Web-based GIS development methodologies (adapted from Tavtasoftware, 2015)

NO.	Methodology name	description	Advantages	disadvantages
1.	Waterfall model	It is one of the most commonly used models. It aligns the software development process in a linear sequence where one phase only begins when the previous one has been completed.	<ul style="list-style-type: none"> • It is easy to understand and use. • It easy to manage since each phase has specific deliverables. • It is time saving since phases are processed and completed one at a time. • Works more effectively in smaller projects where requirements are very well understood. • Testing is easier as it can be done by reference to the scenarios defined in the earlier functional specifications. 	<ul style="list-style-type: none"> • Can only be used where very precise up-front requirements are available. • It is impossible to go back and edit something once the application is in the testing stage. • It is not suitable for long and ongoing projects. • The method is not ideal for projects with moderate requirements and great scope for modification.
2.	Prototype model	It is a software model that allows developers to create only the prototype of the solution to demonstrate to the client for modifications before developing the	<ul style="list-style-type: none"> • It gives the client a clear understanding of the complete functionality of the application. • It reduces the risk of failure since potential risks can be identified in 	<ul style="list-style-type: none"> • Prototyping is done at the developers cost hence requires use of minimal resources so as to contain the project budget. • Too much client involvement doesn't always favor the

		actual application.	<p>the early stages and rectified.</p> <ul style="list-style-type: none"> • Communication between the client and software developers create a very conducive environment during the project. • It helps in requirements gathering and analysis when there is lack of requirements document. 	<p>developer.</p> <ul style="list-style-type: none"> • Too many modifications may not be good for the project as it easily disturbs the workflow of the entire software development team.
3.	Agile software development methodology	This model is used for designing disciplined software management process that allows some frequent alterations in the development project.	<ul style="list-style-type: none"> • It has an adaptive approach that is able to respond to changing requirements of the client. • Direct communication and constant feedback from customer representatives leave no space for any guesswork in the system. 	<ul style="list-style-type: none"> • The methodology focuses on the working software rather than documentation hence may result to lack of documentation. • The software development project often gets off track if the customer is not very clear about the final outcome of his project.
4.	Rapid Application Development (RAD)	This model is designed to provide much quicker and high-quality results. It is designed to take maximum advantage of software	<ul style="list-style-type: none"> • It helps to reduce the risks and required efforts on the part of the software developer. • It helps clients to take a quick review 	<ul style="list-style-type: none"> • It depends on strong team and individual performance for clearly identifying the exact requirements for the business. • It demands for high skilled

		development. The goal is achieved by allowing active user participation in the development process.	<p>of the project.</p> <ul style="list-style-type: none"> • It encourages customer feedback which always provides improvement scope for any software development project. 	<p>developers and design team.</p> <ul style="list-style-type: none"> • This method is not applicable for use in small projects as its cost is very high.
5.	Dynamic system development model methodology	<p>This in an iterative and incremental approach that emphasizes on continuous user involvement. Its aim is delivery of the software on time and budget.</p> <p>It is based on the philosophy that nothing is developed perfectly in the first attempt and considers an ever-changing process.</p>	<ul style="list-style-type: none"> • Users are highly involved in the development of the system so they are likely to get a grip of the software development project. • Basic functionality is delivered quickly with more functionalities being delivered at frequent intervals. • It provides an easy access by developers to end users. • Projects are delivered on time and on a budget. 	<ul style="list-style-type: none"> • The system is costly to implement as it requires both users and developers to be trained to employ it effectively. • It may not suitable for small organizations.

6.	Joint application development methodology	It is a requirement-definition and user-interface development methodology in which all stake-holders attend intense off-site meetings to work out and finalize software system.	<ul style="list-style-type: none"> • It allows for simultaneous gathering and consolidating large amounts of information. • Software development mode effectively produces large amounts of high-quality information in a short period of time. • Differences are resolved immediately. • It provides a forum to explore multiple points of view regarding a topic. 	<ul style="list-style-type: none"> • It takes a lot as it requires planning and scheduling efforts on the on the part of the development team. • It requires a significant investors commitment in terms of time and effort. • It requires trained and experienced personnel for effective implementation.
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3.3 GIS and Web-GIS for utility companies

Utilities range from small private localized companies to large state-owned companies whose ownership, size and commercial set up vary from nation to nation. The primary goal of any utility is the delivery of commodities be it water, natural gas or electricity to its customers in the most resource efficient way (Meyers, 1999). In order to achieve this goal, utilities have been embracing various technologies with the aim of cutting down operational costs while offering excellent services to its customers. GIS is one such technology that has seen a major adoption at the utilities.

3.3.1 History of GIS and web-based GIS at the utilities

In the early 1970s when GIS software was not popular and acquiring it required huge capital investment, many utility companies in the world relied on hardcopy maps to manage facilities. Towards the end of 1970's and early into 1980's, automation at the utilities mainly focused on the production of digital maps which was largely a graphics driven task (Meyers, 1999). Most utilities at that time invested on Computer Aided Design/Drafting (CAD) software as a means for map reproduction. This software formed a basis for systems that came to be called Automated Mapping/Facilities Management (AM/FM) (Meyers, 1999).

Soon, this technology became questionable since managers could not tangibly match the value of investment on data acquisition with the benefits utilities reaped from it (Smith, 2005). This was due to the fact that the data acquired could not on its own be used to carry out any meaningful analysis. In a utility company where operations are not static there was need for development of a robust system that was not only able to cater for the day's needs, but could be modelled to solve future problems efficiently. The selected technology needed to have the ability to cater for future demand scenarios and to provide optimal solutions and not simply confined to analyzing the present needs and GIS provided just that (Nawaz-ul-Huda *et al*, 2012).

Today a typical AM/FM/GIS system sits on a client/server architecture where both geographical and attribute data is stored on a central server accessible to users in different environments (Gittings *et al*, 1994 as cited by Meyers, 1999). This data supports a wide range of non-GIS applications and serves from one or two to hundreds of users. The following section illustrates the resultant benefits achieved through the increased uptake and use of GIS in the utilities.

3.3.2 Utilization of GIS and web-based GIS at the utilities and resulting benefits

Utilities are harnessing the power of GIS in their day-to-day operations in order to improve time and resource efficiency as well as increase productivity. GIS has broadly been incorporated by utilities in their major functions such as engineering and construction, operations and maintenance as well as in customer service. Below is an illustration of some of the instances where utilities have stood to benefit from utilization of GIS and web-based GIS services.

a) Improved company operations and maintenance

Utilities are constantly grappling with striking a balance between the cost of maintenance and replacement of its equipment against the revenue generated from the use of these equipment. Field assets form the bulk of investment for utilities and an accurate inventory of these assets guarantees their protection and improves operation efficiency (Sultan & Hilton, 2019). For developing countries technical and commercial losses have been the main cause of revenue losses. Technical losses are attributed to faulty equipment, overload of equipment, physical damage of equipment etc. while commercial losses occur due factors such as theft, customer under-billing, under-cutting by utility personnel among others. GIS supports versioning which entails changing features from their original state to a past or future projection and carrying out analysis to define trends that assist in minimising occurrence of losses (Meehan, 2007).

In their studies (Brussels & Ali,2005; Totimeh, 2016 and udo *et al*, 2017) demonstrated the role of GIS and web-GIS in improving operations and maintenance for utilities. They argued that since most of the processes for utilities are location-based GIS would be a great tool for visualization. These utilities were now able to analyse their equipment and come up with a maintenance schedule, locate the location of all customer meters for billing purposes, evaluate areas requiring system reinforcement to enhance supply among others.

Damanhur city in Egypt was struggling with a number of important aspects in operations and maintenance of its water distribution network (Brussels & Ali,2005). Over the years, the city had witnessed growth in demand for supply of water yet the replacement of old and narrow pipes was slow. Brussels and Ali collected all the

spatial and attribute data available at the utility company to develop a geodatabase. This geodatabase was used to carry out an analysis of the distribution network to come up with a maintenance and replacement schedule of its water pipes. This was done by considering the age of the water pipes as a factor of length and type of material used against the revenue generated from the water supply. This cost benefit analysis enabled the utility to balance between maintaining and replacing old pipes.

Ghana did not have an operational GIS system and was struggling with system and technical losses. In his study, Totimeh (2016) developed a web-based GIS that would be used for asset and customer tracking to reduce system losses. The resultant web-based customer information system provided a platform for proper revenue mobilization through billing since all meter positions were accurately mapped. It also reduced system losses through timely maintenance and replacement of faulty equipment.

In Nigeria, Udo *et al* (2017) installed theft detectors with customer details including their location onto prepaid meters. The detector would send a (Short Message Service) SMS message to the utility company whenever there was a mismatch between the input and output voltages symbolizing a meter by-pass. This helped to locate and curb the problem of electricity theft in Nigeria.

b) Proper resource allocation

Every organisation strives to optimally employ its limited resources to achieve maximum returns. The major task for utilities is to plan for supply to customers in the most optimal and resource efficient way. To cut down capital costs and increase reliability, engineers at the utilities leverage on the analytical tools of GIS to automate many of their functions (Meehan, 2007). This is achieved through modelling and visualization of various scenarios before settling on the most cost-effective option. Through monitoring of demand for certain materials within a given locality on a GIS system, one is able to monitor inventory turn-over and plan for proper stocking and distribution of materials between warehouses (Meehan, 2007). Enterprise GIS provides an integrated system where every stakeholder in the utility company is able to monitor what others are doing and are thus able to make informed decisions.

In order to provide a solution to electricity theft and mal-distribution in Karachi, Pakistan, a GIS model for its distribution network was developed (Nawaz-ul-Huda *et al*, 2012). The study linked patterns of distribution, demand, consumption and losses to identify priority areas for investment. A GIS distribution system was developed based on the concept of an organized electricity management system with provision for publication of monthly electricity consumption. A spatial assessment of levels of energy requirements and socio-economic development were analyzed to come up with optimised supply of electricity framework to target areas. The selection of appropriate and cost-effective technology was identified as a key to improving the distribution systems with their extensive conductors and installations.

c) Better decision-making

GIS is a powerful tool for decision-making in a distribution network since it supports processing of large amounts of data and allows for interpolation of decision problems in a geographical dimension for model synthesis (Gemelli, 2013). An enterprise GIS provides an integrated and interoperable environment in which individual departments/functions of an enterprise create, access, view and analyse data and information relevant to their tasks (Dasgupta, 2010).

In a case study of Khartoum state, Southern Sudan, Adam & Ali (2013) designed a common geodatabase for use by various utilities within the state. They combined feature datasets from the various utilities with a common land base map. Various software' were used to come up with a common multi-user geodatabase that was used to manage the existing utilities network as well as plan for future expansions of the network. The study demonstrated how GIS offered a solution to a commonly recurring problem of network damage by a utility company working on an area due to lack of information on the location of other utilities equipment.

In another study Al-Sakkaf & Al-Ramadan (2013) emphasised on the benefits utilities stand to reap by integrating other systems data with GIS data. They created a GIS database and integrated it with other company information systems. The resultant enterprise GIS system was used to carry out systems audit, load management, network planning and analysis among others. These two studies demonstrate how utilities can leverage the visualization aspect of GIS to enhance their decision making.

d) Improved customer service

Every utility distribution network terminates at the customer premise which forms the revenue stream for the utility and their satisfaction determines the sustenance of such utility in the market. Over the years, customer demand for these services has grown tremendously, overburdening the utility company resources (Meehan, 2007:76). Frequent system breakdowns with prolonged restoration time has become a major setback for most utilities. Billing and revenue recovery have also become challenging as the customer geographical spread continues to widen (Sowmya & Jitendra, 2016). By having a GIS system that is up-to-date, utilities can identify transformers nearing their limit; identify zones requiring additional personnel for billing and revenue collection; locate faults and dispatch emergency teams on time; inform affected customers of faults or planned outages on time to prevent damage to their gadgets among others. The use of web-based GIS enables the utility to gain user satisfaction (Fu & Sun, 2011).

In a case study of India's electricity distribution network, Manju (2009) noted that most of its distribution losses occurred on both sides of the meter. This was as a result of an increase in power generation output while the distribution network remained the same. To curb this problem, Manju acquired data from the utility company containing the number of consumers and connected load, demand data and network data. This data was fed into a GIS system and was used in the real-time monitoring of the distribution network providing for timely fault location and resolution.

