University of Nairobi

School of Engineering

DEVELOPING A WEB-BASED GIS APPLICATION FOR MAPPING THE ELECTRICAL GRID NETWORK IN KENYA

CASE STUDY: NAKURU COUNTY

BY

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F56/88230/2016

A Project Report submitted in partial fulfilment of the requirements for the Degree of Master of Science in Geographic Information Systems, in the Department of Geospatial Engineering and Space Technology of the University of Nairobi

July 2018

DECLARATION

I, Innocensia Owuor, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

Innocensia Owuor …………………

Name of student Date

This project proposal has been submitted for examination with our approval as university supervisor(s).

Dr.-Ing S. M. Musyoka ...…………………

Name of supervisor Date

ACKNOWLEDGEMENTS

Many thanks to the staff from Kenya Electricity Generating Company Limited, Kenya Electricity Transmission Company Limited, Rural Electrification Authority and Kenya Power for providing me with the spatial datasets that were critical for this study and also taking time to answer all my questions concerning their GIS systems.

I also wish to thank my supervisor, Dr.-Ing S. M. Musyoka for his suggestions and guidelines on how I should structure this project report.

ABSTRACT

The Kenya Power sector comprises of the following main agencies: Kenya Electricity Generating Company Limited (KENGEN), Kenya Electricity Transmission Company Limited (KETRACO), Kenya Power and Lighting Company and the Rural Electrification Authority (REA) which are mandated to generate, transmit and distribute electricity. A look into the roles played by these specific agencies shows that there are some overlapping responsibilities. For instance, Kenya Power manages and maintains the electric network that is built by REA and portions of the transmission network.

Each of the aforementioned agencies, independently collect and store spatial and non-spatial data pertaining the electrical infrastructure under their mandate in databases that are not accessible to other players in the sector. Considering how intertwined the functions of these agencies are, data collection efforts are usually duplicated leading to wastage of resources. It is therefore, important for all the data pertaining this infrastructure to be visualized and mapped on a platform such as a web GIS application since different datasets can be integrated and made accessible to users in various geographic locations provided they have an internet connection. Access to comprehensive data through a web GIS platform will help to consolidate data collection efforts, give a better view of the spatial distribution of the infrastructure, support better decision making and electrification planning.

This project execution involved combining GIS database design and web development using open source resources. The following 3 main tasks were undertaken: User needs assessment, Database design and Web GIS development. The User needs assessment enabled the requirements of the potential users to be considered during the Database design. The Web GIS development was based on GeoDjango which is a python based geographic web framework that supports the PostgreSQL database that was used to store the electric grid data for this project. HTML, CSS and JavaScript were employed in building the web GIS application interface. The resulting web GIS platform not only visualized and mapped the electric grid data but is also equipped with interactive functions that enable data querying, data download and printing of maps. Map controls for geocoding, zooming in or out, drawing tools, area and distance measuring tools are also included. The web GIS application was deployed online using a virtual server provided by Digital Ocean and can be accessed through http://167.99.203.86 with the credentials given in Chapter Four of this report.

DEDICATIONS

To my parents, Mr. Joseph Owuor and Mrs. Veronica Owuor for their unwavering support which enabled the successful completion of this project.

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LIST OF ABBREVIATIONS

CAD - Computer Aided Diagram

CPU - Central Processing Unit

CSS - Cascading Styling Sheets

E-R - Entity Relationship

ESMAP - Energy Sector Management Assistance Program

FDB - Facilities Database

FK - Foreign Keys

GDAL - Geospatial Data Abstraction Library

GDP - Gross Domestic Product

GIS - Geographic Information System

GML - Geography Mark-up Language

GPS - Global Positioning System

HTML - Hypertext Mark-up Language

HTTP - Hypertext Transfer Protocol

IIS- Internet Information Services

IP- Internet Protocol

IPPs - Independent Power Producers

ISO - International Organization for Standardization

JSON - JavaScript Object Notation

KENGEN - Kenya Electricity Generating Company Limited

KETRACO - Kenya Electricity Transmission Company Limited

KV - Kilovolts

KWh - Kilowatt Hour

MVT - Model View Template

MW - Megawatts

OGC - Open Geospatial Consortium

PHP- Hypertext Preprocessor

PK - Primary keys

PNG - Portable Network Graphic

PPAs - Power Purchase Agreements

RAM - Random Access Memory

RAP - Resettlement Action Plans

REA - Rural Electrification Authority

RGB - Red, Green, Blue

SDGs - Sustainable Development Goals

SVG - Scalable Vector Graphics

UTM -Universal Traverse Mercator

W3C - World Wide Web Consortium

Web GIS -Web-based Geographic Information System

WFS - Web Feature Services

WGS84- World Geodetic System 1984

WMS - Web Map Services

WPS - Web Processing Services

XHTML - Extensible Hypertext Mark-up Language

XML - Extensible Mark-up Language

CHAPTER ONE

1. Introduction

1.1. Background

Electricity is a critical component in almost every facet of our lives since it provides us with the energy to operate most of the devices that we use daily for lighting, heating and refrigeration, manufacturing and communicating. Despite the ubiquity of electricity in most of the technology we rely on to navigate the modern world, there are still about 1 billion people who have no access to it (documents.worldbank.org, accessed on 15th March 2018).

Kenya's current rate of electricity access is at 56% and the Government aims at raising that figure to 70% by 2020 and achieve universal access to electricity by 2030 (www.usaid.gov, accessed on 15th March 2018). Kenya Power is the lead government agency tasked with distributing power to consumers and has therefore, been carrying out the universal access to electricity campaign in earnest in collaboration with other power sector agencies such as Rural Electrification Authority (REA), Kenya Electricity Transmission Company Limited (KETRACO), Kenya Electricity Generating Company Limited (KENGEN) and the Ministry of Energy and Petroleum.

The aforementioned power sector agencies maintain an extensive infrastructure used in electricity generation, transmission and distribution. For better management of the electric grid assets, each agency collects copious amounts of spatial data pertaining the infrastructure under their mandate but the data is stored and managed in disparate databases with access privileges to only users within an agency.

There is therefore, a need for all the spatial data to be portrayed and mapped on a single platform as this will provide timely access to information necessary for decision making and planning especially at this time when the power sector agencies are trying to achieve universal access to electricity. A web-based Geographic Information System (web GIS) platform is thus critical for this sector since it is accessible through the internet and will provide access to the geographic data regarding the electrical network to users in different locations. This platform will consequently also help to consolidate data collection efforts since the spatial distribution of the current electric infrastructure will be showcased. Countries such as Tanzania, Zambia and Nigeria governments in collaboration with the World Bank, Energy Sector Management Assistance Program (ESMAP) and the KTH Royal Institute of Technology in Stockholm have created a web based GIS showcasing all their countries transmission and distribution electric lines and this has been valuable in electrification planning (www.esmap.org, accessed on 15th March 2018).

1.2. Problem Statement

The State Department of Energy in Kenya has several semi-autonomous agencies engaged in the creation of energy policies, generation, transmission and distribution of electricity. The main agencies namely: KENGEN, KETRACO, REA and Kenya Power independently collect and manage spatial data regarding the electrical infrastructure under their mandate in different databases. These agencies' functions are usually closely intertwined which often results in the overlapping of responsibilities and a look into their electrical infrastructure databases reflects this interrelation. In some cases, the databases usually contain similar datasets with only a few differences in data formats which consequently implies that data collection is often done more than once by the different agencies. Tracking goals such as universal access to electricity which depend on electrical infrastructure development is also hampered by lack of access to comprehensive electric power grid spatial data which is held in various databases. This also impedes quick decision making.

To achieve critical milestones such as universal access to electricity by the year 2030, a collaborative approach is needed in the visualization and mapping of the electrical infrastructure data from the various energy sector agencies. The first step in this endeavour should be the integration of the data in the separate databases into one platform that is accessible to users in the various agencies.

A web-based GIS portal is therefore, important as it is able to visualize the electrical infrastructure in a single platform that is accessible to users in various geographical locations provided they have a connection to the internet. Timely access to comprehensive data will help the multiple power sector agencies to meet their mandate by facilitating better decision making, help to eliminate duplication of efforts in data collection, assist in electrification planning, enable the better assessment of electricity access and influence policy making.

1.3. Objectives

1.3.1. Main Objective

The main objective of this project is to develop an interactive web-based GIS application that will visualize and map the electrical infrastructure of interest for use by the power generation, transmission and distribution utilities.

1.3.2. Specific Objectives

1. To carry out a user needs assessment to identify and acquire geospatial data for the infrastructure used in electricity generation, transmission and distribution.
2. To design and develop a geodatabase where the geospatial data will be stored.
3. To design a web-based GIS platform that depicts both spatial and multi-dimensional attribute data regarding the electrical infrastructure.

1.4. Justification for the Study

A web-based GIS platform provides a convenient access to geospatial data which is vital for decision making especially for the power sector agencies in Kenya which have interrelated roles. It provides access to spatial data pertaining the electrical infrastructure in one platform to users in different locations and this facilitates the use of consistent information across all the agencies.

Over the last few years the Kenyan government and donors have invested billions of shillings in modernizing and expanding the electrical infrastructure in support of the universal access to electricity efforts. For transparency and accountability purposes, the visualization and mapping of this network in a web GIS is critical for investors since it will showcase accurate data concerning their investments, help in assessing the impact of their investment projects and assist in drawing policies.

Geographic Information System (GIS) is a popular decision support and planning tool for a variety of sectors because it is efficient in data management. The power sector agencies manage extensive datasets, and capturing electrical infrastructure data in a web-based GIS is key in minimizing duplication of efforts in data collection caused by difficulties in accessing information about the infrastructure that has already been mapped by an agency.

A web GIS will also give clear insights on the spatial distribution of the entire electric power grid which is critical for electrification planning and network expansion strategies.

Procurement and training costs usually incurred in the desktop GIS solutions that are catered for mostly users with GIS background are also eliminated because web GIS applications are designed to be user friendly for most people regardless of their GIS skills.

1.5. Scope of work

1.5.1. Study Area

This project aims to visualize the electricity generation, transmission and distribution infrastructure in Nakuru County on a web GIS application. Nakuru is the fourth largest County in terms of population with over 1.6 million residents in an area of 2,325.8 square kilometres. In terms of its political administration, it is headed by a Governor and its economy is driven mainly by agriculture, tourism and horticulture. About 34% of the population has access to electricity but outside Nakuru town the rate is still low. It was selected as a study area because it consists of electric network elements that are of interest to this study. Figure 1.1 shows a map of Nakuru County.

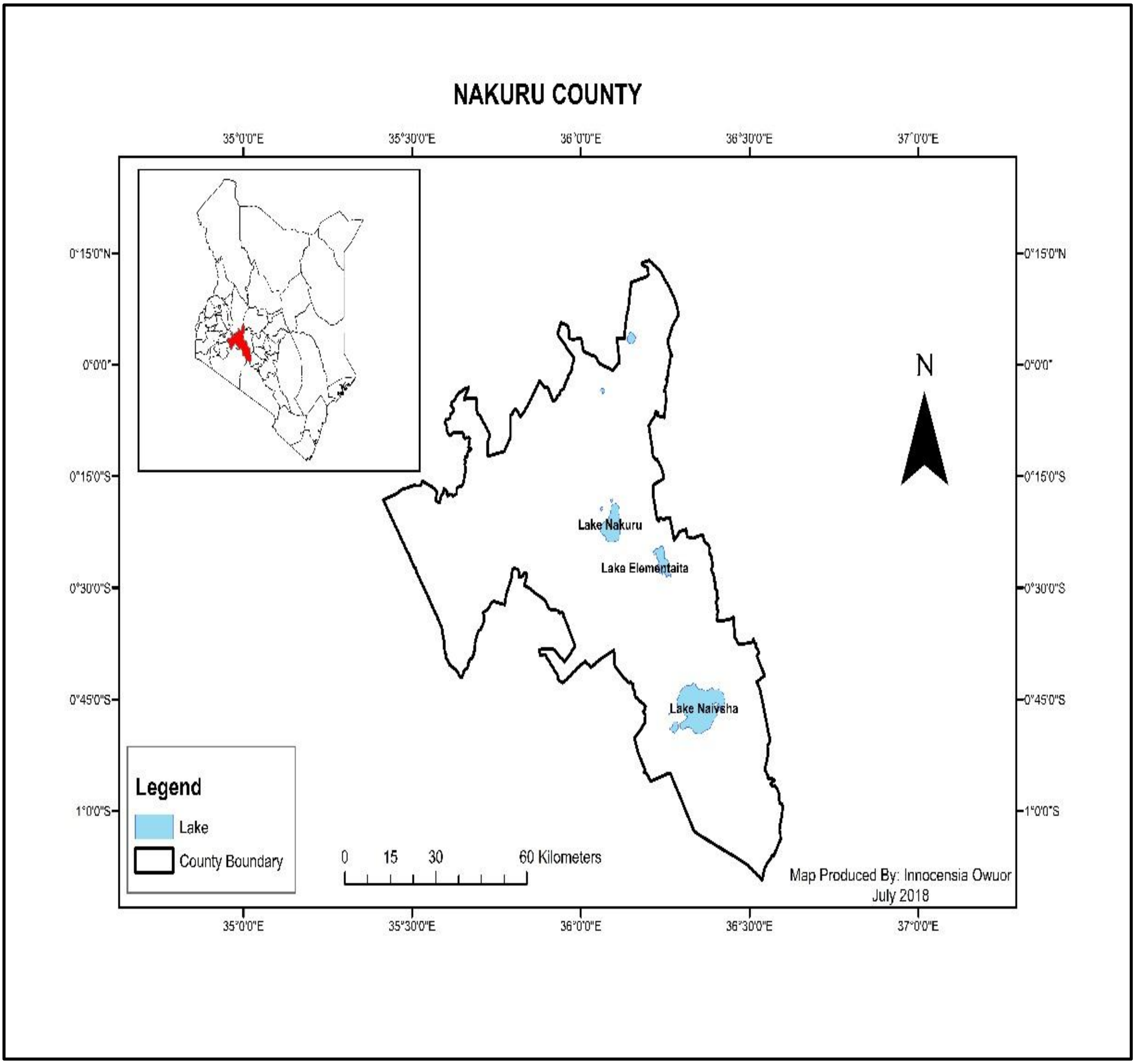


Figure 1.1 A map of the Study Area

1.5.2. Study Limitation

The following datasets were mapped and visualized in the web- based GIS platform:

- The location and attributes of the power generation plants.
- The location and attributes of transmission substations and lines.
- The location and attributes of 11 and 33 kilovolts medium voltage lines.