In another study in Kenya, Silali (2018) developed a web and mobile GIS application for use by customers to record and upload meter readings and electricity incidences. In his study, Silali noted that the electricity company in Kenya relied on physical visit to customer premises for meter readings and customer verbal or written description of an incidence and its location. This often resulted to some meters not being read with customers getting estimated bills and delayed incidence resolution. The web and mobile applications developed enabled customers to record and upload the meter readings and digitally log incidences location and upload a photo by use of the device's GPS and camera capabilities. This would reduce the time taken by the emergency team to locate the incidence location as well as enhance their preparedness in terms of tools required for repairs. The application would also

improve customer confidence in the billing process thus enhancing their satisfaction. These two studies illustrate how utilities can harness the power of GIS and web-based GIS to improve on productivity and enhance resource and time efficiency.

3.3.3 Research context for Kenya and KPLC

The studies discussed above (Brussels and Ali, 2002; Manju, 2009; Nawazul-ul-Huda *et al*, 2012; Al-Sakkaf & Al-Ramadan, 2013; Adam & Ali, 2013; Totimeh, 2016; Udo *et al*, 2017 and Silali, 2018), illustrates the widespread use of GIS by utilities to improve efficiency for better services delivery to their existing customers. However, there is dearth of documented research and real-world applications on the use of GIS in securing new customers for utilities especially in developing nations and specifically in Africa. Given that 600 million people in Africa still lack access to electricity (International Renewable Energy Agency [IRENA], 2015) and another 44% of homes in sub-Saharan Africa lack access to piped water (Rolfe, 2019), it is important to investigate how GIS can be used for the millions of potential customers across the continent who still lack access to electricity and water. This research attempts to address this gap by developing a web-GIS application to improve efficiency in the new customer connection process.

From figure 2.3 showing the extent of spread of the distribution network, it is evident that in Kenya we still have a substantial number of households lacking access to electricity. According to a recent research done by the World bank (2018) only 75% of Kenyan households had access to electricity. There has been increased growth in the number of new enquiries for electricity supply in the recent past, due to government initiatives such as the last mile project that aims at maximizing customer connections within a radius of 600 radial meters from a distribution transformer. The electricity company initiatives such as provision of financing opportunities e.g., stima loans has also contributed to this upsurge. This has resulted to a strain to the existing framework for new connection that has seen customers go for months or even years without being connected to the grid. This translates to billions of revenue loss by the utility company ranging from customers seeking alternative sources of power to others going for short-cuts and getting connected to the grid illegally.

In Kenya, the revised energy act 2019 has brought about a shake-up in the Energy industry and particularly for KPLC. The revised act has stripped off the company the

monopoly it has been enjoying as the sole electricity distributor and retailer throughout the country. It has also empowered customers with knowledge on their rights and privileges. This has challenged the company to look into its business strategies in order to remain competitive. One of the major loop-holes is in its new connection process which is largely manual. From figure 2.4 it is evident that most of the processes are either manual or semi-manual. This has presented many challenges in the past; such as the designers taking too long to locate the customer premise in order to collect information required for design, customers having to visit the office severally before they get connected, and resource wastage while printing forms and quotations. These challenges have always made the 21 days' connection deadline unattainable.

There is need for use of Web-based GIS to aid the new customer connection process by enabling applicants to upload coordinates of their supply location onto the system. This is particularly important in Kenya just as with other sub-Saharan countries, where the cadastral systems still suffer from lack of computerization and decentralized administrative systems (Wayumba, 2013). Cadastres are still manual and outdated with no single approach followed when giving labels to plots making the use of route sketch maps a misleading and cumbersome approach. This will ensure that minimal time is taken in getting the new customers onto the grid, as well as reduced time wastage as a resource in trying to figure out customer's premise. The study by Silali (2018) has demonstrated the willingness and positive embrace by the general public to participate in VGI to avail information to KPLC.

The study will develop a web-GIS application that will augment and integrate all the manual and semi-manual processes (see figure 2.4) into streamlined digitally automated business focused processes. The table below illustrates how this new web application will fit into the existing company processes.

Table 3.2: Processes that will be improved by the new web-based GIS application.

PROCESS	FUNCTION ON THE APP
Download, filling and submission of application form.	A digital form will be available on the application where the customer will input the enquiry for supply specifications and upload required documents.
Submission of a route sketch map	The application will be capable of accessing the user's device

to show customer supply location.	location service to capture the supply location coordinates.
Recording of new applications received on a black book.	The application will be capable of querying its database to check if the customer exists and if not automatically trigger his/her creation.
Creation of new customer into the system.	Customer enquiries will then be logged sequentially on an electronic book and a reference number generated for each enquiry.
Creation of a new job.	Business development clerks will then be able to download customer details from the application to facilitate verification before progressing each job into the inCMS system for ADMD approval.
Taking of technical details while on site.	The designer will be able to make site notes for a job on the application to be used in the design process. These notes will be available for use by any designer in the office immediately the field designer uploads them.
Filling of supply contract form.	A digital supply contract form will be accessible on the application.
Printing of customer quotation.	The business development clerk will be able to upload the quotation on the customer profile and send an email/short message alert to the customer.
Job contracting.	The business development clerk will be able to download necessary document from the web application for contracting and filing purposes.
Accessing design proposal.	The construction engineer will be able to view the design proposal on the application for use during construction.
Recording of changes made during construction of the supply to the customer.	The construction engineer will be able to record all changes made on the application and send a notification to the FDB section for GPS survey.
New process.	Upload of customer meter number, account number and XY coordinates of his meter on the web application accessible via customer profile.
New process.	Customer will be able to modify his contact details on the web application.

This will greatly impact the new customer connection work flow by reducing new connection time and eliminating resource wastage. By so doing KPLC will reap the benefits of web- based GIS as a tool for improved efficiency and as an enabler for better decision-making process (Al-Sakkaf & Al-Ramadan, 2013).

3.4 Conclusion

“The utility industry has realized that GIS is a valuable tool not only for mapping facilities but also improving decision making and better management of infrastructure” (Fischer & Leung, 2001). GIS for the utility industry is not about making maps but empowering utilities to serve their customers in the most cost effective and intelligent way (ESRI, 2019). GIS can effectively manage information on the distribution of a given utility service to customers and information describing the attributes of each customer such as location and utility use.

Electric utilities are realising the benefits of GIS technology in the management of facilities for engineering construction; operations and maintenance; and customer service purposes (Damilola, 2013). “GIS implementation coupled with the integration of other electric-based applications, such as customer information systems, outage detection systems and engineering analysis, has become crucial to the successful operation and growth of any utility” (Rudolph, 2018). It is also evident that utilities are harnessing extended functionality of web-based GIS system and VGI (Silali, 2008) to improve services for their current customers, but there is less usage for unconnected customers. From the research gap discussion, it has been illustrated that there is need for the implementation of the use of GIS functionalities and capabilities to attend to the large number of potential customers in need of utility services.

CHAPTER 4: METHODOLOGY

This chapter is concerned with the Web-GIS application development for KPLC. The main System Development Methodology (SDM) used for the development of this application is the waterfall SDM. A waterfall SDM is a form of SDM that adopts a sequential and systematic flow of processes. In this methodology the next stage of development only commences once the preceding stage has been completed. The results of one stage acts as input for the next stage. This chapter is divided into seven sections with the first section being an overview of the methodology. The second to the sixth section discusses each step in the system development cycle. The seventh section which is the last section of this chapter contains the conclusion segment of the methodology.

4.1 Overview of the Methodology

For this research the waterfall SDM was selected due to the fact that the project requirements had clearly been defined in the objectives of the study. It is also a very simple and straightforward model to follow whereby one only moves to the next stage once all the processes in the preceding stage have been completed and tested. In order to ensure that mistakes from one stage were not transferred onto the next stage, a thorough review and testing of each stage was done for purposes of identifying faults and rectifying them. Its System Development Life Cycle (SDLC) comprised of 5 major stages. These stages are as shown in figure 4.1 with the first stage being the requirements analysis and the last one being the web-based GIS application use and maintenance. The resultant Web-based GIS application would be known as ‘JICONNECT WEB APP’.

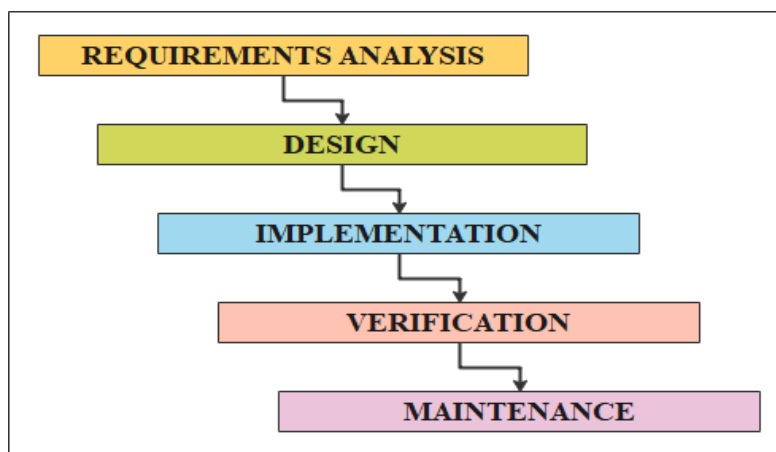


Figure 4.1: Web-based GIS development cycle

4.2 Requirements analysis

This stage involved an in-depth evaluation of the existing new connections business process and the major shortcoming experienced while using it. Its aim was to understand the problem at hand and come up with recommendations on the possible solutions. This process served as the basis for all the software development processes that would be carried out in the future. Its various steps are outlined on figure 4.2.

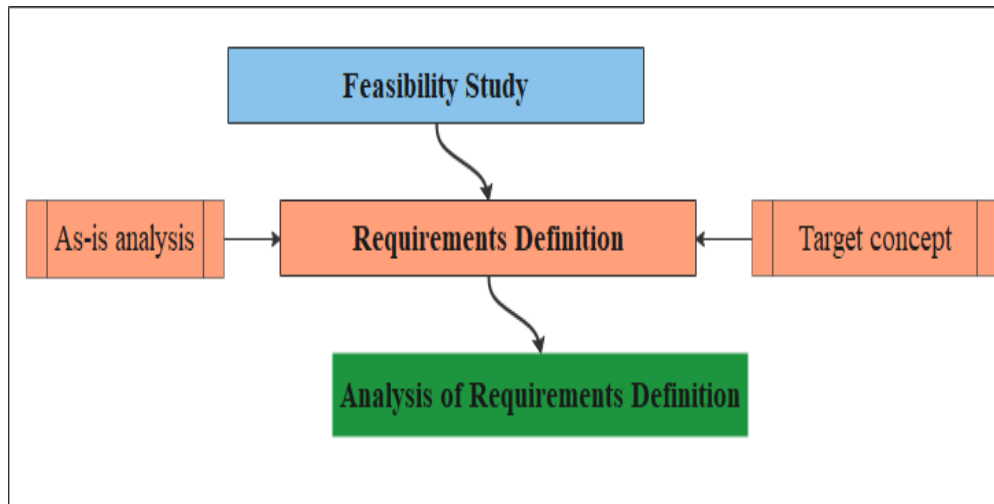


Figure 4.2: Steps in Requirements analysis

4.2.1 Feasibility study

This step involved a critical evaluation and quantification of all the benefits expected to be realized by the company once the new system was developed and adopted. Listed below are some of these benefits to the company.

Efficiency

The web application being developed was aimed at improving efficiency in the new customer connection process at KPLC, by integrating it with the already existing systems in the company. Table 3.2 demonstrates the processes that were to improve through automation. This would ensure a smooth process flow from the time a customer requested for connection up to when they got connected to the grid. A sequential electronic register would mean fairness when serving customers as the 'first come first serve' rule will be easy to uphold. The standard 21 days connection period would significantly be reduced since most of the manual and semi manual processes would now be automated/augmented.

Existing structure

Currently customers' enquiry for supply forms and supporting documents go back and forth from one section to another during information retrieval. This exposes them to misplacement, mix-up and even loss which necessitates the customer to submit a fresh set of documents. Such misfortunes translate to delays in connecting these customers to the grid. Through automation and system integration this problem would completely be eliminated. By so doing customers would have improved confidence in the company's business processes due to their ability to take part in the process, and the assurance that their documents would be safe.

People and policies

Introduction of a web-based GIS application and its integration with the existing company systems would not in any way change the roles played by each personnel in their respective sections. Instead, these employees would have been empowered to carry out their duties digitally which would translate to a lighter work load. There would be no further costs incurred by the company in terms of training as the application would be straightforward with modules for each set of users. Each module would be tailored in a manner that it would only contain the functions of each independent section.

4.2.2 Requirements definition

At this stage an analysis of the current situation was done and a target concept defined. A target concept defined the functions and properties that the application had to have in order to meet the requirements identified. At this stage all users of the GIS web-based application were identified and their specific needs in terms of functionality identified and documented as outlined on table 4.1. These users were the KPLC's customers, Business development personnel, Design and Construction Engineers and the Information and Technology (IT) personnel who would be in charge of maintaining the application.

Table 4.1: Change of responsibilities with the new mobile web application

USER	AS-IS ANALYSIS	TARGET CONCEPT
Business development head/clerk	<ul style="list-style-type: none"> • Receive, verify and record customers' enquiry for supply forms. • Manually allocate jobs submitted by customers to clerks. • Insert customer request into the inCMS to generate reference number and carry out ADMD approval. • Transfer jobs to the DCS and physically handover enquiry for supply forms together with the route sketch map to the designer. • Generate and print customer quotation. • Receive and verify customer supply contract and other supporting documents. • File customer documents for future reference. 	<ul style="list-style-type: none"> • Customers' enquiry for supply forms to be sequentially logged in an electronic book and a reference number generated to create a job. • Application to electronically transfer jobs to business development clerks' profiles. • Verify customers' details on the application and progress jobs into the inCMS system for ADMD approval. • Designer to access customer supply location from the application once the business development clerk has transferred the job into the DCS. • Upload customer quotation on the web application and send email/sms notification to the customer. • Download and document details relevant for contracting and file all documents electronically.

Design Engineer	<ul style="list-style-type: none"> • Use sketch map and telephone number provided on the application form to locate customers supply location. • Collect and record on a note book all the technical details to be used in the design. 	<ul style="list-style-type: none"> • Access customer's location details on the web application. • Record and upload technical details on each job and send electronically to fellow designer in the office. • Upload the approved design proposal for use by the construction engineer.
Construction engineer	<ul style="list-style-type: none"> • Prints approved design proposal for use in the field. • Notify GIS section via mail of jobs to be surveyed long after construction. 	<ul style="list-style-type: none"> • Access approved design proposal on the web application. • Make notes and send to the GIS section on changes made during construction on the application while still on site.
Customer	<ul style="list-style-type: none"> • Download, print, fill and submit enquiry for supply form. • Draw and submit a route sketch map to their premise. • Download, print, fill and submit supply contract form. • Visit KPLC's offices to obtain a quotation. 	<ul style="list-style-type: none"> • Fill and submit a digital enquiry for supply form on the web application. • Capture and submit X and Y coordinates of their premise on the web application. • View and download quotation on the web application. • Amend contact details on the web application.
IT personnel		<ul style="list-style-type: none"> • Manage users on the application.

4.2.3 Analysis of the requirements definition

This refers to the process of breaking down complex problems into sub-tasks and developing appropriate solution strategy for each sub-task. From section 3.4.2 above, five sets of users with different system functionality requirements were identified. Each user had their own view of the system being developed. An external model which is the end user view of the data environment was developed. It involved subdividing the project requirements into functional modules that could be examined within the framework of their external models. Each module represented a set of users who did not necessarily care about the system view of another set of users.

Figure 4.3 shows the external model of the project. The name of the system is ‘JICONNECT’ web application. The term ‘JICONNECT’ was coined from a combination of a Swahili word ‘Ji’ that refers to an action done to self and the English word ‘connect’ which simply means join. When combined the two words form a slung word that means self-joining or self-connection. In the context of this project this word would simply refer to self-service for customers wishing to have electricity connection to their premise.

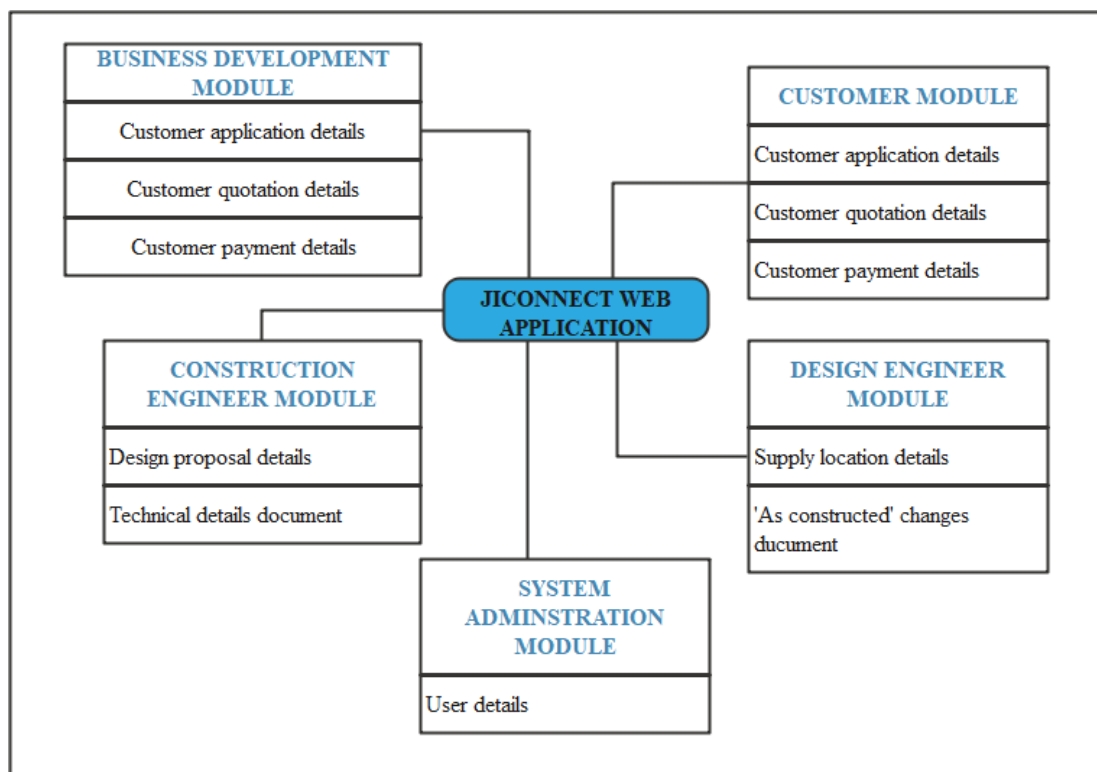


Figure 4.3: External model of the ‘*JICONNECT WEB APP*’.

4.3 Design

This stage looked at how the application was to be built and how it would operate by defining the hardware, software, network infrastructure and user interface to be adopted. Its main aim was the creation of a blueprint that satisfied all the documented requirements by identifying all inputs, processes and outputs needed. The main aim of this study was to develop a web-based GIS application to improve efficiency in the new connection process. The project was divided into two parts; web application development and geodatabase development. A web application with capabilities of running on several browsers and devices was developed. This application would be accessible to the users via a URL link. The application was enabled to access and use the device's GPS and location features. An object-oriented relational geodatabase was developed to store customer application details, proposed designs, supporting application documents from customers and notes taken by design and construction engineers. It was not necessary to duplicate the electricity network on this geodatabase as there already was an existing geodatabase in the company hosting the electricity network infrastructure.

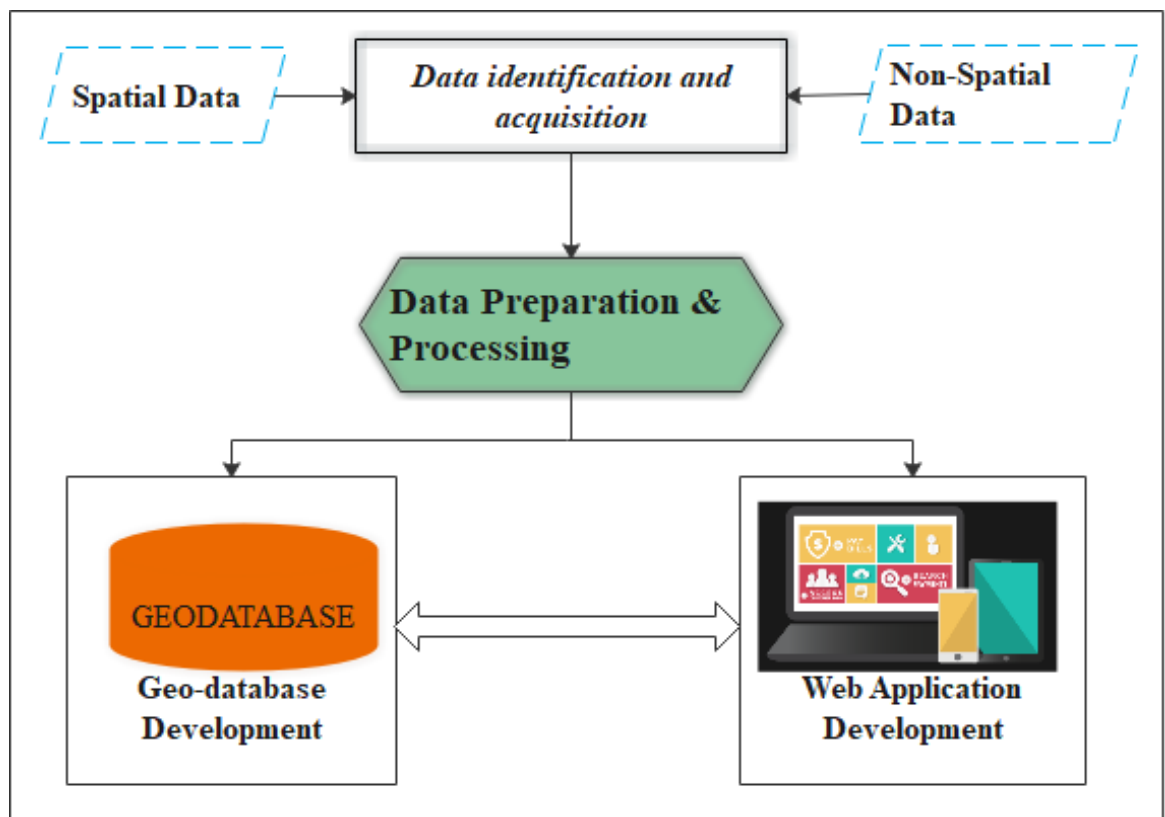


Figure 4.4: Web application development process

4.3.1 Data identification and acquisition

In order to enhance the new customer application process, the following datasets were identified as crucial for the development of the web-based GIS application: -

- Digital online base map- an open street map from Google was obtained. This map would act as a guide to the design engineer when visualizing the customer supply location for site visit planning purposes. It contained all the major roads and landmarks captured and mapped as at December 2019.
- County data- a PDF file containing county data in the country was obtained. This data would be used by the customer while inputting supply location data on the web application. It contained a table listing of all counties in the country and their subsequent constituencies; and a list of wards contained in each constituency as mapped during the last general election in the year 2017. This data was retrieved from the Independent Electoral and Boundaries Commission (IEBC) website.
- Enquiry for supply form and supply contract forms- PDF formats of the two forms were downloaded from the KPLC website. These forms contained important information that require filling by a customer seeking connection services from the company.

4.3.2 Data processing

The PDF file containing the counties details was first converted into an excel workbook and a filter created on the county names column. Only six constituencies that make-up the Coast region under the KPLC's jurisdiction were relevant in the study, namely: - Mombasa, Kwale, Kilifi, Lamu, Tana River and Taita Taveta counties. Each county was then individually filtered and its details copied into a separate .CSV files containing the counties, constituencies and wards information respectively. Each file was organised in such a manner as to resemble the table column format that would be used in the geodatabase. Examination of the county data was done to verify spelling of the constituencies and ward names.

Key features on the enquiry for supply and supply contract forms were analysed to come up with a structure of tables that would be used to store customer application data in the geodatabase. These forms contained information on the applicant's

personal details, supply location data, the type of application data, customer appliances details, wayleaves consent and a supply agreement declaration.

4.3.3 Geodatabase design

This was the first and most critical step in the geodatabase development process. It began by identifying the data entities and the representation of each data entity. It involved the definition of how the spatial and non-spatial data would be represented in the geodatabase, the relationship between entities as well as the rules and constraints governing these datasets. One of the objectives of this study was to create a relational database capable of handling both spatial and non-spatial datasets with ease. PostgreSQL was chosen as the ideal RDBMS for this project. This was due to its ease of integration with other programming languages, high scalability, user-friendliness and attraction to a diverse community of supporters.

The geodatabase contained the following datasets; customer details, application details, appliances details, county details, constituency details and ward details, supply location details, raster imagery (open street map from google), pdf documents (customer quotation, application supporting documents, design proposals) and text documents (designers field notes, construction engineer field notes). Its design was divided into two distinct stages namely, conceptual modeling and logical modeling.

i. Conceptual modeling

A conceptual model defines what the system contained and represented the needs of the various functions. Its main aim was to establish entities, their attributes and the relationship between entities. It was independent of the DBMS and hardware used in the project. Tables for storing various datasets were designed and the relationship between them set. Primary and secondary keys were then assigned. Figure 4.5 shows the entity relationship diagram for the conceptual model. PK represented the primary key, while FK represented the foreign key.