- The location and attributes of secondary substations.

The limitation to this research is that only a portion of the infrastructure will be showcased because the electric grid infrastructure is very expansive and the purpose of the project is to demonstrate how the above data can be visualized in a web-based GIS platform.

1.6. Organization of the Report

The report is organized in the following segments: Chapter one focuses on presenting the background of the study, motivation behind the project, the objectives, benefits and scope of the study. Chapter two covers the literature review which describes the technologies that facilitated the study and discusses a similar project implemented elsewhere. Chapter three gives an account of the techniques and procedures that were employed in the study while Chapter four showcases the results achieved. Lastly, Chapter five comprises of an assessment of the accomplishment of the study objectives and recommendations for related future projects.

CHAPTER TWO

2. Literature Review

2.1. Universal Access to Electricity

The Sustainable Development Goals (SDGs) require everyone to be connected to the National Grid or to Off-Grid sources of electricity by the year 2030 (www.undp.org, accessed on 15th March 2018). Most of the population that has no access to electricity is mostly located in sparsely dense areas with people with low incomes such as the North-Eastern part of Kenya but to spur developments in the area and to reduce poverty levels, access to electricity is vital.

Kenya's Vision 2030 social pillar also links to the SDGs in that it aims at ensuring everyone has access to affordable and clean energy. Enabling electricity access especially in sparsely populated remote areas is very costly and therefore requires partnership between the government and private sector players to invest in the generation, transmission and distribution of electricity. Countries are supporting universal access to electricity by increasing electricity generation capacity and expanding their electric grid which is being facilitated by geospatial electrification portal. This portal visualizes the current status of the electrical infrastructure on a web map which makes network expansion strategies easier to draw.

2.2. Kenya Vision 2030

Kenya Vision 2030 is an overarching plan that aims to make Kenya a globally competitive and prosperous nation with a high quality of life by the year 2030. This development Master Plan covers the period from 2008 to 2030 and seeks to transform Kenya into a middle-income country. It is centred on three pillars: the economic, the social and the political. The economic pillar aims to achieve an average Gross Domestic Product (GDP) growth rate of 10% per annum. The social pillar seeks to build an equal, fair and unified society in a clean and secure environment. The political pillar aims to realize a political system with leaders that respect the rule of law, and protect the rights of everyone (www.vision2030.go.ke, accessed on 9th March 2018).

Clean and affordable energy is critical in this development blueprint since it will power all the fundamental Vision 2030 undertakings. By the year 2030, Kenya is supposed to generate most of its power from renewable sources and also increase the installed capacity so as to meet the energy demands by the many large infrastructural projects that are in the pipeline such as Lamu

Port, Nairobi Commuter Rail System, Standard Gauge Railway from Nairobi to Malaba and Konza City Technology Park.

2.3. Kenya Power Sector Organization

Kenya is the largest economy is the Eastern and Central part of Africa with a GDP of about 70 billion dollars as of 2016 and with a population of about 48 million people, its power consumption per-capita is 154 Kilowatt Hour (KWh) (www.worlddata.info, accessed on 10th March 2018).

The main players in the sector are: Ministry of Energy and Petroleum, Energy Regulatory Commission, REA, KENGEN, Kenya Power, KETRACO, Independent Power Producers (IPPs), off-grid producers and the power consumers. There are three main roles played by these partners, that is, electricity generation, transmission, distribution and consumption.

The Electric Power System Grid shown in Figure 2.1 comprises of the following: the power generation plants that produce electrical energy which is then moved to transmission substations that step it up to high voltage electrical energy so that it can be transported over long distances through high voltage transmission lines to the primary substations. The primary substations step down the high voltage electrical energy to lower voltages which are then carried by power distribution lines to the secondary substations which further transforms the voltage to lower levels for safe use by the consumers, once this is done power is supplied power to consumers through the low voltage lines.

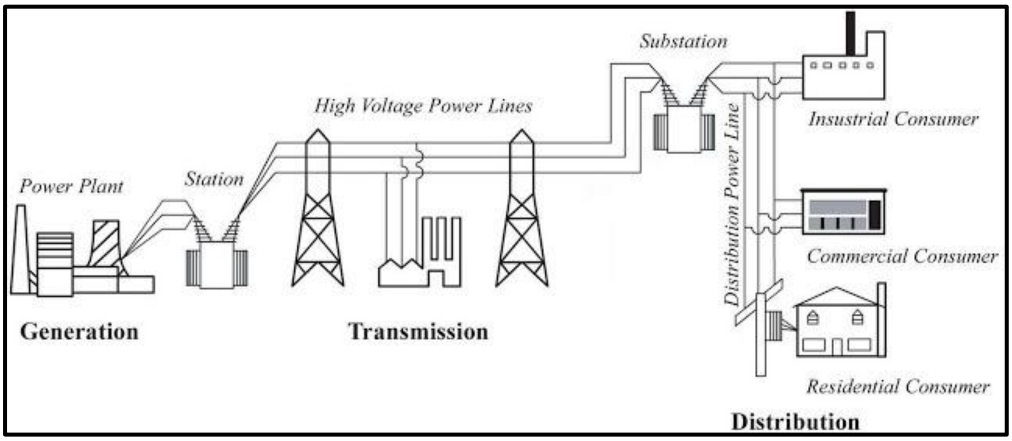


Figure 2.1 Electric Power System Grid

2.3.1. Electricity Generation

Kenya's installed capacity is at 2336 Megawatts (MW) which is generated by about 42 Generation Plants and 19 Off-grid Stations. This capacity comprises mostly of renewable sources such as Hydropower (827 MW), Geothermal (593 MW) and Wind (26 MW). The non-renewable sources include: Fossil Fuel (751 MW) and Gas Turbines (60 MW). The IPPs which are made up of 10 Diesel Generators, 3 Small Hydro Plants, a Biomass Plant and Geothermal Plant, produce 30% of the installed capacity (www.usaid.gov/powerafrica/kenya, accessed on 15th March 2018).

Generation of electricity from the publicly owned energy sources is operated and managed by KENGEN which was established in 1954 and has been selling electricity to Kenya Power in bulk through Power Purchase Agreements (PPAs) (www.kengen.co.ke, accessed 5th March 2018).

The company operates about 31 generation plants, 15 of which are Hydroelectric power plants that include: Gitaru (225 MW), Kiambere (168 MW), Turkwel (106 MW), Kamburu (94.2 MW), Kindaruma (72 MW), Sondu (60 MW), Masinga (40 MW), Sangoro (21MW), Tana (20 MW), Wanji (7.4 MW), Ndula (2MW), Gogo (2 MW), Sagana (1.5 MW), Sosiani (0.4 MW) and Mesco (0.38 MW).

About half of the power consumed in Kenya is generated from geothermal energy which comes from Geothermal Power Plants such as Olkaria II (105 MW), Olkaria IV Unit 1 (73 MW), Olkaria I (45 MW), Wellheads (30.6 MW) and Eburu (2.5 MW). During drought, thermal power plants supplement the power generation capacity from sources such as Kipevu III Diesel (120 MW), Kipevu I Diesel (73.5 MW), Embakasi Gas Turbine (54 MW), Lamu (2.8 MW) and Garissa (5.9 MW).

Generation of power from Wind energy currently contributes about 5.1 MW from the Ngong Wind Power Station. In late 2018, the construction of a transmission line from Lake Turkana Wind Power Station which generates 310 MW will be connected to the national grid.

2.3.2. Electricity Transmission

The transmission network in Kenya comprises of 66, 132 and 220 Kilovolts (KV) power lines which total to about 4149 Kilometres and transmission substations. There are also 400 and 500 (KV) lines being constructed that will connect the Kenya electric grid network to Ethiopia, Uganda and Tanzania.

KETRACO was established in 2008 to build and maintain the transmission network as it is critical in achieving the vision 2030 goal of improving the quality of power supplied by expanding the transmission network to areas that are not yet covered by the National Grid (www.ketraco.co.ke, accessed 15th March 2018).

About 1800 Kilometres of transmission lines have been built since KETRACO was established, the rest are owned and maintained by Kenya Power. The Transmission lines built by KETRACO include; 132 KV lines such as Sondu Miriu Kisumu line, Chemosit Kisii line, Rabai Galu line, Kamburu Meru line, Sang'oro Sondu line, Mumias Rangala line, Nyaga line, Kilimambogo Thika Githambo line, Kindaruma Mwingi Garissa line, Eldoret Kitale line, Sotik Bomet line, Machakos Konza line, Menengai Soilo line, and Ishiara Kieni line. Only a few 220 KV lines have been constructed since the corporation was established and they include: the Rabai Malindi Garsen Lamu line, Olkaria 1AU Suswa line and Olkaria IV Suswa line. There currently only two 400 KV lines and they are: Suswa Isinya line and Mombasa Nairobi line.

2.3.3. Electricity Distribution

Electricity access in Kenya now stands at 56% (trackingsdg7.esmap.org, accessed 9th May 2018). Distribution and supply of power is the mandate of Kenya Power which buys power in bulk through negotiated PPAs from generation companies and distributes the power to about 6.2 million customers it has today. Its power distribution network is robust and consists of over 100,000 kilometres of medium voltage and low voltage lines, 297 distribution substations and approximately 65,713 distribution transformers all over the country. It also manages a significant portion of the transmission network that was built before KETRACO was established (www.kplc.co.ke, accessed 15th March 2018).

Distribution of electricity in rural areas is carried out by REA which was established in 2006. Its main goal is to construct distribution lines and install distribution transformers. Recently, REA has increased electricity access in rural areas through a campaign that targeted electrification of primary schools and the communities that were 600 meters near the transformers in the primary schools (www.rea.co.ke, accessed 15th March 2018).

2.4. Geographic Information System

A Geographic Information System (GIS) is a computer-based information system that facilitates the capture, analysis, manipulation, management, storage, display and dissemination of land referenced data for decision making and planning (Bartelme, 1995). Typical components of a GIS include; data, hardware, software, personnel/users and procedures.

2.4.1. Data

It is the most expensive component of GIS. It comprises of raster which is basically an image that is represented using pixels and vector which are x, y coordinates that represent a point, line or polygon geometry. It can be acquired from data producers freely, bought from data vendors or collected by the interested party through various ways.

2.4.2. Hardware

Hardware refers to the physical electronic components that make up a GIS System and runs the GIS software that carries out operations such as data analysis and storage. It is mainly the computer workstation which comprises of the Central Processing Unit (CPU), hard disk, monitors, mouse, keyboard and peripheral devices such as memory stick, printers, speakers, scanners and projectors.

2.4.3. Software

Programs used to perform various functions. It can be divided into: Application software which directly perform a request from the user. This software such as ArcGIS (proprietary) and QGIS (open source); System software supports the application software to perform its functions. It includes Windows operating system or Linux and Middleware software that mediates between the application & system software.

2.4.4. People

This component includes the users of the GIS system and technical specialists that manage it such as database administrators, GIS technicians and GIS programmers.

2.4.5. Procedures

These are guidelines that should be adhered to in the daily operations of the GIS system. It entails procedures for data capture, processing, manipulation and storage of the data.

2.5. Evolution of Geographic Information System

The first application of GIS dates back to 1832 in France, where a geographer named Charles Picquet created a map showing the 48 districts in Paris that had cholera outbreak. About 20 years later in 1854, John Snow made a similar map that depicted the locations of the cholera outbreak in London, on this map he also showed property boundaries and water lines. This map helped him to realize that the outbreak locations were near water lines and this proved that the disease was waterborne. This marked the start of spatial analysis and the use of GIS as a problem solving tool.

Maps back then were still mostly paper based and were used to locate points of interest, planning and development. The need to represent different datasets on one paper map using various layers of data led to integration of computing with mapping. Advancements in technology enabled the use of printers to print maps and data storage in computers propelled further the development of GIS.

The story of modern GIS began in earnest when a geographer, Roger Tomlinson, created a computer program called the Canadian Geographic System in 1964 that was used to map geographic data. The motivation to create this program was the need to create a catalogue of all the resources in Canada. Tomlinson, later coined the term GIS in 1974, when he wrote a publication on the use of GIS in regional planning (Tomlinson, 1974)

From the mid-1970 to 1990, the GIS software development and commercialization took place since many government agencies around the world were adapting digital mapping. The Harvard Laboratory Computer Graphics developed the first vector GIS called Odyssey GIS which the Esri's ArcINFO was based on. Odyssey led to the commercialization of GIS software. By the mid-1980s, there was a proliferation of GIS software vendors such as Grid and Geomap. Powerful and cheaper computers, variety of software, accessibility of satellite data at the dawn of the new millennium up until 2010, led to more wide adoption of GIS.

Dawn of the internet age and the development of Web 2.0 technologies enabled the emergence of web GIS which was the solution to the accessibility challenge that was being experienced with desktop GIS. Web GIS facilitates access to GIS applications from anywhere with only the need of internet connection as a requirement.

2.6. Geographic Information System Implementation in the Kenya Power Sector Agencies

Kenya's Power sector agencies are greatly interconnected and depend on each other. It is therefore, important for a common understanding to be established among the various players with regard to the status and current spatial distribution of the electric network as this will assist them in meeting their future plans such as driving up the installed capacity to 5000 MW by the year 2020, achieving universal access to electricity by the year 2030 and improving the quality of power supply by expanding the transmission grid.

Implementation of a robust GIS system provides an efficient way to collect, organize, maintain and manage geospatial data about the location and condition of every component of the electric power grid system. This makes GIS vital in today's power system planning, analysis, system operations and maintenance. Kenya Power sector agencies have employed GIS as follows;

2.6.1. Kenya Electricity Generating Company Limited (KENGEN)

KENGEN acquired an enterprise GIS system that comprises of ArcGIS software, high speed computers and handheld GPS for acquiring data. Data pertaining their assets is stored in ArcGIS Server which avails the data to users in the organization through a GIS web portal (kengengis.co.ke). Geospatial professionals working in the Geomatics section update the database using Mobile Mapper handheld Global Positioning System (GPS) which they use to collect the infrastructure data. Work procedures for collecting, analysing, manipulating and displaying the data in the database are also in place.

The GIS system contains data on company assets such as the wind turbines, geothermal wells, power plants, reservoirs, steam fields and geological mapping. GIS system analysis tools are also used for topographic analysis and identifying potential geothermal fields; recently GIS was successfully used to identify Lake Bogoria and Menengai geothermal wells.

A lot of geoscientific data is also hosted in the database since it is a robust system that can handle various types of data and this offers better support for geothermal resources development, exploration, exploitation and overall better interpretation of information.

2.6.2. Kenya Electricity Transmission Company Limited (KETRACO)

KETRACO acquired the ArcGIS software, handheld GPSs and computers to set up GIS in the company. Procedures for data capture, analysis, manipulation, storage, display and dissemination have also been put in place by the Geospatial engineers in the survey section who keep the database up to date and offer GIS support services to the other departments in the company. Data collection is done by Geospatial engineers or contracted surveyors using Mobile Mapper handheld GPS.

KETRACO projects are usually large with impacts such as the displacement of communities. GIS is used in identifying land for resettlements and this is useful when drawing Resettlement Action Plans (RAP).

2.6.3. Kenya Power

The company has since 2015 been implementing a GIS system, known companywide as the Facilities Database (FDB) System. It is a customized GIS system built on the Oracle Spatial database which stores geographic data pertaining the transmission and distribution network that is owned and maintained by the company.

The system was built by Indra, a company based in Spain. FDB is a thick client software developed using Java and contains different profiles for different users. Query profiles; enable a user to only retrieve information from the database, Maintenance profile; enable a user to query the database and make changes to it but these are subject to approval by a user with an Approval profile who can query, maintain data and effect changes in the database. The last one is the Administrator profile, which enables the administration of the system, debugging, creation and deletion of profiles, update and retrieval of data from the system.

The GIS system is maintained and updated from a central department dubbed the FDB section. The section is made up of Geospatial engineers who collect data and update the database. Data is collected using Geoxt Trimble GPS and is imported in the database through the shapefile format. The section also offers support services and training to other staff throughout the company. FDB has facilitated better asset and data management of the company’s infrastructure.

2.6.4. Rural Electrification Authority (REA)

REA has not yet implemented a GIS system. AutoCAD is mostly used to represent geographic data pertaining the power lines and distribution transformers that they have installed. Geospatial engineers who work in the survey section inspect data collected by contracted surveyors. The data is mostly stored in Computer Aided Drawing (CAD) format.

2.7. Web Based Geographic Information System (Web GIS)

The advent of the internet democratized access to information as we know it and in addition to the development of Web technologies, the GIS industry has been able to circumvent the distribution and accessibility challenge that comes with desktop GIS through web GIS.

Desktop GIS is where one installs the GIS software in a personal computer and uses it to display, manipulate, query and analyse geographic data. With the dawn of the information age where information is now an economic good there was a need to make GIS products accessible to users in various locations.

Web GIS is a distributed information system, made up of a GIS server and a web browser accessible on a desktop or mobile application. It is essentially, a GIS that employs the web to communicate between a GIS server and a browser. High costs of GIS software and long learning curve for GIS training are some of the factors that have also necessitated the shift to Web GIS. Web GIS has also been widely enabled by the internet, web and standards.

a) Internet

This is computer network that provides connectivity to various distributed applications. It enables the transfer of files through protocols such as Hypertext Transfer Protocol (HTTP), sharing of data, software and hardware. HTTP is used to send client requests made through a web browser to the web server

b) World Wide Web

This is an application that runs on the internet. It is a distributed application that introduced the general public to the internet which was only exclusively used in the United States of America military. The application became really appealing to the civilian population because it was easy to use, provided content on-demand, supported a number of users regardless of geographical location and served the users with same content.

c) Standards

With the mass of geospatial information being produced and published to the Internet, issues emerge with regard to accessibility, usability, credibility and suitability. To deal with the concerns mentioned, the following standards were developed.

i) International Organization for Standardization Standards

International Organization for Standardization (ISO) through ISO/TC211; a technical committee that focuses on standardization in the field of digital geographic information established a set of standards for information concerning objects that are directly or indirectly associated with a location relative to the Earth. The standards provide guidelines for geographic information regarding the following: tools and services for data management, methods for acquiring, processing, analyzing, accessing, presenting and transferring such data in digital or electronic form between different users, systems and locations.

Implementation standards for geospatial web services are specified by web map server interface standards are detailed on ISO 19128 which outlines ways of retrieving maps served online and the operations that can be used to retrieve them. The ISO 19115, is the standard that provides guidelines on metadata pertaining geographic datasets and this enables location of data and evaluation of appropriateness of data (trac.osgeo.org, accessed 22nd June 2018).

ii) Open Geospatial Consortium Standards

Founded in 1994, the Open Geospatial Consortium (OGC) is a non-profit, international, voluntary consensus standards organization, which is leading the development of interface standards for geospatial and location based services. OGC standards are designed to be implemented in applications and products. Many OGC standards use ISO 19000 series standards as their abstract model. The following standard protocols facilitate the serving of geospatial data on the web (www.opengeospatial.org, accessed 22nd June 2018).

Web Map Services (WMS)

WMS is an OGC standard protocol that provide users with a means to serve georeferenced maps available from a GIS server over the web. Open source software that provide web map services capability include: Geoserver and MapServer. Proprietary server software that allow providing web map services include: ArcGIS Server, ArcIMS and GeoWebPublisher,

Web Feature Services (WFS)

The WFS interface permits users to access and manipulate geospatial feature information from GIS server. Data on a WFS is usually in vector form and enables user interaction through mouse clicks. Geoserver and QGIS server offer WFS support.

Web Processing Services (WPS)

The OGC Web Processing Service (WPS) Interface Standard provides rules for standardizing how inputs and outputs (requests and responses) for invoking geospatial processing services, such as polygon overlay, as a web service. The WPS standard defines how a client can request the execution of a process, and how the output from the process is handled.

2.7.1. Web GIS Components

It typically comprises of the following:

1. Web Server

A web server is a computer program that processes the users' requests and returns the results to the user over a computer network (internet or local area network).

There are several companies that offer website hosting for web applications through various web servers such as Apache HTTP web server from Apache Software Foundation which is freely distributed, open source and is the market leader in the web hosting world. It is usually used on Linux operating systems but it also supports Windows.

Internet Information Services (IIS) is also a commonly used web server from Microsoft. It is free for use, reliable and has high performance but only runs on Windows operating systems. Lighttpd is also a free web server that is secure, uses less CPU resources and runs very fast. Sun Java system web server is free but not open source and works with both Windows and Linux systems.

2. Client

A client is a computer that makes requests to a computer server and receives the result of the request over a computer network through a web browser. There are three groups of Computer clients.

a) Thin Client

Here the processing of the requests are done in the background by the server and the client only displays the results. This type of client is mostly used in the public environment. System administrators have control over these systems and centrally manage it. Computer devices here are also very small and have no hard drive. A low powered laptop accessing software such as ArcGIS on installed a server qualifies to be a thin client.

b) Thick Client

All of processing of requests are carried out on the client-side and not the server. A personal computer is an example of a thick client which does not rely on a server for any resources since all processes are carried out locally, has its own hard drive and software applications.

c) Hybrid

This is a mixture of thin and thick client. All the processing needs are carried out on the client side but it relies on the server to store data.

3. Web Map Server

Web map server executes a user's requests based on the given parameters and sends the results to the web server which relays the result to the client. The main categories of web map servers are:

a) Open Source Web Map Servers

Open source web map servers which are free to use include: MapGuide Open Source, QGIS Server, Geoserver, World Wind Server, GeoWebCache and MapServer. Geoserver and Mapserver are the popular ones in the industry today.

GeoServer is built using Java and uses the standards from OGC that make it interoperable thus enabling the viewing and sharing of geospatial data in various formats such as shapefile or from databases like PostGIS. Its development was a collaboration between Boundless Spatial, Refractions Research and GeoSolutions.

MapServer also enables the publishing of geospatial data and supports implementation of interactive mapping applications on the web. It was built at the University of Minnesota.

b) Proprietary Web Map Server Software

Some examples under this category include: Oracle MapViewer, ArcGIS server, GeoWebPublisher, ArcIMS and GeoMedia. These require licenses to be used.

One of the widely used GIS software is ArcGIS built by ESRI also comes with ArcGIS server which avails geospatial data stored in the server to a variety of users who have an internet connection.

4. Response Format

Server responses to the client can be images or text displayed on a web page that is developed using Mark-up languages such as Hypertext Mark-up Language (HTML) or Extensible Mark-up Language (XML), scripting languages such as JavaScript and Cascading Styling Sheets (CSS).

a) Mark-up Languages

Mark-up languages are mostly used for the presentation of text on the web. The formatting style of the text is defined in the language using tags. Examples of mark-up languages include: HTML, XML, Extensible Hypertext Mark-up Language (XHTML), Geography Mark-up Language (GML) and Scalable Vector Graphics (SVG). These languages were pioneered by the World Wide Web Consortium (W3C); an international organization that develops standards and protocols for the World Wide Web.

HTML is the most used Mark-up language for creating webpages. Text is defined and formatted using opening and closing tags such as <head> text </head>which indicate the text is a heading on the webpage, <p>text</p> indicate paragraphs and <b> text <b> makes the text bold. XML is self-descriptive mark-up language that was designed to store and transport data. It uses tags just like HTML but its main objective is to carry data. The tags on an XML are not predefined like in HTML but are made up by the user as they the write code. It simplifies data sharing, transport and accessibility. XHTML combines XML and HTML. SVG is XML based language used to define vector graphics on a webpage. It enables animation and interactivity on a webpage. GML is also a variance of XML that is used to define geographic features.

b) Scripting Languages

These are languages that communicate with other languages in the web environment and usually introduce more functionality to a webpage. They are mostly embedded in the HTML code. There are mainly two types of scripts; those that are executed on the client side by web browsers and those processed on the server side. The most widely used server side script is Hypertext Preprocessor (PHP). PHP can generate dynamic content, read, write and close files on the server. JavaScript is a scripting language used on the client-side to program the behaviour of elements on a webpage. It is usually embedded in the HTML code when creating webpages and mostly used to introduce interactive functions.

2.7.2. Web-GIS Application Features

a) A web application

An application program that does a specific function for a user. A web GIS application on the other hand, is a program that runs on a GPS enabled phone or a web browser and provides an interface with tools that a client can interact with and visualise the geographic data on.

b) Digital Base maps

These are critical in web GIS as they make the data on the platform more intelligible by providing a geographical context. Base maps can be a topographic base map, satellite imagery or terrain. Examples of some of the open source base maps include: Open Street Map and Open Topo Map.

c) Data layers

It contains the different datasets of interest that the web GIS aims at visualizing. These layers are dynamic in nature and are usually responsive to user mouse clicks. For instance, for a power distribution web GIS, the data layers would include, the distribution lines and distribution transformers. Data layers are often streamed from the web map server to the client especially if the data is large but if not it can be rendered by the browser.

d) Tools

These are tools that enable users to carry out certain tasks on the web GIS, for instance, zooming in or out, pan, measuring distance and calculating areas.

e) Database

This contains all the datasets that supports the web GIS application. It may contain a group of shapefiles, imagery datasets or other relevant datasets that can be can retrieved to provide information to a user. Examples of databases that can accommodate geographic data include: PostgreSQL with PostGIS extension, ArcSDE and Oracle Spatial. These databases are described below.

i) PostgreSQL

It is a free and open source object relational database with a spatial extension called PostGIS for managing geographic data. It is reliable, stable and compatible with all operating systems. It was created by the PostgreSQL Global Development Group in 1996. It includes “pgadmin” which provides the graphical user interface tools for managing PostgreSQL over the web or on a local desktop. PostgreSQL can also be queried using psql which is a terminal-based front-end to PostgreSQL.

ii) ArcSDE

It is a server based proprietary software from ESRI. It facilitates the management of geospatial data within relational databases and is interoperable with Data Management Systems such as Oracle, DB2 and SQL server.

iii) Oracle Spatial

This a proprietary software from Oracle which supports the management of geographic data and other location service applications. It comprises of modules that supports basic mapping functions, routing, geocoding and online map viewing.

2.7.3. JavaScript Web Mapping Libraries

There are number of Java libraries employed in web mapping in order to provide interactive and customization tools on a web map.

a) Open layers

This is a free and open source JavaScript library for creating dynamic maps. It was developed by a company called Metacarta in 2006 and can display base maps, vector geospatial data and data from web map servers such as Geoserver on web browsers. It also enables the addition of interactive tools such as zoom controls, geocoder and measure tools.

b) Leaflet

This library is free and open source. It facilitates the development of interactive web mapping applications and was created by Vladimir Agafonkin in 2011. It is quite popular and has been used by websites such as Foursquare, Flickr and Pinterest. It works well with both desktop and mobile applications.

c) Mapbox Graphics Library

This is a JavaScript library based suite of open-source libraries for creating highly interactive web maps for use in the web through mobile or desktop applications. It was created in 2010 by a company called Mapbox. It enables various style customizations of on a map.

2.7.4. Web GIS Architecture

The architecture captured in Figure 2.2 is based on the Client-Server model, where a client makes a request through a protocol such as HTTP and a server processes the requests and provides feedback. For a user to view GIS data, plugins are added to the web browser. This model can be implemented in two ways as follows.