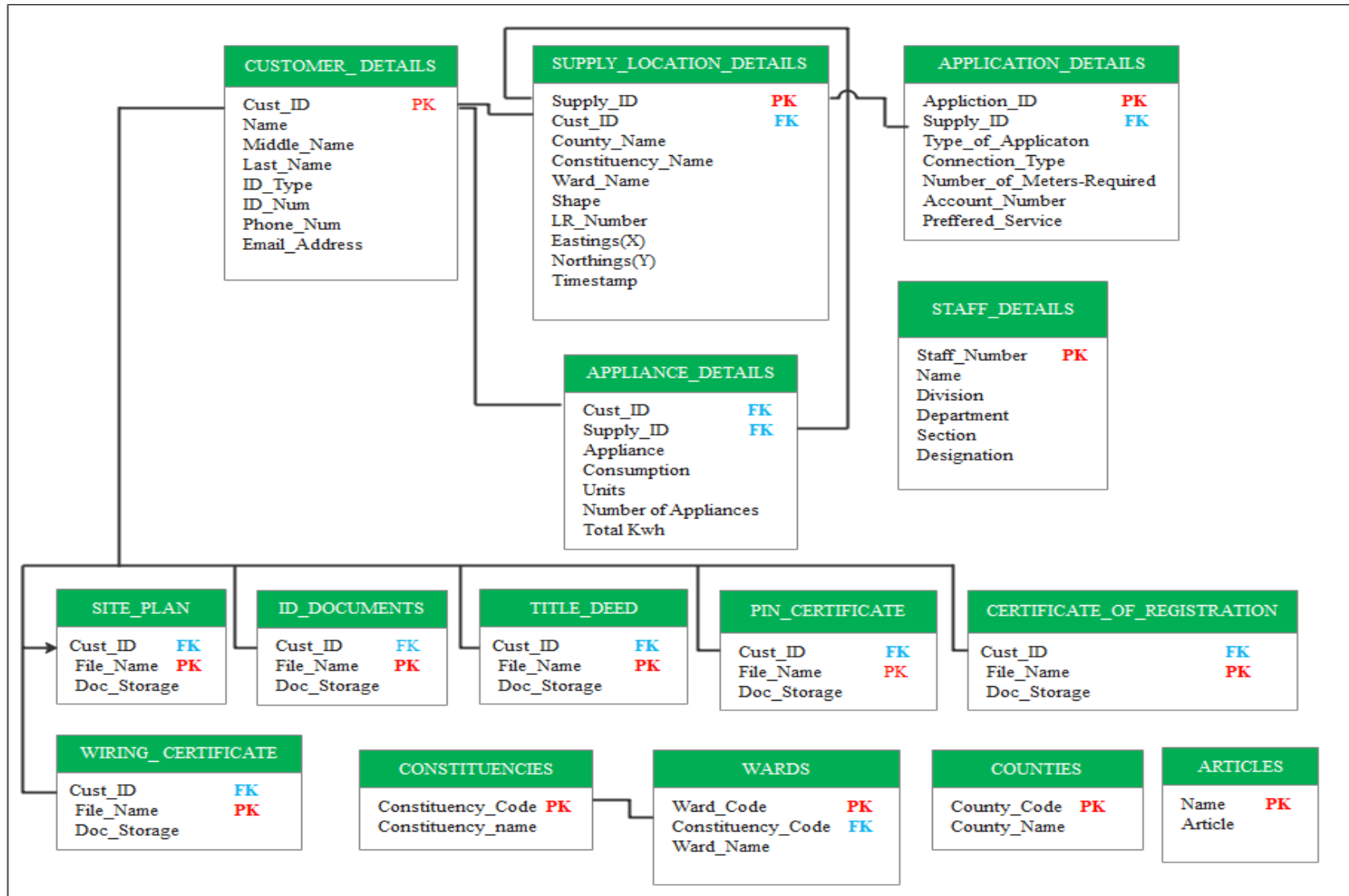


Figure 4.5: Entity relationship diagram for 'JICONNECT' database

ii. Logical modeling

A logical model defined how the system would be implemented. This was done by considering the structure of the kind of DBMS to be used in our case a relational database model. Each attribute on the database tables (see fig 3.6) was assigned a data size and type and all rules and constraints defined. The aim of this step was to ensure that data storage, input, update and retrieval would function properly. Figure 4.6 shows the various attribute types for each table that would be stored on the database.

Relational databases stores metadata in a structured way called the data dictionary or a system catalog. The following are the typical metadata that would be stored in the geodatabase:

- Technical metadata- this would contain all information pertaining the database schema which includes tables, columns and rows, primary keys, foreign keys, constraints, data types and values.
- Business metadata- this metadata is business specific and would include information such as users, user groups, privileges, user defined functions, data ownership, views, stored procedures and triggers.
- Descriptive metadata- this would contain information such as size of tables, files and indexes in bytes, timestamp, device used to upload files, name of persons uploading the files.
- Operational metadata- this would contain information on data which is on operation such as sessions, connection history and query history.

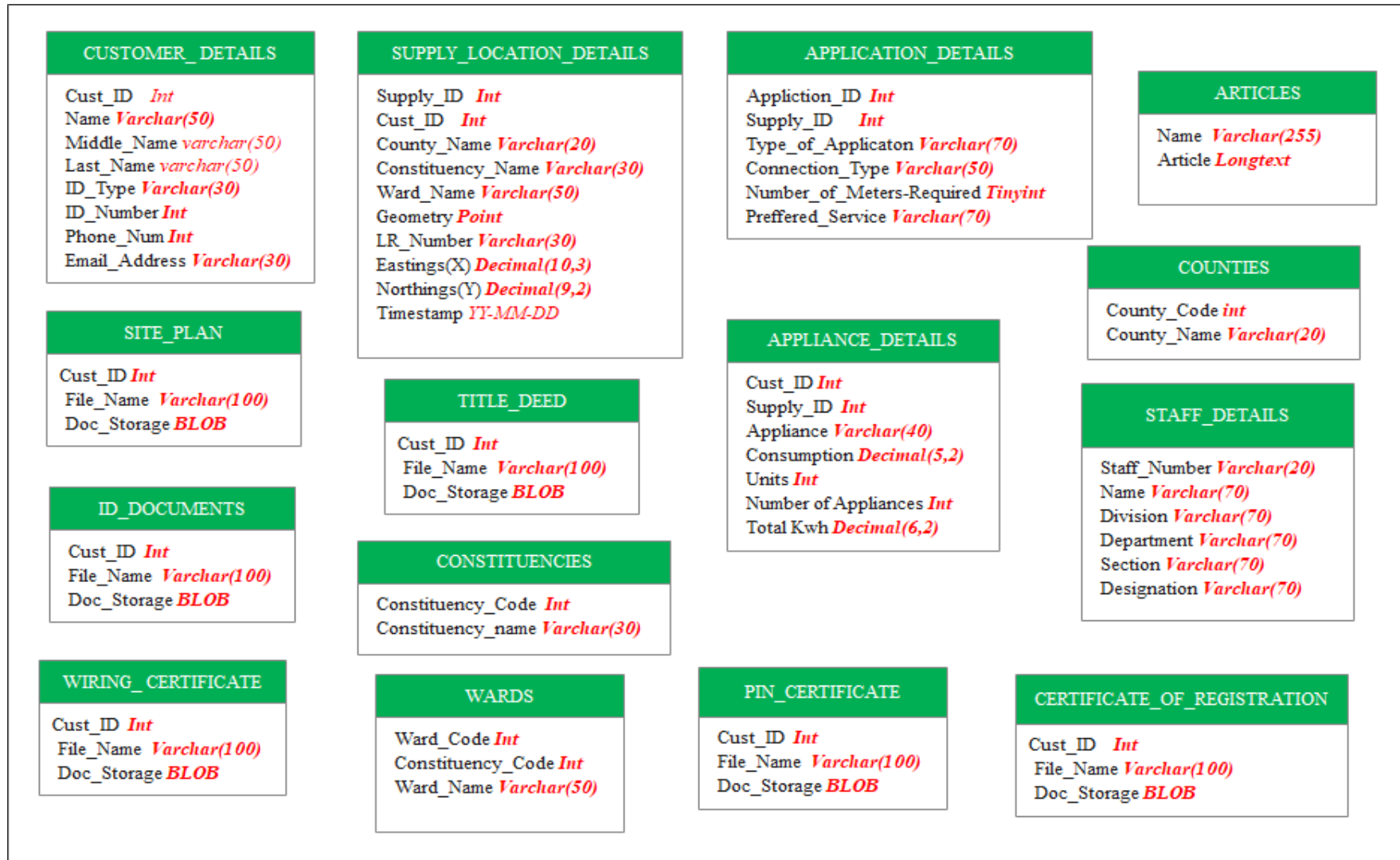


Figure 4.6 Logical model of the 'JICONNECT' geodatabase

4.3.4 Web Application Design

Web application is the face of any web-based GIS system and thus one had to be keen on its design. Its design focused on how the final application would look like and the experience the user would have with the application. Each user interface for each module was carefully designed using mockflow wireframe pro software. All the icons, their colors and graphics were organized as they would appear once the application was completed. This allowed for visual inspection to check for omission of functionalities.

4.4 Implementation

This phase marked the actualization phase of the by-products in the design phase and its output would be a complete application. Here all the design architecture was implemented. Individual components were separately developed and underwent module unit testing for functionality. This phase was divided into two distinct phases the back-end and the front-end. The back-end implementation phase involved the geodatabase and application development as well as the server configuration. This phase was hidden from the clients and the only interaction would be via queries. At the front-end implementation phase, the user interface to be used by the client was developed. It was composed of a code that was executed on the client's side and run in the user browser. Once each unit component had been tested, they were then integrated systematically to form one complete product that was ready for testing.

4.4.1 Back- end implementation phase

Here the main point of action was the geodatabase and the application development as well as the server configuration. The main software and programming language for these developments were: -

- **PostgreSQL**- an open-source object RDBMS that supports both relational and non-relational queries. Coupled with postGIS extensions it supports geospatial databases for GIS.
- **PostGIS**-an open-source software program that provides support to geographic objects on PostgreSQL RDBMS.
- **Python**-a general purpose coding language that can be used in web development, data science, writing system scripts among others. It is an open-

source language with a large community of developers that offer technical support and solutions. It has a large standard library which reduces the length of codes significantly. It also offers cross-platform efficiency and reliability.

- **JavaScript**-a programming language used for creating web pages as a scripting language.
- **Django**- an open-source web application framework written in python used for website development. It is highly secure and helps developers to avoid common security issues such as cross-site scripting, SQL injections among others. It is also a cross platform framework that supports most of the major databases. It can be used in a variety of application as it is fully loaded with extras and provides for scalability and adaptability.
- **Nginx**- an open-source web server. Its architecture scales well on generic server hardware and across multi-processor systems. It offers better bandwidth utilization, consumes less RAM and CPU; and serves more requests per server. Its most preferred due to its high performance, scalability and availability.

PostgreSQL and postGIS software were installed in a local computer and the ‘Jiconnect’ Geodatabase created in PostgreSQL RDBMS system. A physical model for creating tables in the PostgreSQL environment was adopted. Each table was then displayed for visualization to check for spelling errors and conformity to all the set conditions. Table 4.2 and 4.3 shows the generic SQL statement that was used in the creation of tables and an example of the SQL statement used in the creation of the ‘STAFF_DETAILS’ table respectively.

Table 4.2: Generic SQL statement for the creation of a table in PostgreSQL

Create table <i>'insert table name'</i> (
<i>'Insert column name' 'insert data type' 'insert condition',</i>
<i>'Insert column name' 'insert data type' 'insert condition',</i>
<i>Define Primary key,</i>
<i>Define Foreign key,</i>
);

Table 4.3: SQL statement for creation of the table 'STAFF_DETAILS'

Create table STAFF_DETAILS (
Staff_Number VARCHAR (20) NOT NULL,
Staff_Name VARCHAR (70) NOT NULL,
Division VARCHAR (70) NOT NULL,
Department VARCHAR (70) NOT NULL,
Section VARCHAR (70) NOT NULL,
Designation VARCHAR (70) NOT NULL,
PRIMARY KEY (Staff_Number),
);

The counties, constituencies and ward data in .CSV file format was then imported into their respective tables in the geodatabase. Table 4.4 shows the generic command that was used to import these files into the geodatabase tables.

Table 4.4: Generic command for .CSV files importation into PostgreSQL table

<i>COPY 'specify the table name with columns'</i>
<i>FROM 'specify the .CSV file path'</i>
DELIMITER ','
CSV HEADER;

Django framework templates were used in the application development. Python and JavaScript was used for coding all the commands and queries related to proper functioning of the application. Nginx was configured and served as the web server connecting the client to the geodatabase.

4.4.2 Front-End implementation phase

Front end dealt with the development of the user interface from the wireframe (See sec 4.3.4) earlier developed in the design stage. Here the main approach was the development of each of the five user modules which entailed bringing into life all the

functionalities identified in section 4.2.3. The user experience while interacting with the application as well as aesthetics were put into consideration. The following software was used in the front-end development: -

- **HTML 5**- this is a basic language that acts as a building block of a website. It is used to organize items in a website and describe the web page appearance. It is a free software and requires no any plug-ins to function. It is also supported by all browsers available today making cross-platform operability of sites. It is supported by a wide variety of web development tools and is the most search friendly programming language we have.
- **CSS (Cascading Style Sheets)**- this is a programming language that is used for styling HTML documents. This language was chosen due to its numerous advantages. It allows one to adapt the presentation to different types of devices by scaling how items appear on each device. It saves on time during coding since one is able to re-use one CSS sheet in multiple HTML pages and allows one to write only one CSS rule of a tag for use in all instances of that tag hence less coding which translates to shorter loading time. It is easy to maintain as a global change on a web page requires one to only change the style and all elements on the pages are automatically updated. It has a much wider array of attributes compared to HTML hence enables one to create better looking HTML pages.
- **Bootstraps 4**- this a free and open-source framework that contains CSS, HTML and JavaScript templates. It is used for the creation of responsive website designs quickly and efficiently. It was preferred for its adaptability as it provides identical display of sites on different devices and browsers thus promoting cross-platform use. It also offers a wide variety of templates and ready-made solutions that accelerates the creation of layouts. It is also very easy to learn and use as it only requires some basic knowledge on working with layouts.
- **JavaScript**-was also used to power the interactivity of the web pages. It allows web pages to respond to user activity and dynamically updates themselves without requiring a page reload to change its appearance. It also gives the site additional functionalities that are not achievable with HTML

and CSS alone e.g., it enables the loading of a pop-up with questions when a check-box is clicked.

4.5 Verification

This was the fourth stage in the waterfall system development methodology. It involved the integration of individual components of the web application into a complete unit which was then subjected to a series of tests to check for its performance. This stage saw the integration of the geodatabase, web application and web server into a complete unit. All the application files were then copied from the local host computer onto the cloud. Digital ocean spaces was chosen as the ideal cloud storage provider. This was due to its ability to offer scalable object storage for unstructured data such as images, videos, audios etc. It is developer friendly, has an easy-to-use user interface with excellent documentation on its use. It provides an easy and cost-effective means to store and serve massive amounts of data.

The web-based GIS application was then made available on <https://jiconnect.site/>. With the application now available on the web, a unit test was carried out to test it before its release to the final users. A total of 40 sample customer application sites were used for the test. These samples were spread within five regions identified within the study areas. These areas were chosen based on the level of electricity infrastructure development and the availability of telecommunication towers. These areas were categorized into three zones namely: -

- i. Poor infrastructure areas- areas with less low voltage electricity distribution network and few telecommunication towers.
- ii. Medium infrastructure areas-areas with medium low voltage electricity distribution network and average number of telecommunication towers.
- iii. High infrastructure areas- areas with high low voltage electricity distribution network and large number of telecommunication towers.

Samples from an individual zone represented only one type of application with Tudor area representing two types of application as shown on Table 4.5. The samples were evenly distributed within the zones according to their sizes.

Table 4.5: Zones identified for application testing

ZONE	AREA	INFRASTRUCTURE COVERAGE	NO. OF SAMPLES	TYPE OF APPLICATION
1	MWAKIRUNGE	POOR INFRASTRUCTURE AREA	10	New Connection
2	JOMVU	MEDIUM INFRASTRUCTURE AREA	5	Re-routing
3	LIKONI	POOR INFRASTRUCTURE AREA	10	Group Application
4	NYALI	HIGH INFRASTRUCTURE AREA	5	Temporary Supply
5	TUDOR	HIGH INFRASTRUCTURE AREA	10	Additional load & Meter separation

Figure 4.7 represents a map of the study area showing the five zones identified with all the 40 samples mapped out. For purposes of testing all the customer details used were dummy details and did not represent any real potential applicant. A document containing the customer details for input to be used in the sample collection was pre-prepared before the actual site visit.

utility company and if accepted, it would then be integrated with the existing business systems. A pilot project would then be rolled out for testing by actual users whereby any hiccups with the system would be identified and corrected. With successful completion of the pilot project the application would then be rolled out for use throughout the country with periodic system maintenance being carried out to ensure proper functioning.

4.7 Conclusion

Web-based GIS application development requires one to follow a systematic and well-laid out development methodology just like any other system development. Waterfall SDLC has proven to be a straightforward and easy to implement system development methodology, as long as all the project objectives and deliverables are known prior to commencement of the system development. Open-source software and programming languages are more efficient to use as they are backed by a large community of developers that readily offer support and solutions to problems encountered in their use. They are also cross-platform which saves the developers from writing different scripts for launching the application on different devices and browsers. Web application development frameworks have become enablers for faster and efficient web application development as they provide ready tailor-made templates and solutions for web app development saving the developers the hustle of re-inventing the wheel.

CHAPTER 5: RESULTS AND DISCUSSION

Chapter Five contains the findings of the study and a discussion on the impact the integration of the web-based GIS application brings to the electricity utility company. It focuses on the analysis of the results obtained mainly to ascertain the system functionality. It also discusses the efficiencies that will be achieved by integrating the web-based GIS application with other business software as well as any weaknesses thereof. There will also be a discussion on the general socio-economic benefits that can be achieved by use of information stored/generated from the application. This chapter is divided into four sections. Section one covers the findings of the research together with a demonstration of the system functionality. Section two touches on project viability through integration with other existing systems within the company's business structure, while section three focuses on the benefits brought about by having the system in place. Section four contains the conclusion which is a wrap up to the chapter.

5.1 Findings

5.1.1 Waterfall System Development Methodology

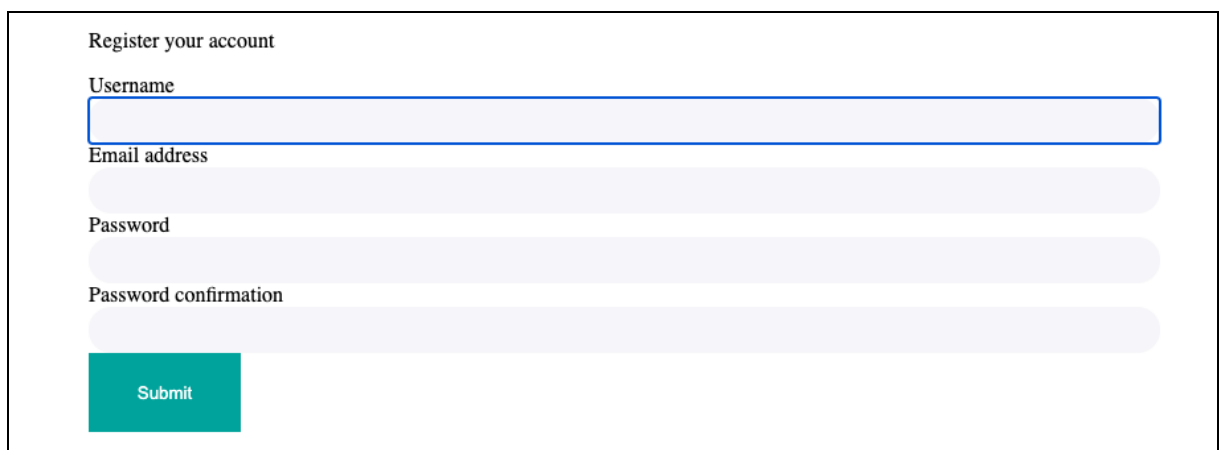
The resultant web-based GIS application was evidence of the successful use of the waterfall SDM. This was made possible by the fact that the project's objectives had clearly been defined prior to commencement of the application development with deliverables clearly documented (see table 3.2). Prior knowledge of the research objectives made it easier for one to presume the expected results, as interpolation was used to determine the project input requirements that would yield those desired results.

Since the company already had an existing GIS system in place, there was no need to replicate the electricity network infrastructure onto the web-based GIS application database. This made it even more efficient to collect data as it eliminated going to the field for data collection. County, constituency and ward data obtained from IEBC made it efficient for users of the web application to fill out the digital form as it eliminated the user having to type the whole name but instead select their location from the drop-down list. Customer notification on the readiness of quotation was restricted to emails notification due to the financial implications that would result from engaging with telephone service providers.

Project outcome was measured at the end of each stage by comparing obtained results against the target concept document (see table 3.1). This made sure that development was on track and avoided the hurdle of not being able to go back and edit anything once the application was in the testing stage. The comparison also made it easy for one to have periodic forecast of the expected results by analyzing the input data. This SDM proves to be quite effective time wise as each phase was processed and completed one at a time avoiding the confusion that can results from processing different phases concurrently.

5.1.2 ‘Jiconnect’ Web Application

The developed web-based GIS application has been configured to launch on any mobile device, laptop or desktop using any browser. There is a common registration/login interface which redirects the users to their respective modules depending on the user details that have been input. Utility company personnel are first pre-registered by the system administrator and are categorized according to their sections and roles. Each person is thereafter provided with login credentials with a password that should be reset on first logon. For customers, one has to register the first time they access the web-based GIS application and are free to change their passwords from time to time. Figure 5.1 shows the registration page while Figure 5.2 shows the web-based GIS application’s homepage.



The image shows a registration form titled "Register your account". It contains four input fields: "Username", "Email address", "Password", and "Password confirmation". Each field is represented by a light gray rounded rectangle with a blue border. Below the input fields is a teal "Submit" button.

Figure 5.1: Registration page

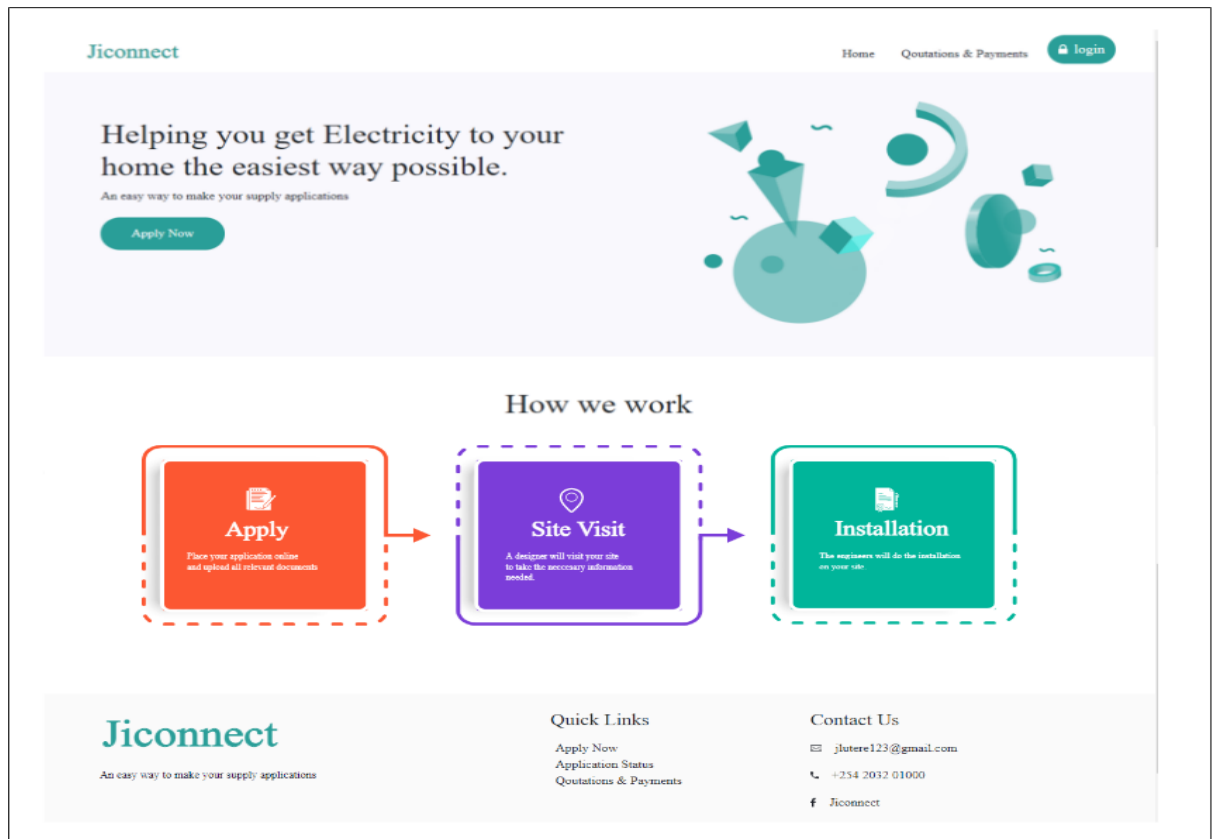


Figure 5.2: Web-based GIS application homepage

The web-based GIS application has five user modules which have been customized to support each user' requirements. Customer applications go through several statuses before completion. Each status change is triggered by the activities of either of the users i.e., the customer, the business development personnel, the design engineer or the construction engineer. These statuses are: - under review, on design, site visited, waiting for quote, pending payment, payment settled and installed.

a) Customer module

This is the customer user interface that enables the customer to fill and submit a digital enquiry for supply form, record their supply location, upload all the supporting documents related to their enquiry, sign the wayleave forms and supply contract forms, view and download job quotation as well as amend their contact details. The web-based GIS application automatically picks the customer location details immediately they fill in their enquiry for supply details. The customer is also able to view and follow their job progress from the interface. A user is able to key in multiple applications at a go under their profile and record coordinates each time they change the supply location. This module has an active timestamp that records

the date an application was submitted and is tied to each of the customer application throughout the new connection process. Figure 5.3 shows the customer user interface.