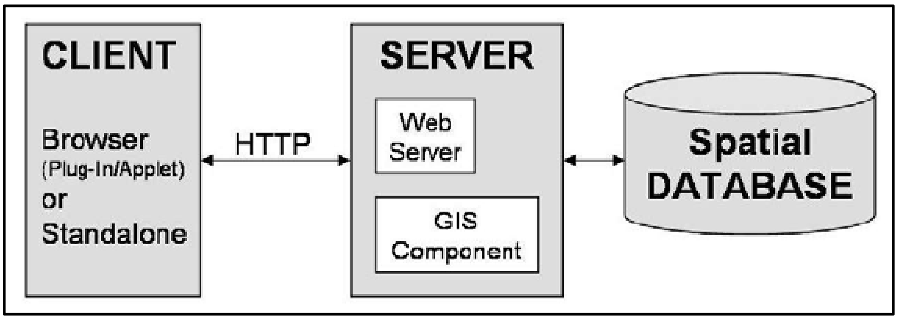


Figure 2.2 Web GIS Architecture (Held, Rahman, & Zlatanova, 2004)

a) Thin Client Architecture

Here the client sends request to the server which return results. A lot of the GIS functionality and workload occurs on the server side and therefore, the computers on this side are usually very advanced vis-à-vis the ones on the client side. The client does not need to know what is happening on the server side but the application developers must have this know how since they maintain it. A web GIS built using this format is based on a central database and is easy to update. Data is stored on the servers.

b) Thick Client Architecture

Bulk of the workload takes place on the client side. Interaction with user requests and processing of the various users operations occurs on the client. It provides clients with flexible interactions and customizing capabilities. Client requests are carried out on a user's local machine and data may also be stored on the server or local user's machine. This architecture is not suitable for public environments and upgrading it is not easy compared to thin clients where updates only need to be done on the server side.

2.7.5. Advantages and Disadvantages of Web-Based Geographic Information Systems

Advantages of Web GIS

1. Provides access to data to a wider audience since it employs the internet and web technologies.
2. Data is quickly distributed compared to desktop GIS.
3. With web 2.0 technologies, it enables a user to customize data to match their needs.
4. It enables hyperlinking to other datasets.
5. Easy to use and therefore, the learning curve is short and training costs are low.

Disadvantages of Web GIS

1. Relies on the internet such that if there is an internet outage the GIS data will not be accessible.
2. Accessing data on a web GIS requires high data bandwidth.

2.7.6. Case Studies of Successful Implementation of Web Geographic Information Systems in the Energy Sector in Africa

ESMAP under the auspices of the World Bank has over the years undertaken studies aimed at assessing electricity access in about 115 countries. The results of these analysis have been crucial in devising World Bank policies which inform government subsidies for electricity supply in the areas where access rates are low. Affordable and reliable supply of electricity spurs economic growth and consequently assists in the alleviation of poverty. Geospatial data comprising of population data, electricity transmission and distribution network data and poverty rates reports have been at the focal point of these studies by ESMAP as they have assisted in evaluating electrification rates in the various countries through visualization of the data in web maps that have been shared freely for download in the ENERGYDATA.INFO platform.

The platform gives access to GIS datasets, apps and data statistics pertaining the energy sector to commercial bodies, non-governmental organizations, government bodies and individuals. The most notable application hosted on ENERGYDATA.INFO is the Africa Electricity Grids Explorer which is a web map that depicts the planned and existing 66 Kilovolts transmission lines in Africa and the Middle East (africagrid.energydata.info, accessed on 15th June 2018). The map aims at highlighting progress made in infrastructure development in the two areas and support initiatives that aim at improving electricity access. It enables users to get information about a particular entity through mouse clicks on the entity of interest. It has limited map controls and has no search feature capabilities, in addition to the user not having the freedom to switch layers on or off. It still meets its objective of visualizing the data.

For this application, web development was carried out using HTML, CSS and JavaScript and the Mapbox Graphics Library. This is one of the many successful attempts made by World Bank to publish, visualize and make electric network geospatial data accessible online.

Uganda is discussed below as one of the success stories in East Africa that have successfully used web GIS to share electric grid data in the Energy Sector.

The Uganda Energy Sector GIS Working Group created a web GIS portal that displays the generation sites, transmission and distribution networks that are operational, planned and the and under construction in Uganda. This was prompted by the need to standardize the use of GIS because various agencies in the sector were using different data formats and coordinate systems. The web GIS was developed once all the power sector players had settled on the mapping standards and a coordinate system that would be used across the agencies by the various GIS professionals (www.energy-gis.ug, accessed on 5th August 2018).

The electrical infrastructure data was stored in the ArcGIS geodatabase and the web map server that was used to server the maps and data online was ArcGIS server. ArcGIS server enabled this data to be accessed online from a web browser or through ArcMap and ArcGIS Explorer. ArcGIS Application Program Interface for JavaScript was used to create functionalities for querying data, sharing, bookmarking views, measuring distance and printing maps. The web

GIS is accessible from https://uetcl.maps.arcgis.com/ accessed on 5th August 2018). The platform has helped in sharing information about the electric grid across the Energy Sector in Uganda and this has improved decision making and planning due to the convenient access to the data.

The Web GIS platform for this study was created using Django web development framework. HTML, CSS, and Leaflet JavaScript library built the client side of the application. The development uses mostly open source software such as PostGIS to store the electric grid data and *python 3.65* to develop the back end of the application.

CHAPTER THREE

3. Materials and Methods

3.1. Materials

3.1.1. Data

The datasets below enabled the implementation of this project.

The **Generation plants** dataset was acquired for the study area from KENGEN. The data was in shapefile format and based on the World Geodetic System (WGS84) Geographic Coordinate System. It contained 10 generation points.

Transmission Network dataset consisting of fifteen 132 and 220 KV Transmission lines and 9 substations in Nakuru County was obtained from Kenya Power which also manages a portion of the Transmission network. This dataset also included transmission substations that are owned by KENGEN. The data format was shapefile and was based on the Universal Traverse Mercator (UTM) projection and the Arc 1960 datum.

The **Distribution Network** dataset was also sourced from Kenya Power in shapefile format and based on UTM projection and the Arc 1960 datum. It contained 18 Primary substations (distribution substations), 10, 33 KV distribution lines, 50, 11 KV distribution lines and 2314 secondary substations.

Nakuru County Boundary was also acquired from Kenya Power. This dataset was also based on UTM projection and the Arc 1960 datum. It was also in shapefile format.

Table 3.1 gives a summary of the aforementioned datasets.

Table 3.1 Datasets Table

DATA	CHARACTERISTICS	DATA SOURCE	PURPOSE
Generation Plants	Geometry: Points Format: Shapefile Coordinate System: WGS84 Datum: WGS84 Total Number: 10 plants	KENGEN	Represent the locations and attributes of Generation plants.
Transmission Substations	Geometry: Point Format: Shapefile Projection: UTM zone 37 South Datum: Arc 1960 Total Number: 9 substations	Kenya Power	Depict the location and characteristics of Transmission substations.
Transmission Lines	Geometry: Line Format: Shapefile Projection: UTM zone 37 South Datum: Arc 1960 Voltage: 132 and 220 KV Total Number: 15 lines	Kenya Power	Typify the Transmission lines in Nakuru County.
Distribution(Primary) Substations	Geometry: Point Format: Shapefile Projection: UTM zone 37 South Datum: Arc 1960 Total Number:18 substations	Kenya Power	Represent the position and properties of the primary substations.
Distribution(Primary Feeder) Lines	Geometry: Line Format: Shapefile Projection: UTM zone 37 South Datum: Arc 1960 Voltage: 11 and 33 KV Total Number: 60 lines	Kenya Power	Present the geographical locations and attributes of the power distribution lines in the study area.

Secondary substations	Geometry: Point Format: Shapefile Projection: UTM zone 37 South Datum: Arc 1960 Total Number: 2314 substations	Kenya Power	Portray the location and characteristics of Secondary substations in Nakuru County.
Nakuru County Boundary	Geometry: Polygon Format: Shapefile Projection: UTM zone 37 South Datum: Arc 1960	Kenya Power	Delineate the Nakuru County boundary.

3.1.2. Hardware Overview

Computer hardware is the physical (tangible) elements that make up a computer system. A Laptop with the following specifications; 500 Gigabyte Hard disk drive, an Intel Core i5 processor with a 2.20 Gigahertz speed and a 4 Gigabyte Random Access Memory (RAM) was used in the data processing, manipulation, results analysis, web GIS development and report compilation.

3.1.3. Software Overview

A software is a computer program that furnishes a computer with instructions for directing it in the processes it should carry out. For this project several software types were employed during the project execution, they include;

- Windows 10 operating system from Microsoft was used to run the laptop because it is compatible with most of the other software used in this project.
- Microsoft Office 2013 suite was employed in the project report preparation and presentation.

The rest of the software applied during the different stages of the implementation of this project are discussed in the sections that follows.

3.2. Methodology Overview

In a bid to meet the main objective of developing an interactive web-based GIS application that will visualize and map the electrical infrastructure of interest for use by the power generation, transmission and distribution utilities. A three-pronged strategy was applied for the achievement of the 3 specific objectives listed in Section 1.3 of Chapter One. The strategy was segmented into the following three main tasks: User Needs Assessment, Database Design and Web GIS Development. The discussion following describes the tools, techniques and procedures that were employed in the execution of these tasks.

3.2.1. User Needs Assessment

Below is an account of the techniques used in the attainment of specific objective 1.3.1 listed in Section 1.3 of Chapter One and is outlined as follows: *To carry out a user needs assessment to identify and acquire the infrastructure data used in electricity generation, transmission and distribution*. The following research questions were used to achieve the objective.

a) Who are the potential users for this web GIS application?
b) What are the web GIS users' needs requirement?
c) Which coordinate system will be used to represent the data?
d) Which attributes will be used to describe the various electrical infrastructure elements?

These questions assisted in identifying the end users of the application and their specific needs.

Tools

1. Microsoft Word 2013

It is part of the Microsoft office suite that is used for word processing. It was used to jot down responses from potential users when carrying out stakeholder interviews.

2. QGIS

This is an open source GIS software that facilitates geospatial data editing, analysis, manipulation, storage, display and management. At this stage it was used to convert the coordinate system of the various datasets.

The User Needs Assessment process involved the following procedures:

(i) Stakeholder Interviews

The staff in the survey section and electrical engineers from the various power sector agencies were interviewed to better understand the difficulties in accessing spatial data from other agencies and the information that they expected to see in the web GIS. Potential users of the platform and the coordinate system for representing the datasets were also discussed during these interviews.

The questionnaire used during the interview process contained the following questions that helped to assess the user requirements.

1. Question 1: Do you encounter and difficulties when trying to get data from other energy sector agencies? If yes, what are the challenges?
2. Question 2: Who do you think will use a web GIS platform that provides access the electric grid data?
3. Which coordinate system should be used in representing the electric grid data in a web GIS system?
4. Which entities should be mapped in the web GIS platform?

Responses to the questions from the interviewees are summarized in the Table 3.2

Table 3.2 Interview Questions Responses

	KENGEN	**KETRACO**	**KENYA POWER**	**REA**
Question 1 Answer	Yes. Requires formal request to the managing director of the agency with the data. It takes almost two weeks to access data	Yes. Formal letters must to written to the directors of the agencies. Average time to access the data is 21 days.	Yes. Formal requests must be made to the other agencies. Feedback and data is given mostly after two weeks.	Yes. Requires formal letters to be sent requesting access to data. Process takes around 20 days.
Question 2 Answer	GIS professionals, Geoscientists and Mechanical , Electrical engineers	Surveyors, Electrical and Civil engineers	Geospatial and Electrical engineers	Cartographers, Geospatial and Electrical engineers
Question 3 Answer	WGS84 Geographic Coordinate System	WGS84 Geographic Coordinate System	WGS84 Geographic Coordinate System	WGS84 Geographic Coordinate System
Question 4 Answer	The generation sites, transmission substations and lines.	Generation plants, transmission network	Generation plants, transmission and distribution network	The distribution network.

It was clear from discussions with the interviewees that the platform should be made open to all relevant staff within the power sector agencies but only selected Geospatial professionals from each agency would be given rights to update the database. There was consensus to use the WGS84 Geographic coordinate system to represent the data since it is commonly used in web mapping, is based on a global datum and thus facilitates better data sharing.

Table 3.3 highlights the data layers that will be stored in the GIS database and the attributes of interest for the various datasets that will be displayed on the web GIS application.

Table 3.3 Data Layers and Attributes of Interest

Data Layer	**Attributes of interest**
1.Generation Plant	Name of the Generation plant and Generation Capacity.
2.Transmission Substation	Name of the Transmission Substation, Ownership, Incoming and Outgoing Feeder Voltages.
3. Transmission line	Name of Transmission Substation serving the line, Name of Transmission Line and Line voltage.
4. Primary Substation	Name of the Primary Substation, Ownership, Incoming and Outgoing Feeder Voltages.
5. Primary Feeder (Distribution Line)	Name of Primary Feeder, Name of Primary Substation and Line voltage.
6. Secondary Substation	Name of Primary Feeder supplying power to the Secondary Substation and Name of Secondary Substation.
7. Nakuru County Boundary	Name of County.

ii) Assessment of Existing GIS system

The existing independent GIS systems run by the different power sector agencies were reviewed to obtain insights about GIS software used, entities mapped and attributes stored. Kenya Power, KENGEN, KETRACO all have implemented GIS systems but REA still has not set up one yet as detailed in Section 2.6 in Chapter Two of this report. KENGEN has a web GIS system that has captured all the Generation plant infrastructure that they manage while KETRACO has a desktop GIS storing all the data regarding the Transmission network that is under their management. Kenya Power also has a GIS that constitutes both the distribution and transmission network dataset that they manage.

iii) Data Acquisition

From the interviews it was clear that the biggest challenge in data sharing according to the interviewees was the red tape in the procedures for accessing data from the different agencies. The generation, transmission and distribution network data were obtained from KENGEN and Kenya Power. These datasets were in shapefile characteristics are detailed in Table 3.1.

iv) Projection Transformation

Datasets that were in the UTM projection were transformed to WGS84 coordinate system using QGIS software. WGS84 was selected since it is a worldwide accepted format because it based on a global datum and therefore, supports better data sharing.

3.2.2. Database Design

The techniques described below were implemented in order to achieve specific objective 1.3.2 which was outlined as follows in Section 1.3 of Chapter One: *To design and develop the geodatabase where the infrastructure data will be stored.*

The following research questions enabled the achievement of this objective.

a) What method will be used to design the database?

b) Do the attribute tables of the acquired datasets need to be normalized?

c) Which database management system will be used to manage the data?

Tools

1. Microsoft Visio 2013

A software in the Microsoft Office suite that is used create diagrams and charts. This aided in the creation of the External, Conceptual and Logical models below.

2. QGIS

It was used to normalize the tables in the datasets acquired from the various agencies since some columns were duplicated and some fields were missing data. The 1st normal form was undertaken to ensure that every field had values.

The Database design and development was carried out in the following steps.

Due to the field data type length restrictions in the data that was acquired from the various power sector energy players, the aliases of the table columns were used during modelling for easy understanding of the electric infrastructure attribute that was being referenced to in the database.

i) External Modelling

This involved the identification of end users of the database and their specific information needs. It basically involved depicting the database system from the vantage points of individual user groups. Two approaches were considered at this stage (i) Functional approach and (ii) User view approach. The later approach was employed. From interviews with the staff in the different agencies, the potential users of the database were identified as all the technical staff at KENGEN, KETRACO, REA and Kenya Power. The major functions played by these agencies include: electricity generation, transmission and distribution. Figure 3.1 shows an External model of the Nakuru Electric Grid Database. It was created using Microsoft Visio 2013 and depicts the main agencies in the power sector with data views for the generation, transmission and distribution agencies.

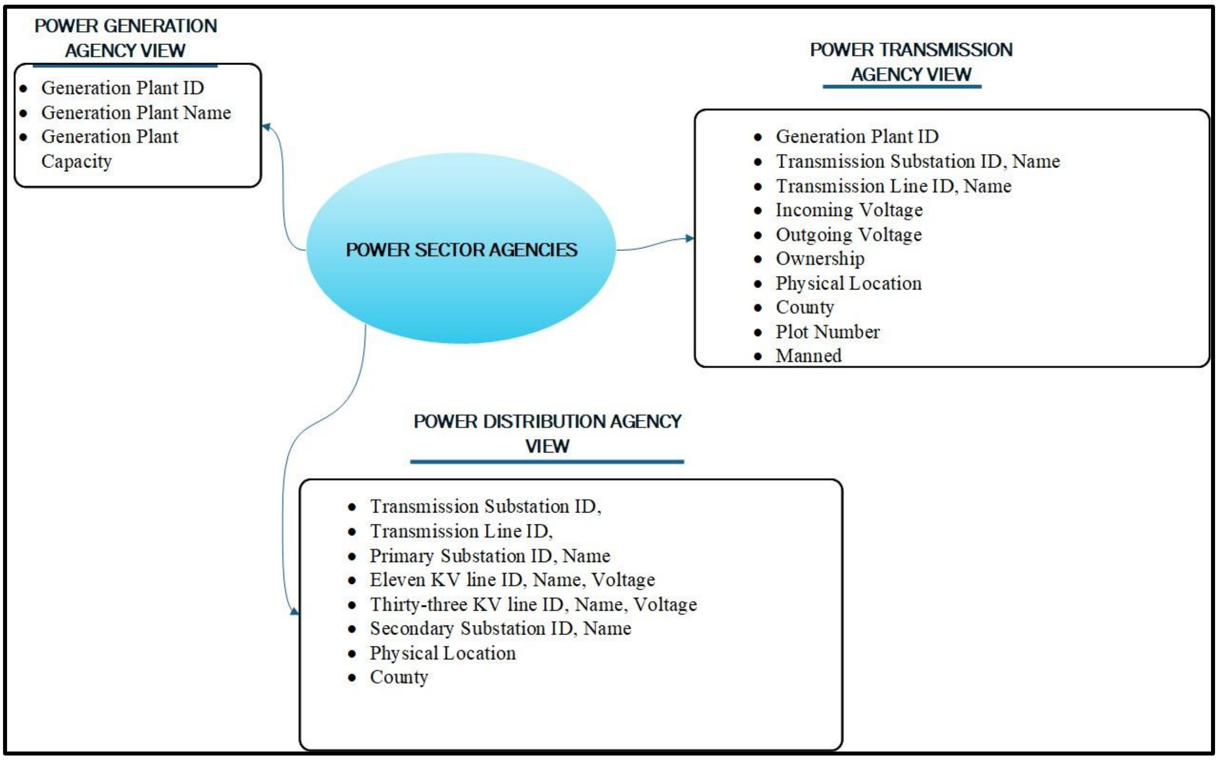


Figure 3.1 External Model of the Nakuru Electric Grid Database

ii) Conceptual Modelling

This is the most crucial aspect in designing a database since it produces an Entity-Relationship (E-R) diagram showing all the entities, their attributes, relationships and also cardinalities which express the range and scope of the relationships between entities. Figure 3.2 captures the Conceptual model of the Nakuru Electric Grid Database.

iii) Logical Modelling

This is the actual representation of the conceptual model. It results in a relation schema showing entities, attributes and highlights Primary keys (PK), Foreign Keys (FK), aliases and field data types. The logical model of the Nakuru Electric Grid Database is shown in Figure 3.3.

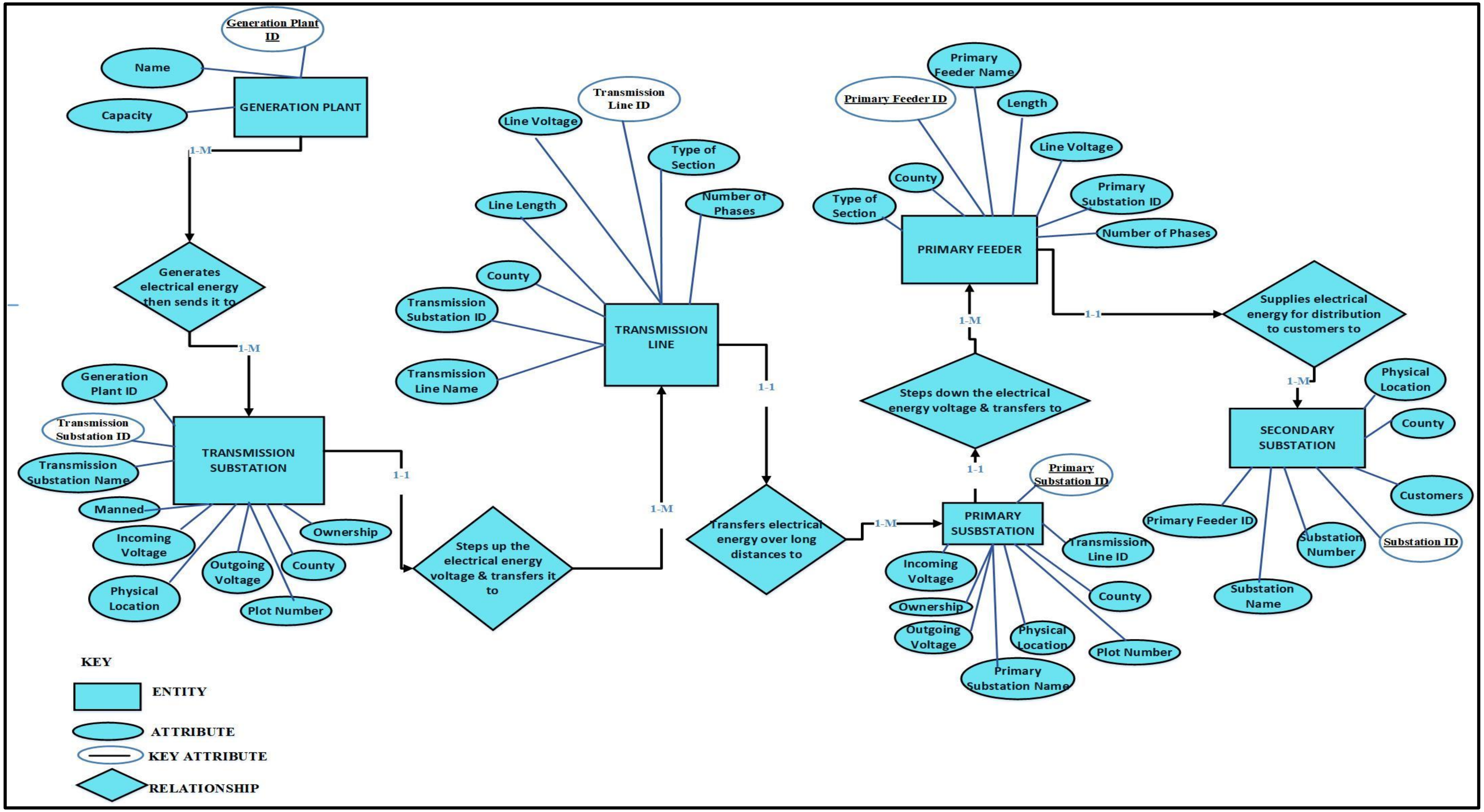


Figure 3.2 Conceptual Model of the Nakuru Electric Grid Database

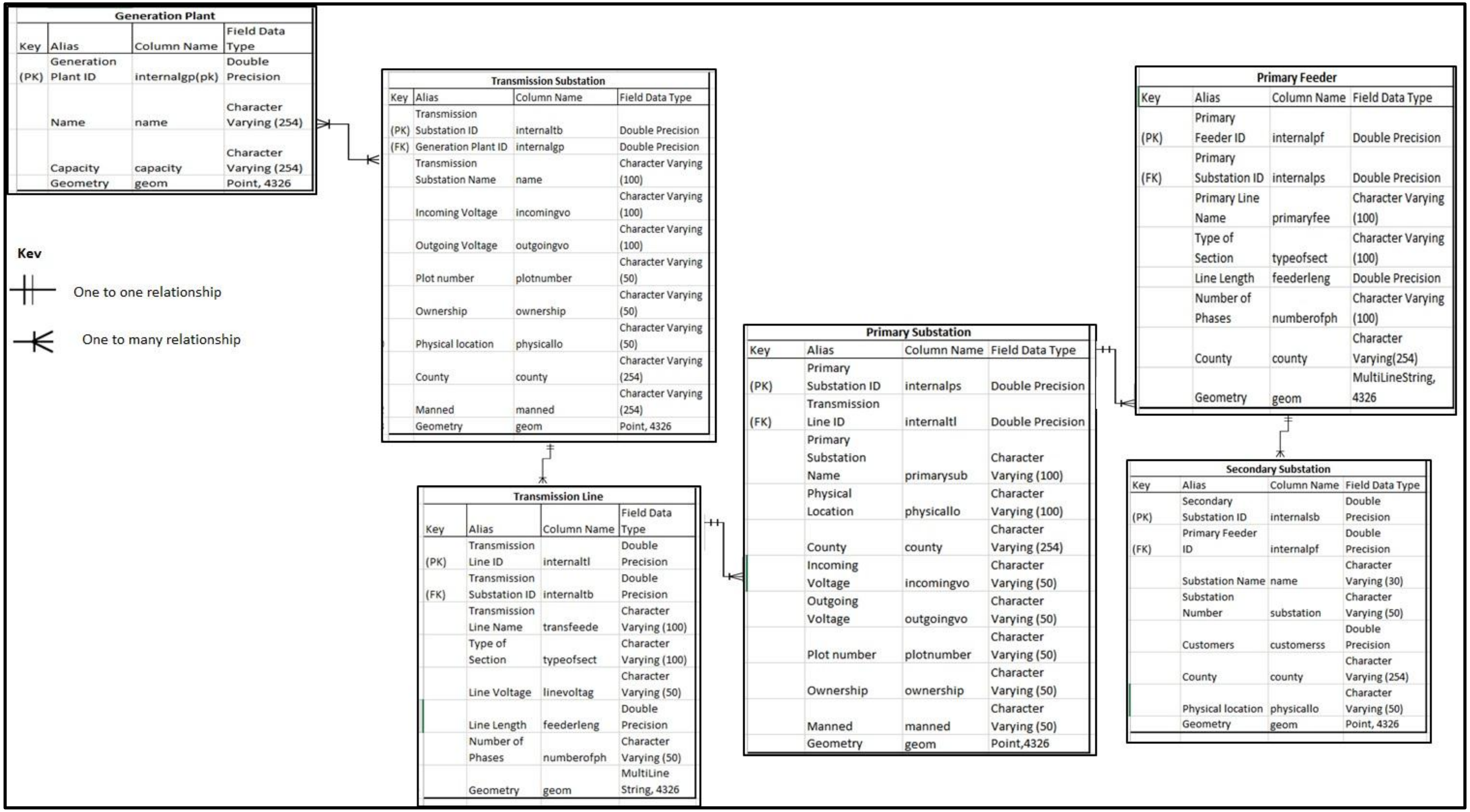


Figure 3.3 Logical Model of the Nakuru Electric Grid Database

3.2.3. Web GIS Development

The methodology described below was implemented in order to achieve specific objective 3 which is as follows: *To design the web-based GIS platform that will depict both spatial and multi-dimensional attribute data regarding the electrical infrastructure*. The following research questions enabled the achievement of this objective.

a) What is the goal of the web-based GIS?

b) Which web development framework will be used?

c) What content will be on the webpages?

Tools/Software/Programming Language

i) **Moqups**

This is a web based app that enables users to create wireframes with its extensive collection of templates, icons and stencils. The free version has a few limitations in functionality but for this project, this version was sufficient.

ii) HTML

HTML is a markup language used to create webpages and overall the interface of a website. It focuses on the text display.

iii) CSS

CSS also handles the interface of the website. It contains a variety of styles that are used to display the HTML elements such as images and videos. It is basically used to improve the appearance of webpages through colours, fonts, and positioning of various elements on a webpage.

iv) JavaScript

This is a programming language that adds interactivity to webpages and is particularly useful for a web GIS platform as it is used to script buttons for zoom controls, legend, drawing tools, and geocoding.

iv) Python 3.65

Python is a high level programming language developed by Guido Van Rossum. It was selected because it is easy to learn, its code readable and is popular in the GIS development world because it can be used to customize functions in GIS software such as ArcGIS and QGIS.

v) GeoDjango

Django version 1.11 which is a web development framework based on *python* was used to implement this project because it is freely available and suitable for projects of this magnitude. Geospatial Data Abstraction Library (GDAL) was installed within the GeoDjango environment and used to transform vector data into a variety of formats. This library also assists in coordinate system setting. Pyscopg2 which is a software package that enables the communication between python and PostgreSQL by converting python classes and variables into tables and fields in the PostgreSQL database was also installed in GeoDjango.

vi) PostgreSQL 9.4

An open source database with a spatial extension called PostGIS that was used to store the data for the project. It was connected to Geodjango.

v) Apache HTTP web server

This web server was used to host the web GIS application when it was deployed online.