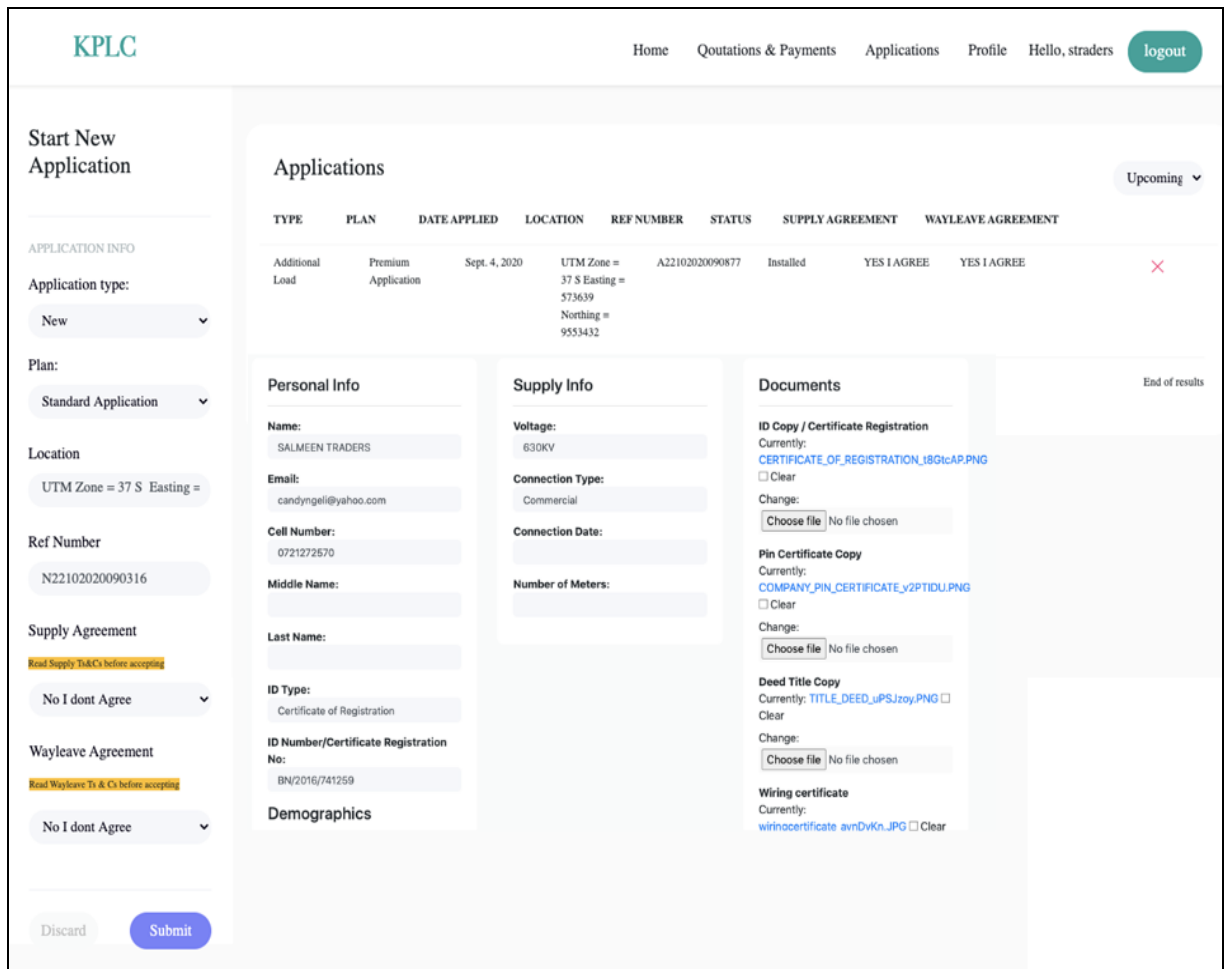


Figure 5.3: Customer module interface

b) Business development module

This module is for use by the business development personnel to countercheck the customer’s application before sending it for ADMD approval. Here the clerk is able to open the enquiry for supply form and confirm its completeness and accuracy. They are also able view all uploaded supporting documents i.e., National Identity card copy/passport copy, Certificate of incorporation (for businesses and companies), Kenya Revenue Authority (KRA) Personal Identification Number (P.I.N) certificate, land title deed copy and a wiring certificate. These documents are used as a means of verifying the customer identity and are checked against the input data on the web forms. Once satisfied, they send the job into the InCMS system and the design

module. They also upload the customer quotation for view and download by the customer. Figure 5.4 shows the business development module.

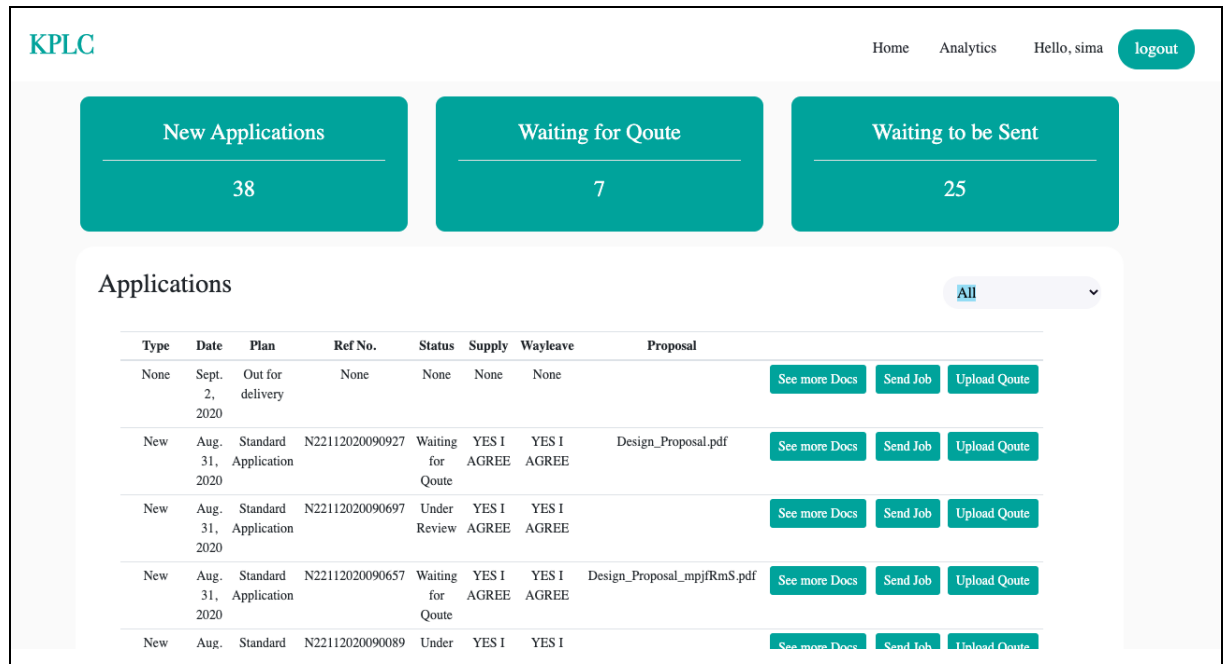


Figure 5.4: Business development module interface

c) Design Engineer module

Here a design engineer is able to view supply location details in form of coordinates and can project them on an open street base map for visualization. He is also able to type the technical details while in the field and forward it to an engineer in the office to carry on with design. Figure 5.5 shows the design engineer module.

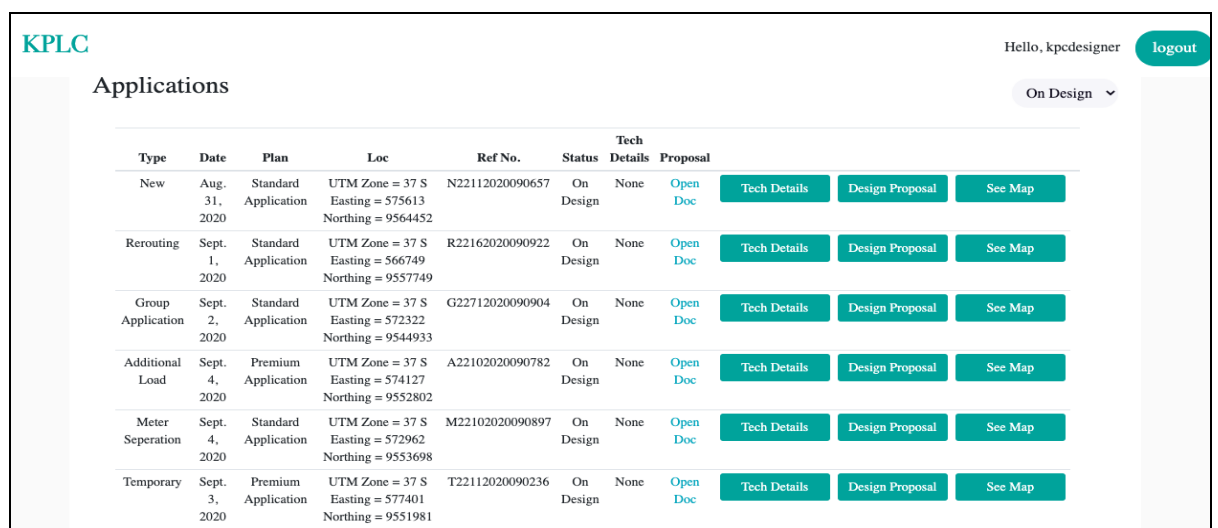


Figure 5.5: Design Engineer Module

d) Construction Engineer module

This module enables a construction engineer to view and download the design proposal for use during the construction of the supply to customer installation. They are also able to make notes on the changes made to the design proposal during construction and send them to the FDB team for updates. Figure 5.6 shows the construction engineer module.

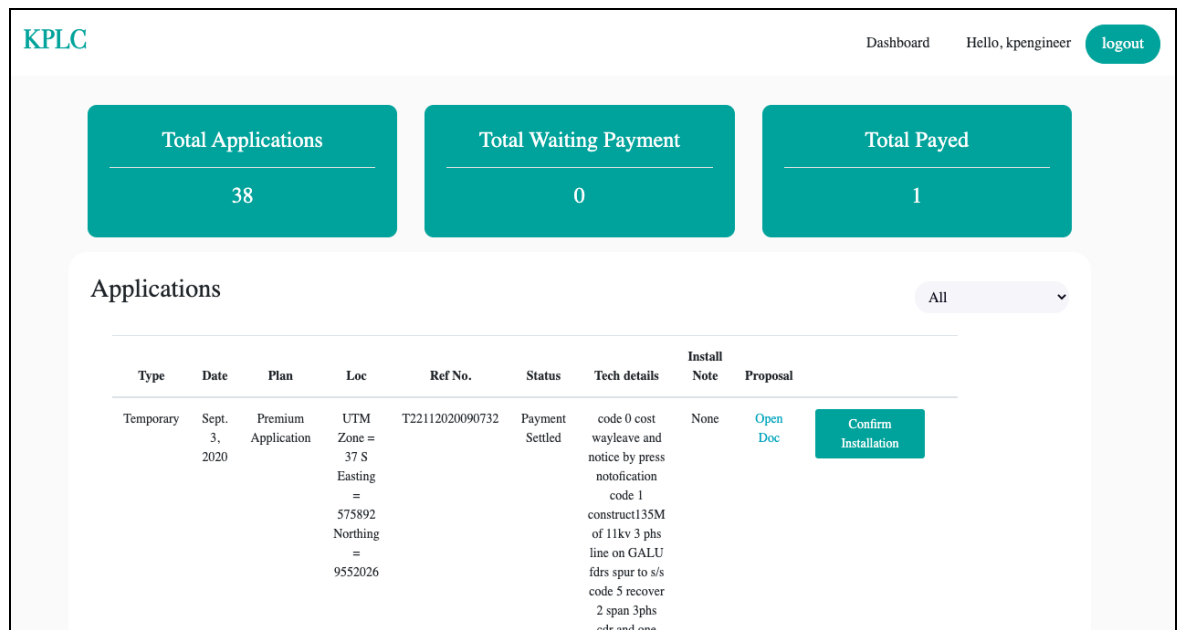


Figure 5.6: Construction Engineer module interface

e) System administrator module

This module is for the system administrator who in most cases would be an IT personnel. Their role is to manage the web-based GIS application users especially the utility company personnel. They are able to create user profiles and assign credentials depending on their role in the business process chain. They also have rights to delete KPLC users that are no longer part of the business process either by virtue of being transferred or resignation.