The web GIS development comprised of blending GIS database design and website development. It was carried out in the following stages.

1. User Needs Assessment

The user needs assessment carried out above influenced the web GIS design. The findings assisted in narrowing down the goal of the web GIS and the expectations of the target audience.

2. Planning and Design

This stage involved outlining the Web GIS Interface design. A wireframe which is the skeletal representation of a website was created using moqups. The wireframe design included the drawing of the user interface which strived to enhance usability of the web GIS interface. Figure 3.4 shows the Web GIS Interface design.

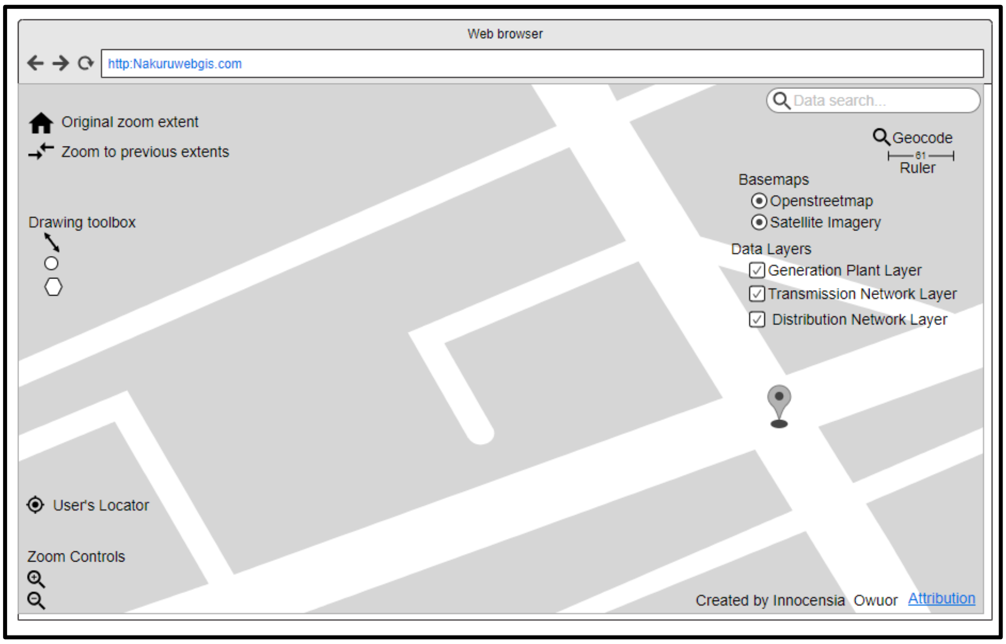


Figure 3.4 Web GIS Interface design

3. Content Writing

This Web GIS application did not require a lot of text on its webpages, therefore, only a few paragraphs of written content were needed to explain the essence of the web GIS application. Typography was considered here since the font styles affects the user interaction with the website. HTML was used to display the text.

4. Web GIS Development using GeoDjango Web Framework

Python's geographic web development framework known as GeoDjango was employed in building the Web GIS platform. It is based on the Model View Template (MVT) architecture. Models are blueprints that a developer uses to describe how they prefer to store their data in a database. For instance, for the Generation plant datasets, the fields for the attributes were specified using python classes and variables. View is the segment in the framework that receives a user requests on the web browser and then renders a HTTP response. HTTP responses can be HTML code or functions. Below are various stages for Web GIS development with the GeoDjango Framework.

a) Definition of Python Classes

The schema of the database that will store the electric infrastructure elements was implemented using Python classes. These classes were created for generation plants, transmission and distribution network elements that encompass this project as captured in the screenshots in Table 3.4. Each class contained variables, that is, attributes of the electric infrastructure elements. The variables were automatically converted to column names and Python class names into tables in the PostgreSQL using Psycopg2. The variables typically included the definition of data types such as characters, date, float, integer and geometry. The geometry variable described whether the class represented a point, multipoint, line, multiline, polygon or a multi-polygon feature. GDAL which is a python package that processes vector geospatial data formats, enabled the reading and writing of shapefile data format that was used to represent the electrical infrastructure in the GeoDjango environment. A python function was used to load the shapefiles into the PostgreSQL database.

Table 3.4 Python Classes

```python
class Generationplants(models.Model):
    name = models.CharField(max_length=254)
    internalgp = models.FloatField(null=True)
    capacity = models.FloatField()
    geom = models.PointField(srid=4326, null=True)

    def __unicode__(self):
        return self.name

    class Meta:
        verbose_name_plural =" Generationplants"
```

```python
class Counties(models.Model):
    name = models.CharField(max_length=6)
    shape_leng = models.FloatField()
    shape_area = models.FloatField()
    geom = models.MultiPolygonField(srid=4326)


    def __unicode__(self):
        return self.name

    class Meta:
        verbose_name_plural =" Counties"
```

```python
class Transmissionsubstations(models.Model):
    name = models.CharField(max_length=100)
    incomingvo = models.CharField(max_length=10)
    outgoingvo = models.CharField(max_length=100)
    county = models.CharField(max_length=254)
    internaltb = models.FloatField()
    internalgp = models.FloatField(null=True)
    ownership = models.CharField(max_length=50)
    physicallo = models.CharField(max_length=50)
    plotnumber = models.CharField(max_length=50)
    manned = models.CharField(max_length=50)
    geom = models.PointField(srid=4326, null=True)

    def __unicode__(self):
        return self.name

    class Meta:
        verbose_name_plural =" Transmissionsubstations"
```

```python
class Transmissionlines(models.Model):
    transfeede = models.CharField(max_length=100)
    internaltl = models.FloatField()
    county = models.CharField(max_length=254)
    typeofsect = models.CharField(max_length=100)
    feederleng = models.CharField(max_length=50)
    linevoltag = models.CharField(max_length=50)
    numberofph = models.CharField(max_length=50)
    geom = models.MultiLineStringField(srid=4326)

    def __unicode__(self):
        return self.transfeede

    class Meta:
        verbose_name_plural =" Transmissionlines"
```

```python
class Primarysubstations(models.Model):
    county = models.CharField(max_length=254)
    internalps = models.FloatField()
    primarysub = models.CharField(max_length=254)
    internaltl = models.FloatField(null=True)
    ownership = models.CharField(max_length=50)
    physicallo = models.CharField(max_length=100)
    incomingvo = models.CharField(max_length=50)
    outgoingvo = models.CharField(max_length=50)
    plotnumber = models.CharField(max_length=50)
    manned = models.CharField(max_length=50)
    geom = models.PointField(srid=4326, null=True)

    def __unicode__(self):
        return self.primarysub

    class Meta:
        verbose_name_plural =" Primarysubstations"
```

```python
class Secondarysubstations(models.Model):
    name = models.CharField(max_length=30)
    substation = models.CharField(max_length=50)
    internalpf = models.FloatField(null=True)
    county = models.CharField(max_length=254)
    internalsb = models.FloatField()
    customerss = models.FloatField()
    physicallo = models.CharField(max_length=50)
    geom = models.PointField(srid=4326, null=True)


    def __unicode__(self):
        return self.substation

    class Meta:
        verbose_name_plural =" Secondarysubstations"
```

<pre>class Elevenkvmvlines(models.Model):
    county = models.CharField(max_length=254)
    internalpf = models.FloatField()
    controlcen = models.CharField(max_length=100)
    internalps = models.FloatField(null=True)
    primaryfee = models.CharField(max_length=100)
    feederleng = models.FloatField()
    typeofsect = models.CharField(max_length=50)
    linevoltag = models.CharField(max_length=50)
    numberofph = models.CharField(max_length=100)
    geom = models.MultiLineStringField(srid=4326)
 	
    def __unicode__(self):
        return self.primaryfee
 	
    class Meta:
        verbose_name_plural =" Elevenkvmvlines"</pre>
	<pre>class Thirtythreekvmvlines(models.Model):
	    primaryfee = models.CharField(max_length=100)
	    internalps = models.FloatField(null=True)
	    county = models.CharField(max_length=254)
	    internalpf = models.FloatField()
	    typeofsect = models.CharField(max_length=100)
	    feederleng = models.FloatField()
	    numberofph = models.CharField(max_length=100)
	    linevoltag = models.CharField(max_length=50)
	    geom = models.MultiLineStringField(srid=4326)
	
	    def __unicode__(self):
	        return self.primaryfee
	
	    class Meta:
	        verbose_name_plural =" Thirtythreekvmvlines"</pre>

b) Processing of HTTP Requests

Views contain python functions (See Figure 3.5) that are parsed through HTTP requests. They receive user requests and render them to a user through HTTP responses. In this stage, python functions were used to convert the datasets to GeoJSON format which is popular with web developers because it can easily be sent and processed between a client and server. JavaScript Object Notation (JSON) is a text based data format. GeoJSON is a JSON format that also includes geometry data and is mostly used when displaying geospatial data on a web application interface. Conversion of shapefile data to GeoJSON is referred to as serializing which implies the conversion of the information in the python classes to other formats such as GeoJSON.

Python functions referencing HTML documents for the dashboard and web map in the Web GIS platform were also created. Lastly, a login/logout page function shown in Figure 3.6. The page was written in order to prompt a user to login once they locate the IP address of the application on a browser, this was done because of the data confidentiality and permissions restrictions. The users' login credentials were created within the GeDjango which has a built-in authentication system and users' details were stored in the PostgreSQL database.

```python
def DashboardView(request):
        return render(request, 'index.html', {})
@login_required
def HomePageView(request):
    return render(request, 'HomePageView.html', {})

def county_datasets(request):
    data = serialize('geojson', Counties.objects.all())
    return HttpResponse(data,content_type='json')

def elevenkvmvline_datasets(request):
    data = serialize('geojson', Elevenkvmvlines.objects.all())
    return HttpResponse(data,content_type='json')

def generationplant_datasets(request):
    data = serialize('geojson', Generationplants.objects.all())
    return HttpResponse(data,content_type='json')


def primarysubstation_datasets(request):
    data = serialize('geojson', Primarysubstations.objects.all())
    return HttpResponse(data,content_type='json')


def secondarysubstation_datasets(request):
    data = serialize('geojson', Secondarysubstations.objects.all())
    return HttpResponse(data,content_type='json')


def thirtythreekvmvline_datasets(request):
    data = serialize('geojson', Thirtythreekvmvlines.objects.all())
    return HttpResponse(data,content_type='json')


def transmissionline_datasets(request):
    data = serialize('geojson', Transmissionlines.objects.all())
    return HttpResponse(data,content_type='json')
```

Figure 3.5 Python Functions

```python
def user_login(request):
    args = {}
    args.update(csrf(request))
    if request.user.is_authenticated():
        return HttpResponseRedirect('/')
    if request.method == 'POST':

        username = request.POST.get('username')
        password = request.POST.get('password')

        user = authenticate(username=username, password=password)
        if user:
            if user.is_active:

                if user.is_staff:
                    login(request, user)
                    return HttpResponseRedirect('/admin/')
                else:

                    login(request, user)
                    return HttpResponseRedirect('/')
            else:
                #return HttpResponseRedirect(reverse("login"))
                messages.error(request, "Error")
        else:
            messages.error(request, "Invalid username and password.Try again!")
            return render_to_response('login.html', args)
    else:
        return render(request, 'login.html', {})

@login_required
def user_logout(request):
    logout(request)

    return HttpResponseRedirect('accounts/login/')
```

Figure 3.6 Python Login and Logout Page Function

c) Web GIS Interface Development

This entailed the use of HTML to create various elements that will host the map graphic in a webpage. The home page of the application with the login window was also created using HTML. CSS was used to improve the visual appearance of the webpages through the use of colours, different font styles and positioning different elements. To add the GeoJSON data to the webpages, JavaScript was used to load the datasets into the webpages. See Appendix A which shows how the Generation plant dataset was loaded into the GIS web application; this was repeated for the other datasets in this project. JavaScript functions were also scripted to enable the querying of the mapped features, zoom controls, geocoder, area and distance measuring and drawing tools.

vi) User Testing

This entailed ensuring the technical functions of the Web GIS platform worked as intended. Functionality such as toggling base maps, querying of features, zoom controls, feature identifier, geocoder, drawing and measuring tools were tested. A few users that were interviewed during the user needs assessment stage were invited to interact with the application.

vii) Deployment of the web GIS on the Internet

In the development stages described above, the web GIS application was only running on my personal computer. Deploying the application on the internet was important as it enabled the application to be accessible online. The web GIS application was deployed on the internet using a virtual server from Digital Ocean; a company that offers cloud computing infrastructure. A Virtual Private Server was bought and an Internet Protocol (IP) address for accessing it was assigned. The Apache Web server was installed in the virtual server to host the web GIS application. To match the environment that was used during development, PostgreSQL 9.4 used to store the project data, Python 3.65 and Django 1.11 which were used web GIS application development were also set up in the server. The data that was in the PostgreSQL database in the local machine was uploaded into the virtual server. The python documents with the functions, classes and the HTML were also uploaded into the server.

CHAPTER FOUR

4. Discussion and Analysis of Results

The web GIS interface is as shown in Figure 4.2 and it can be accessed from a web browser through http://167.99.203.86/ with the following login credentials.

Username: Dr@Musyoka

Password: 12345july

Due to data confidentiality and permission restrictions, a login page was created to ensure only users that have been granted data access rights could use the web GIS application. User Login credentials were created and stored in PostgreSQL. The login page is captured on Figure 4.1.

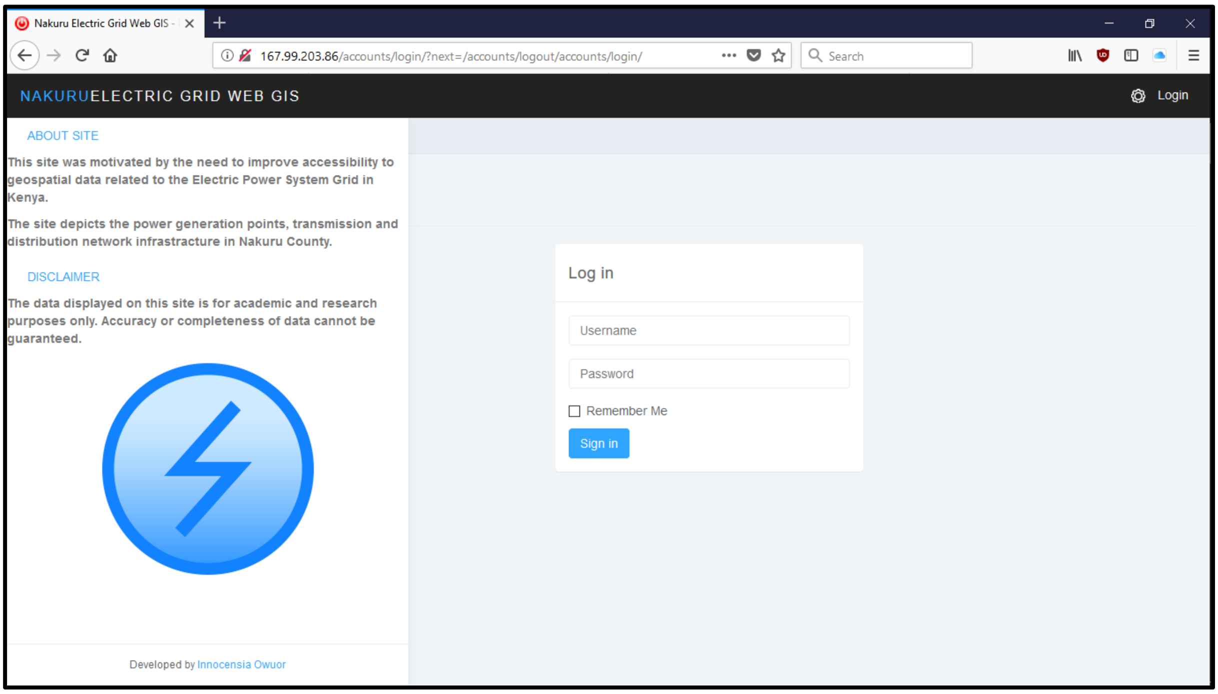


Figure 4.1 Login Page

The web GIS application is easy to use and enables users to search through datasets of interest, download datasets and print maps. It also has basic map controls for zooming in or out, distance and areas measurement tools, default and previous extent views, geocoding and drawing tools. This application makes GIS data accessible to users without the need of any GIS software or training and is also accessible through tablets and mobile phones.

The web GIS application features are discussed below:

4.1. Data Display

This display was characterized by the following:

a) Vector Overlays

The point, line and polygon features that were in GeoJSON format were loaded into the map portal using the JavaScript function which referenced the data that was stored in the PostgreSQL database with PostGIS extension.

Generation plants, Transmission substations, Primary substations and Secondary substations were all represented as point features using point markers of different colours whereas the Transmission lines, 33KV and 11KV medium voltage lines were represented by orange, blue and red lines respectively. The study area was delimited using a thick black line which represented the Nakuru County boundary.

b) Styling of Vector Layers

Different symbology schemes were applied during the development of this web GIS as the symbols and colours helped to distinguish between the features on the map.

For the point features, the point markers that are native to the Leaflet JavaScript library were used and to differentiate the point features, four colours were employed. These markers were in Portable Network Graphic (PNG) format and were loaded in the application using JavaScript. Green point marker represented generation plants, purple point marker depicted transmission substations, yellow point marker portrayed the primary substations and the cyan point markers showed the secondary substations (See Table 4.1).

Since the point features were so many, a marker cluster plugin was used to group the point markers so as to declutter the map and improve its overall visual appearance. The clustering of the points gets automatically disabled once a user zooms into the map and is therefore, able to distinctly see the individual point features.

The line and polygon features were represented using the Red, Green, and Blue (RGB) colour code classification based on the addition principle of Red, Green or Blue primary colours to create a variety of other colours. This colour classification provides a variety of colour combinations that a user can select. The polygon boundary was represented by black whereas the 33 KV and 11KV lines were represented by blue and red respectively. Transmission line was represented using an orange line (See Table 4.2).

Table 4.1 Point Features Legend

			
Generation Plant	Transmission Substation	Primary Substation	Secondary Substation

Table 4.2 Line Features Legend

11 KV Medium Voltage Line	33 KV Medium Voltage Line	Transmission Line

c) Switching Data Layers

The web GIS application enabled the filtering of the different datasets depending on the user's interest. Radio buttons provided a user with the ability to toggle between the various background maps. The options for base maps included: Open Street maps, CartoDB maps, World Imagery and Open Topo maps.

Checkboxes, on the other hand, enabled a user to switch On/Off the datasets displayed on the map. This is an important addition since users from different power sector agencies have different data interests and it is therefore important to enable filtering of data.

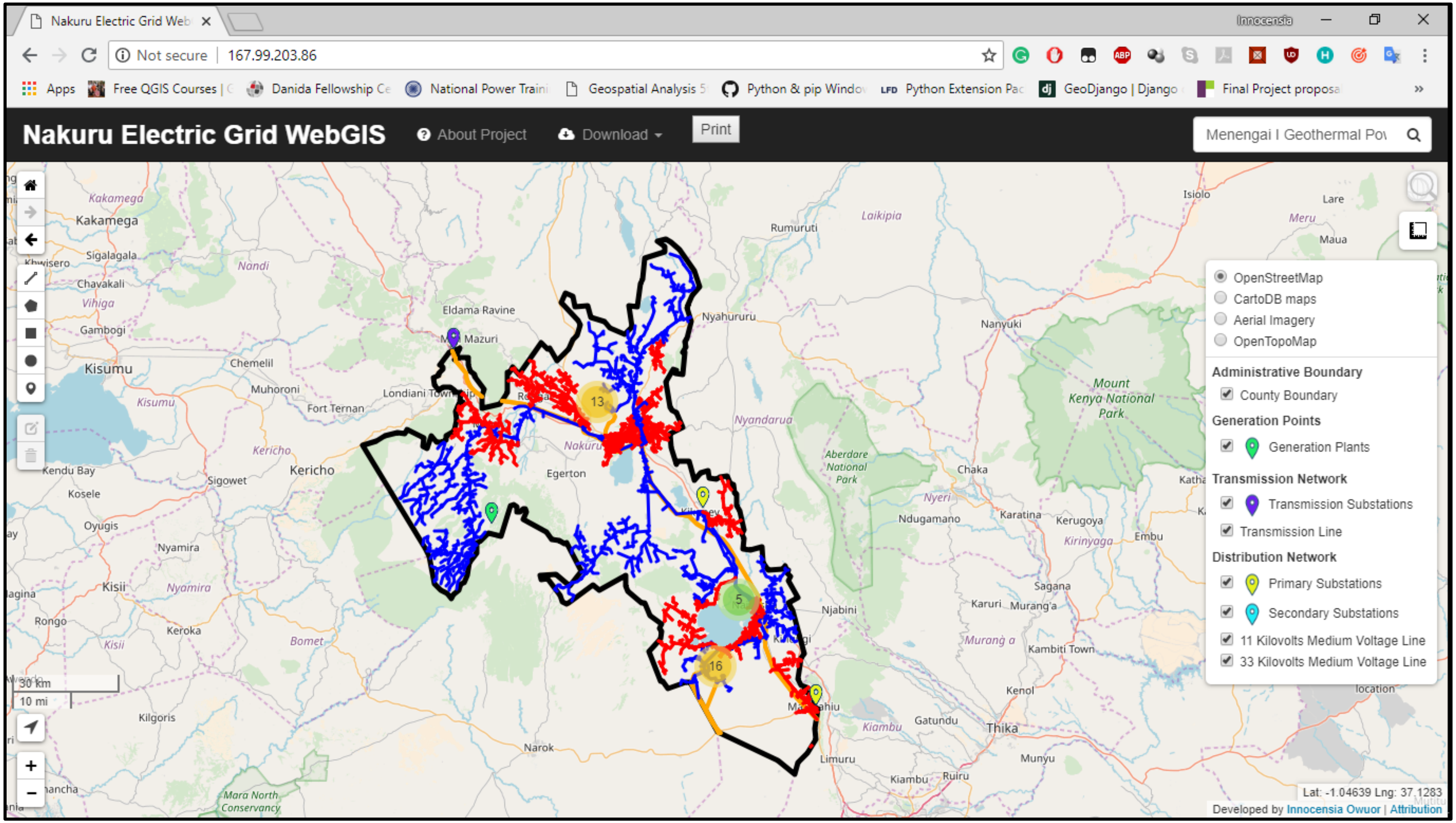


Figure 4.2 Web GIS User Interface

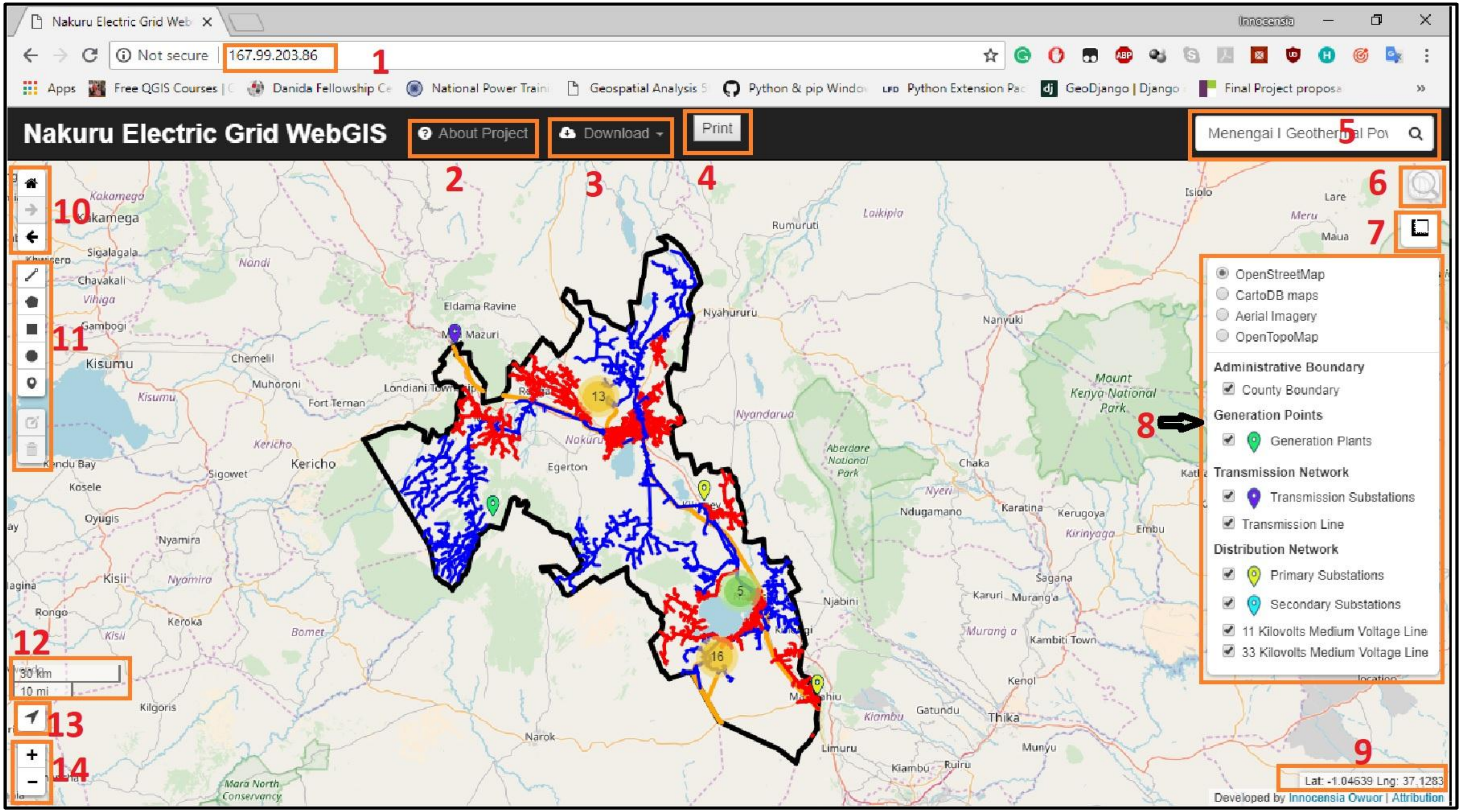


Figure 4.3 Web GIS User Interface Features

Figure 4.3 shows the web GIS application interface features. The features labelled 1-14 are described as follows. **1** indicates the IP address from which a user can access the web GIS application. The project is described on the tab labelled **2,** which recounts the programming languages that were used in the development of the web GIS application and lists the special functionalities enabled. Tab **3** enables a user to download the datasets displayed in the application whereas **4** allows a user to print what is displayed in the window. Data search is facilitated by the search box marked **5** and is equipped with an autocomplete feature that provides relevant suggestions as a user types in the search box for a particular entity. Geocoding and measuring tool are facilitated by the buttons marked **6** and **7** respectively. The widget labelled **8** contains checkboxes that enables a user to switch on/off an operational layer or base map. Label **9** shows coordinates as the user clicks or moves the mouse on different areas of the map. **10** enables a user to view the maps default extents and navigate between it and previous extents. The drawing tools are represented by the label **11, 12** is the scale which changes with the map's zoom level. The device Geolocator is represented by **13** and the zoom controls are marked by **14.**

4.2. Data Query

The platform provides functionality for searching through the displayed datasets to locate a particular entity. The search functionality is based on attribute data or coordinates, for instance, in order to locate an entity such as a generation plant, a user would enter its name on "Data search" search box or enter the coordinate of the entity in the geocoding button. The system is set up in such a manner that the entity of interest will be zoomed to and details about it popup on the screen in form of a table when the search is done using attributes.