5.2 Application viability within the utility company business structure

The main objective of developing this web application was to provide a complementary system that would aid in the new customer connection process in the

electricity utility company in Kenya. This was aimed at improving efficiency in the new customer connection process by integrating it with other already existing systems in the company.

5.2.1 Results from the sample test

A sample test was carried out to test for business process flow and how the web-based GIS application would fit into the existing company business structure (see section 4.5). It took five days to visit all the test locations identified. This was influenced by the study area being at the coastal region, which experiences high temperatures and humidity making it uncomfortable to work outdoors beyond six hours in a day.

A timesheet was maintained to record the time it took to fill in customer details, upload all supporting documents and submit them. It took slightly longer to record customer details in those areas with fewer telecommunication towers (see figure 4.7) as compared to the rest of the areas with medium to high number of telecommunication towers. This was attributed to the fact that it would take time to establish what point of the customer premise had a good internet reception for recording location coordinates. It also took longer to upload supporting documents since the internet speeds in these areas was quite slow. Table 5.1 shows the time taken to carry out test for each region. From the table 5.1 it takes a customer an average of 26 minutes to record and submit enquiry for supply details assuming that they already have all the supporting documents ready.

Table 5.1: Time taken to record customer information per site

AREA	NO. OF SAMPLES	TRAVELLING TIME	TIME TAKEN FOR FIELD WORK	AVERAGE TIME TAKEN PER SAMPLE
MWAKIRUNGE	10	3 Hours	5 Hours	30 minutes
JOMVU	5	2.5 Hours	2 Hours 20 mins	28 minutes
LIKONI	10	3 Hours	4.5 Hours	27 minutes
NYALI	5	1.5 hours	2 Hours	24 minutes
TUDOR	10	2 Hours	3 Hours 20 mins	20 minutes

**** Time taken to move from one site to another was calculated as part of the travelling time.**

5.2.2 Improved business processes and their impact in business efficiency

Time is of essence in any business structure and is often used as a measure against which efficiency is calculated. Time efficiency is termed as a catalyst to improved productivity. For KPLC it was noted that delays were usually occasioned by some processes within the new customer connection structure being either manual or semi-manual as indicated on figure 2.4. These processes would be improved through either automation or augmentation using the developed web-based GIS application. The processes that would improve were outlined in table 3.2 and the user' requirements discussed in section 4.2.2.

From the analysis of the test sample collected table 5. 2 shows the business processes that will improve in terms of time and resource efficiency through digitization and augmentation. A further discussion seeks to elaborate the impact that each of the improved process will have on the overall performance in the new customer connection work-flow.

Table 5.2: Time efficiency comparison table with and without the web-based GIS application

	<i>Business process</i>	<i>Current average time taken per job</i>	<i>Projected average time taken per job after integration with the web-based GIS application.</i>
1.	Customer recording and submitting enquiry for supply forms	2 days	26 minutes
2.	Recording of new customer enquiry by business development clerk	As they come basis	
3.	First insertion of customer to generate reference number	16 minutes	

4.	ADMD approval and sending job to design	12 minutes	12 minutes
5.	Site visit by designer for technical details	Between 20-50 minutes with the least time being when the designer has no challenge locating customer supply location.	20 minutes
6.	Design proposal and approval	As they come basis	As they come basis
7.	Job quoted and customer issued with a quotation	As demanded by customer as long as design proposal has been approved.	Immediately the design proposal has been approved a quote is uploaded on customer profile and a notification sent to the customer.
8.	Payment by customer and submission of the supply contract	Depends on customers financial ability after which they submit the signed supply contract form together with proof of payment.	Depends on customers financial ability after which they upload proof of payment and digitally sign the Supply contract.
9.	Allocation of IO to cost by the finance section	As they come basis.	As they come basis.
10.	Wayleaves acquisition by the Wayleaves officers	As they come basis.	As they come basis.
11.	Job contracting by the business development clerks	6 minutes with weekly filing of supply contract.	3 minutes with immediate filing once the customer signs the supply contract.
12.	Job sent to construction and metering section		
13.	Job sent to FDB for update as 'as constructed'	Periodic compilation of jobs that are sent to FDB by the construction engineer.	Immediately the construction engineer upload notes on the web application.
14.	Job commissioned and meter validated	As they come basis.	As they come basis.

i. Customer information recording and submission

In the sub-Saharan Africa, majority of its countries have poor road infrastructure without proper modern means of transport and Kenya is no exception. Normally it takes a potential customer an average of two working days to download, print, fill out and submit their enquiry for supply form together with all the relevant supporting documents. This time varies between individuals depending on so many factors with the leading one being his proximity to the nearest utility company offices. There is usually no guarantee that their application will be received at the particular office upon submission, since different offices handle application within a given zone.

With the new web-based GIS application, it will take a customer an average of 26 minutes to fill in the digital enquiry for supply form and upload all the supporting documents. This is particularly welcoming for potential customers living in outlying areas with poor roads, as it removes the spatial distance hindrance between the customer and the utility company offices. The system is also able to accommodate customers with mobility impairment, as they do not have to rely on third parties to submit their electricity connection enquiry documents to the utility company offices. This to the utility companies means more applicants thus a bigger customer base that directly translates to increased revenue.

There is a socio-economic benefit to the customer in that it saves them time and resources that would have been spent downloading, printing, filling and travelling to the utility company offices for documents submission. It also eliminates the right office barrier which requires a customer to have prior knowledge of the correct office serving his supply area.

ii. Customer registration on submission of enquiry of supply form

Currently a customer is registered on a black book upon submission of an enquiry for supply form, and their papers arranged on a desk according to type of application and the date of submission. This book acts as an inventory for the applications made as well as being used as reference in case of a customer complaint when their records cannot be traced on the system. This analog way of data storage has often proved to be biased especially when it comes to serving the customers, as many are times when the paper piles get mixed up and fresh applicants get served before older ones.

With the web-based GIS application, customer applications are sequentially logged into the system providing a digital record of all applications made with a date stamp. This eliminates the need to have a business development clerk record all the incoming jobs on a book freeing up some more time for the clerk to carry out other duties. The sequential logging makes it difficult for a clerk to process fresh applications before older ones as the system keeps a record of how long a job takes along each stage and section.

iii. First insertion of customer information by the business development team

Currently new customer application details are manually copied by a business development clerk from the hardcopy form into the inCMS system. On average it takes 16 minutes for a business development clerk to successfully register customer details on inCMS system and generate a reference number. This process is very cumbersome and is prone to errors as the clerk repeatedly copies details from the enquiry for supply forms and other supporting documents from the customers.

With the web application the customer is responsible for recording and uploading their enquiry for supply details. This improves on the accuracy and reliability on the input customer information, as the customer only fills their information minimizing typing errors. Business development clerks on the other hand will now be able to work on other parts of the connections process as the need to manually input customer details is eliminated. This will ensure effective use of human resource by the company, therefore cutting down on operation cost by eliminating the need to hire more business development personnel.

iv. Site visit planning by the design Engineer

Currently a design engineer relies solely on the customer's contact details and the route-sketch map supplied to locate the customer supply location. It takes a design engineer approximately between 20-50 minutes to locate customer's supply location and carry out survey to aid with the design of supply route. This time is determined by the accuracy of the route sketch map and customer availability on phone to direct the designer to their premise. It also becomes challenging for the design engineer to properly plan for field work as they do not have the capacity to plot all supply locations on an individual map for visualization.

With the web-based GIS application, the attachment of a route sketch map has been eliminated and instead the application has been configured to record the customer supply location automatically as they apply. With this automated recording, there is high spatial reliability on the supply location information by the designers and they are able to navigate all the way to customers premise. This will improve on the time taken to complete a design, thus improving on the designers' overall productivity. These coordinates can be plotted on an Open street base map on the application and assist the designer in planning for site visits. Here the power of visualization is amplified and the designer is able to make effective and economically viable site visit schedules.

v. Turnaround time for quotation and supply contract form

Currently when a customer submits their enquiry for supply form, they are asked to visit the utility company offices after 7 days to collect their quotation for the supply as well as the supply contract form. This period is not guaranteed and at times the customer is made to visit the office severally before they are finally issued with a quotation. This is a very tasking arrangement for the customer as it wastes much of their time and energy doing the back and forth visits. By using the web-based GIS application, the customer will be notified via email when a quotation has been uploaded. They will then proceed to pay via bank transfer or mobile money and upload a proof of payment on the application. This will increase the ease of doing business for customers and the company.

vi. Job contracting and progress to construction and metering section

Currently it takes a business development clerk an average of 5 minutes to contract a job on the inCMS system. This process involves physical inspection of the hardcopy supply contract form for verification of customer details and signature before progressing the job to metering and construction section. The hard copy supply contract forms are then filled periodically depending on individual office preferences. With the web-based GIS application, the customer submits a signed digital supply contract form which takes a business development clerk an average of 2 minutes to open and verify its content after which he sends the job to construction and metering section.

vii. Access to design proposal by the construction engineer and job commissioning

In the current business structure, the construction engineer relies on the FDB personnel to fetch and print a copy of the design proposal. They use this hard copy design proposal in the field to carry out the construction work and record any alterations to it during construction. The construction engineer later compiles all jobs constructed and sends that information to the FDB team for update as 'as constructed'. This compilation often takes days or weeks and results to customers not being able to use electricity before their connection has been commissioned and meters validated.

The web application provides a platform for them to view and download the design proposal for use during construction. They are also able to make notes on the application and forward them to the FDB team for amendments immediately they are done constructing. This offers a great edition and storage plan that facilitate a collaborative construction process that sees customers realize the fruits of their investment in time.

5.3 The web application as a tool for decision making

a. Improved efficiency and optimal resource allocation within the utility business process structure

From the web application one is able to create graphs showing the kind of customer applications submitted within a certain period, the average time taken to process applications on each module, number of applications completed among others. This analysis is useful as it will enable the management to facilitate continuous flow in the new application process by identifying blockages and catch points in the business work flow. The management will also be able to assess optimal number of resources ranging from hardware, software, materials and human beings required to improve and maintain efficiency standards.

The management will be able to monitor the use of resources to achieve key staff performance indicators, by assessing the general output of each individual in the business process chain. This will help with investigations as to why certain employees are under performing and coming up with appropriate solutions. The map will also aid in human resource distribution as each area will be allocated an

individual(s) who has(have) expertise in handling different kinds of customer applications. This will help reduce employee-customer friction occasioned by misunderstandings between the two. Figure 5.7 shows the analytics of the test applications.

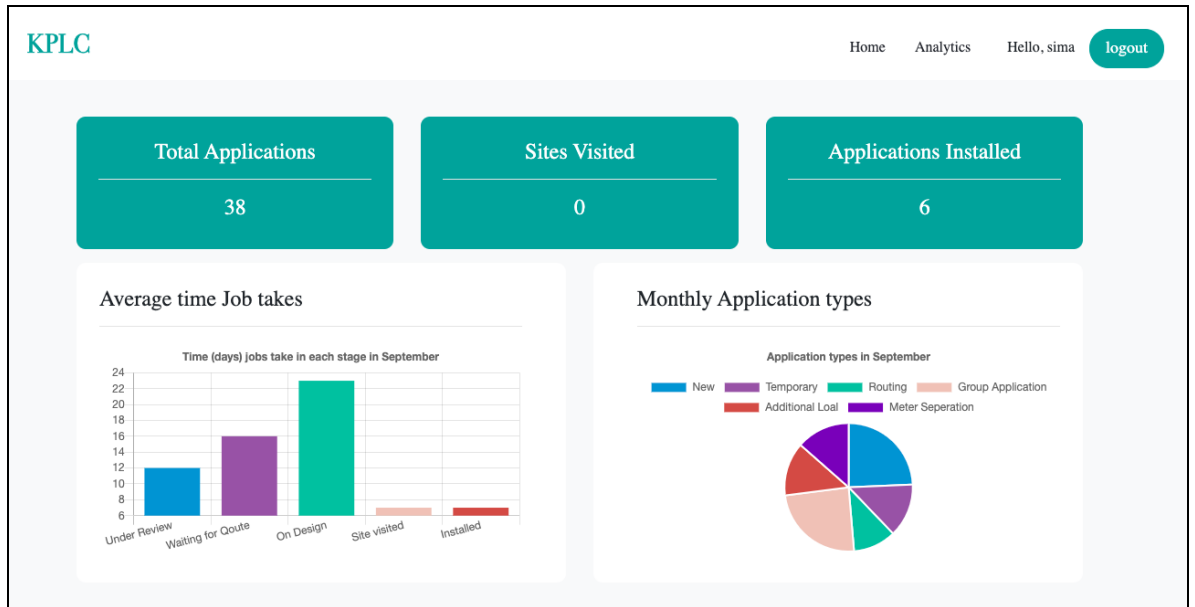


Figure 5.7: Analytics of test applications

b. Improved resource allocation by the government

During the data acquisition for application testing from the field, it was noted that it took 7-10 minutes longer to collect data in zone 1,2 and 3 (refer to figure 4.7), areas where the telecommunication towers were sparsely distributed. This was brought about by the time spent trying to locate the most suitable point with stable internet connection within the supply location. A map (see figure 5.8) showing settlement within the county versus the telecommunication tower coverage was created. The settlement spread was adopted from a high-resolution satellite layer of 2015. A buffer of 800m around the telecommunication towers was adopted as the average coverage area for a mobile telecommunication mast within an urban area.

Figure 4.8 indicates that most areas have good telecommunication tower spread with overlapping cells that allow for seamless transfer of devices from one cell (the coverage area for an individual tower) to the other. However, it can be seen from the map that those areas that took longer to fill and upload the enquiry for supply forms do not have sufficient tower coverage. It can therefore be deduced that the delay was occasioned by either the long distance between the user and the tower, high user

traffic saturating the available radio pockets, gap between two adjacent cell coverages among others. From this analysis one is able to advise the government on underserved areas that require more infrastructural investment.

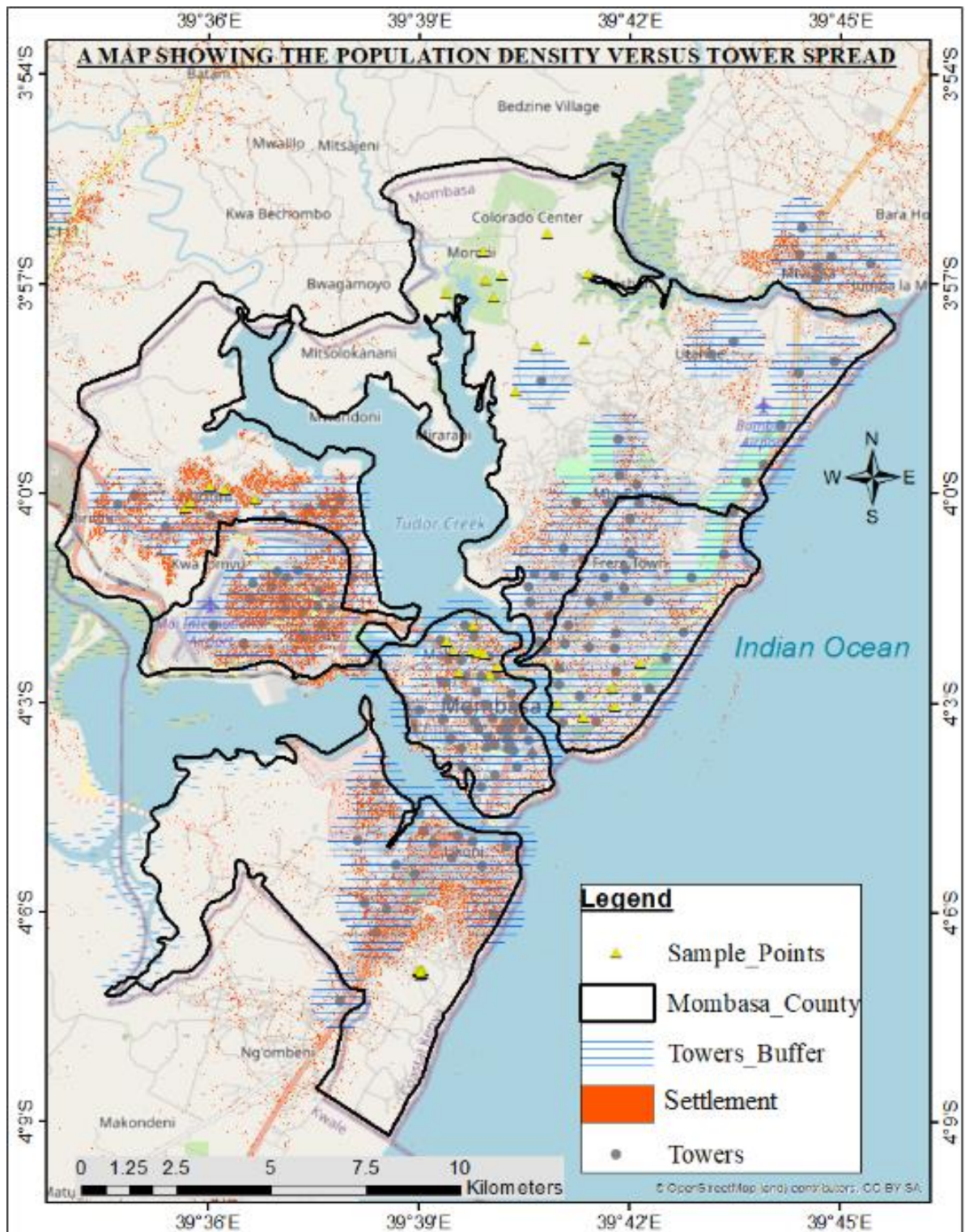


Figure 5.8: A map of Mombasa county showing settlement pattern versus telecommunication tower spread

c. Aid in infrastructural development planning

Currently Kenyan cities and towns are poorly planned due to the rapid urbanization that has been witnessed in the last five decades (Mwau, 2019). This has led to a number of problems ranging from poverty, income inequality, unemployment, underemployment, inadequate housing and access to public services, traffic congestion to environmental degradation (Hope, 2012). It is anticipated that by 2030, over half of Kenya's population will be residing in urban areas (Government of the Republic of Kenya, 2007). In order to achieve its vision 2030, the government has been tasked with the development of a strategy for provision of decent and high-quality urban livelihood under its social strategy. "This goal will be achieved through an increase in the annual production of housing units; high quality urban planning especially for slum dwellers; better development of and access to adequate housing to the rest of the population; enhanced access to adequate finance for developers and buyers and reforms to unlock the potential of the housing sector through private-public partnerships "(Government of the Republic of Kenya, 2007:19).

Improved access to urban infrastructure is one of the avenues that the government should invest in to circumvent some of the problems brought about by rapid urbanization (Hope, 2012:20). The type and spread of customer enquiries on the application can act as a measure of the rate and kind of urbanization taking place. Urban and regional planners are able to evaluate adherence to physical plans produced by evaluating the type of enquiries uploaded e.g., enquiry for additional load in the slum areas is an indicator of improved and upgraded housing in those areas. Developers and financiers are able to study the human settlement patterns to identify new target investment areas, as well as evaluate the number of people seeking their services as a percentage of total developments taking place. The government can plan for infrastructural development in the country by predicting and analyzing trends in human settlement and using such data to solicit for private partnerships. This data can provide useful information to the government as its analysis can help the government to plan for the kind of infrastructural expansions to employ in a given area.

New and additional load customer electricity enquiries would be an indicator of densification and clustering of human settlement in an area. This would provide

information to the local, regional and national government for the provision of town planning and spatial policy, housing amenities such as road network, schools, hospitals, markets and social halls among others. By analyzing these enquiries over a given time period, the government is best positioned to making informed long-term strategic investments on infrastructural development plans.

5.4 Conclusion

Waterfall method was an effective SDM for use in the development of the web-based GIS application for the electricity utility company. Due to its ability to launch on any device and browser, the web-based GIS application is open to a large number of users. In order to accommodate all the user requirements, the web-based GIS application has been configured into modules that are user specific. A customer approximately takes an average of 26 minutes to fill and upload their connection details assuming that they already have all the required documents ready. The recording of supply location requires the applicant to be on site when filling the digital forms, as it automatically adopts the device's location.

Web-based GIS integration with the existing systems within the new customer connection work-flow yields time and resource efficiency as well as improved productivity. The data stored and generated aids in managerial decision-making process through the analysis of information displayed on the analytics dashboard. The government through local administration can use information generated by the web-based GIS application to make informed decisions on infrastructure development and resource allocation within the country.

CHAPTER 6: CONCLUSION AND RECOMMENDATION

This chapter marks the end of the research and contains the closing remarks pertaining the whole study. It gives a broad overview as to whether the objectives of the study were achieved. It is divided into three sections with the first being the conclusion and the second one the challenges. The third and last section contains the recommendations to the study.

6.1 Conclusion

The main objective of the study was the development of a complimentary web-based GIS application to enhance customer application, by improving efficiency in the new customer connection process. This would be achieved by developing a geodatabase for recording and sharing customer connection data, a web application through which customer connection data can be uploaded and retrieved and by publishing, sharing and testing the application on an online platform. In order to carry out the research successfully, there was need to answer the following questions: -

1. What geodatabase specifications are required for recording and sharing customer connection data?
2. What characteristics are required to record customer self-registration and location data?
3. Can a web application facilitate new customer connection data upload and retrieval?
4. Can a web-based GIS facilitate an online registration process for power connection of new electricity users?

In conclusion, the main objective of the study was achieved by the development of the JICONNECT web-based GIS application. This was achieved through development of a geodatabase on PostgreSQL RDBMS for recording and sharing of customer connection data; development of a web-based GIS application using open-source web development software, through which customers' upload connection data and by publishing, sharing and testing of the GIS web application on the DigitalOcean Spaces cloud host.

The geodatabase chosen had the capabilities of storing both spatial and non-spatial data and would accommodate large size of datasets. Digital forms and access to

user's device location and storage functions were required, in order for a customer to self-register their details and location data. The web application was linked to the PostgreSQL geodatabase and is capable of transferring information to and from it. The web-based GIS application facilitates online customer registration for supply of electricity to their premises.

Efficiency would be achieved by integrating this web-based GIS application with the other existing applications in the new customer connection business structure. This is backed by the fact that section 5.2.2 gave a clear illustration of the time efficiencies that would be realised throughout the business structure. Broadly translated, the results and discussion of the study indicated that the web-based GIS application would not only benefit the electricity utility company but the county's administration at large (see section 5.3).

6.2 Challenges and Recommendations

The web-based GIS application developed is most suitable for use by customers with smart /touch screen phones, as it is highly interactive and would pose a challenge to other phone users. It is also dependent on mobile internet connectivity and strength, which determines the time taken to record and upload the customer connection data. With advancement in telephony services and competition among service providers, this challenge will be forgotten in the near future. Integration testing of the application would have been much in-depth had there been more access to KPLC data. However, this can be done in future once the company management is satisfied that the application will indeed improve efficiency in the new customer connection work-flow.

It will also be prudent that in future the web-based GIS application be used to track infrastructural development as a verification measure towards the achievement of Kenya's vision 2030 goals. This will be achieved by incorporating various datasets such as census demographics; cadastral and deeds registry information; rates base and collection; location-based services; spatial planning for urban property development and spatial pattern trends on the web-based GIS database. The kind of electricity connection requests being made on the application within a given time-framework can be used to infer the development within human settlements.

There is an increased involvement in the world's business model more so for utilities, where customers are increasingly getting aware of their consumer rights and options. It is therefore necessary that utilities embrace the growth in technology coupled by the willingness by prospective utility consumers to volunteer information to enhance their business agenda. One way of achieving efficiency in the new customer connection process is in the integration of web-based GIS as a tool for reaching out and capturing a broader customer base. The developed web-based GIS application in this research is suitable for use by different utility providers such as gas and water companies as a platform for recording, uploading, storing and sharing new customer information.

It is important for future research to investigate the reliability and viability of developing a native web-based GIS application for new customer information capture that can work offline. This would save users especially customers the setback of having to rely on internet connectivity and speeds to fill out and submit their information for connection purpose.

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