The autocomplete feature is embedded in the search box and it provides relevant suggestions as a user types by displaying the suggestions in a list below the search box that a user can select.

Figure 4.4 depicts the search process for feature named "Menengai I Geothermal Power Station", with the autocomplete capability, the user only has to type the first few letters in the name of the entity and a list of all the entities with a similar name appears on the dropdown list, a user can then select the feature of interest and the location of the feature will be zoomed to and a popup showing attributes of the feature will appear as shown in Figure 4.5. See Appendix B for a list of attributes that can be used to query the other features on the application.

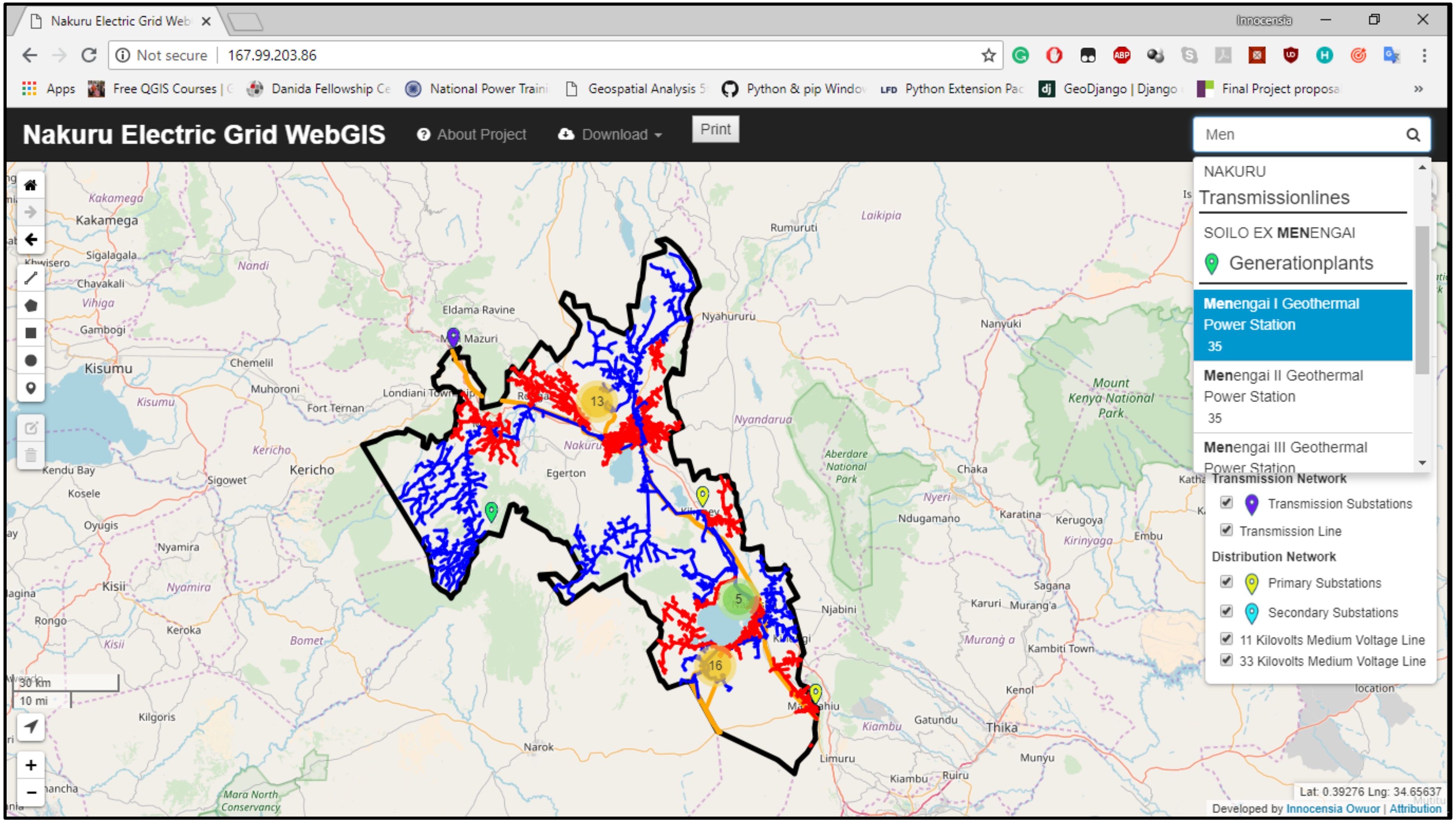


Figure 4.4 Data Query

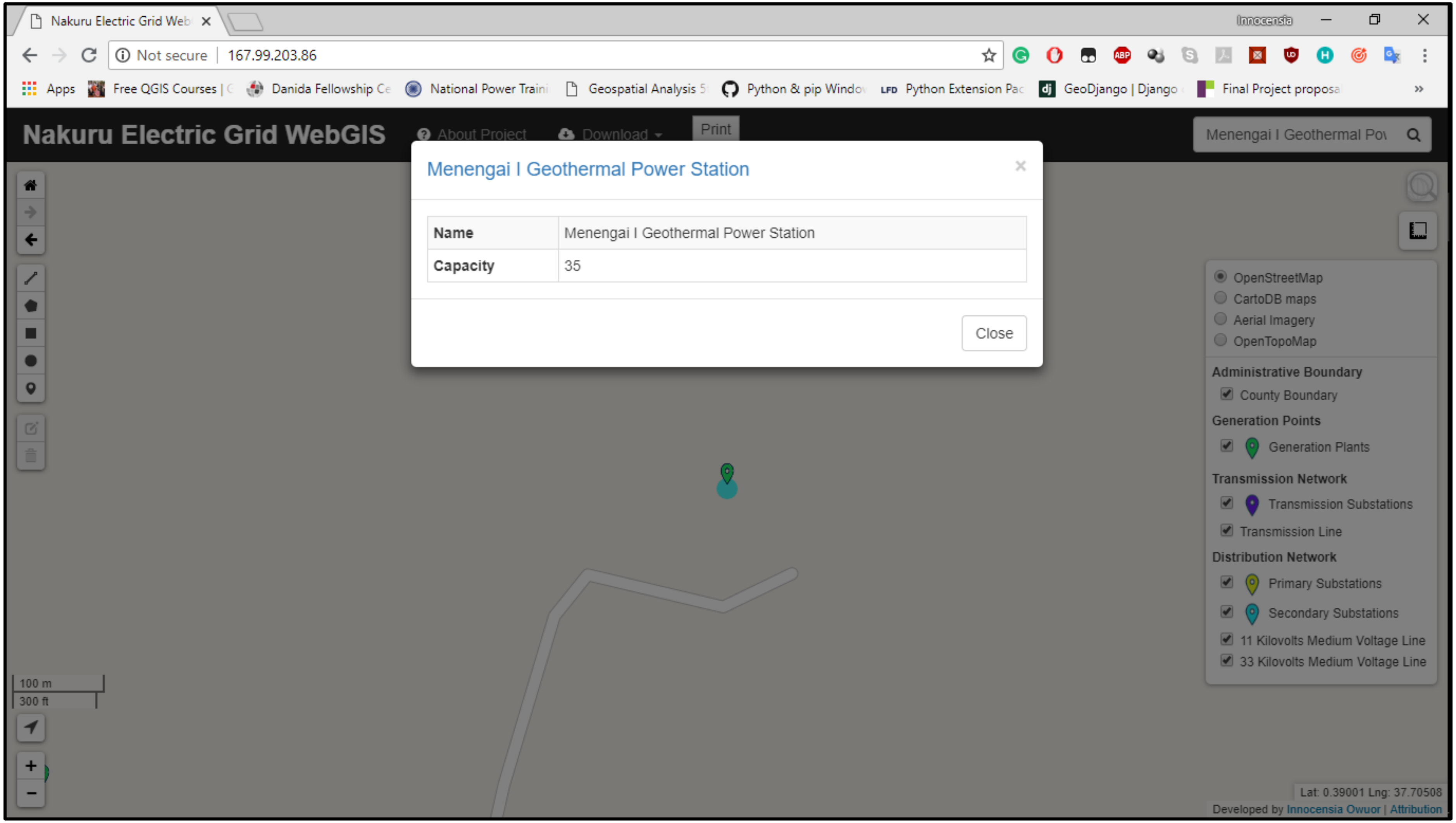


Figure 4.5 Data Query Results

4.3. Data Download

The other major aim of the web GIS platform is to enable access to the electric infrastructure data to the power sector agencies. The data download feature facilitates the acquisition of these datasets in GeoJSON format which can be opened in desktop GIS software such as QGIS and converted to a user's preferred format. Figure 4.6 shows the download tab and the datasets available for download.

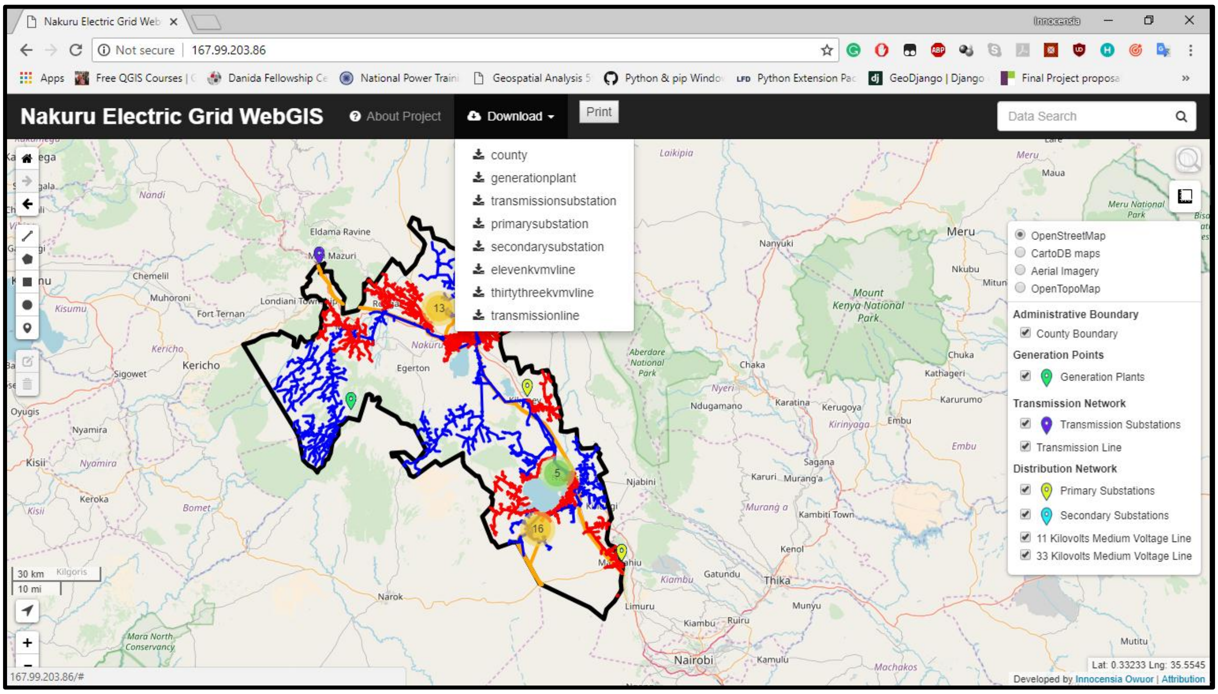
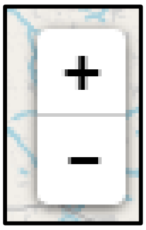


Figure 4.6 Data Download

4.4. Tools

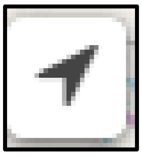
The application is also equipped with various map controls, which include:

a) Zoom Controls



This is for zooming in/out of the map depending on a user's detailed view preference. These controls enable a user to change their viewing perspectives by clicking on the + to zoom in or – to zoom out.

b) Geolocator

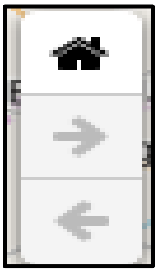


The user device locator, enables the application to locate the user's device location on the web map. This can be useful especially when trying to find different entities on the map and helps in understanding the orientation of the map. Since the connection between the web hosting server Apache and web browser is not secure, this control only works on the local host. Installation of a Secure Sockets Layer (SSL) certificate on the web server would have made the widget function after deploying the web GIS application online but this did not make much economic sense since this project is just for demonstration purposes and SSL certificates are expensive.

c) Geocoder

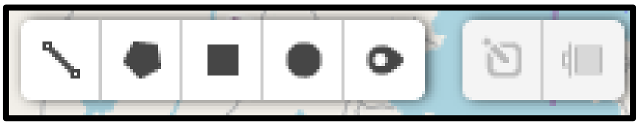
This enables a user to use place names or coordinates to search for places on the platform which is great for map orientation purposes.

d) Navigation Bar



The home button gives a user freedom to navigate between default zoom extents and previous zoom extents.

e) Drawing Tools

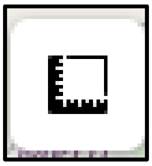


This is a plugin that enables a user to draw point, line or polygon geometries on the web map. These geometries can be deleted or saved on the application. It can be used to highlight an area of interest on the web map.

f) Get Map Coordinates

This functionality enables a user to get map coordinates as they move a mouse on the map. The feature aids in getting coordinates of the any place that is selected on the map. See label 9 in Figure 4.3.

g) Measure Tool



This tool provides functionality for measuring areas and distances using the metric system. Distances are particularly important in electric supply design schemes because entities such as secondary substations can only effectively supply power over certain distances.

h) Scale

This displays the scale in the user's view. The scale is both in the metric and imperial scale.

4.5. Map Printing

Map printing provides the capability to print maps showcasing data of interest to the user based on the window display. The maps can be saved in Portable Document Format (PDF) and printed as shown in Figure 4.7.

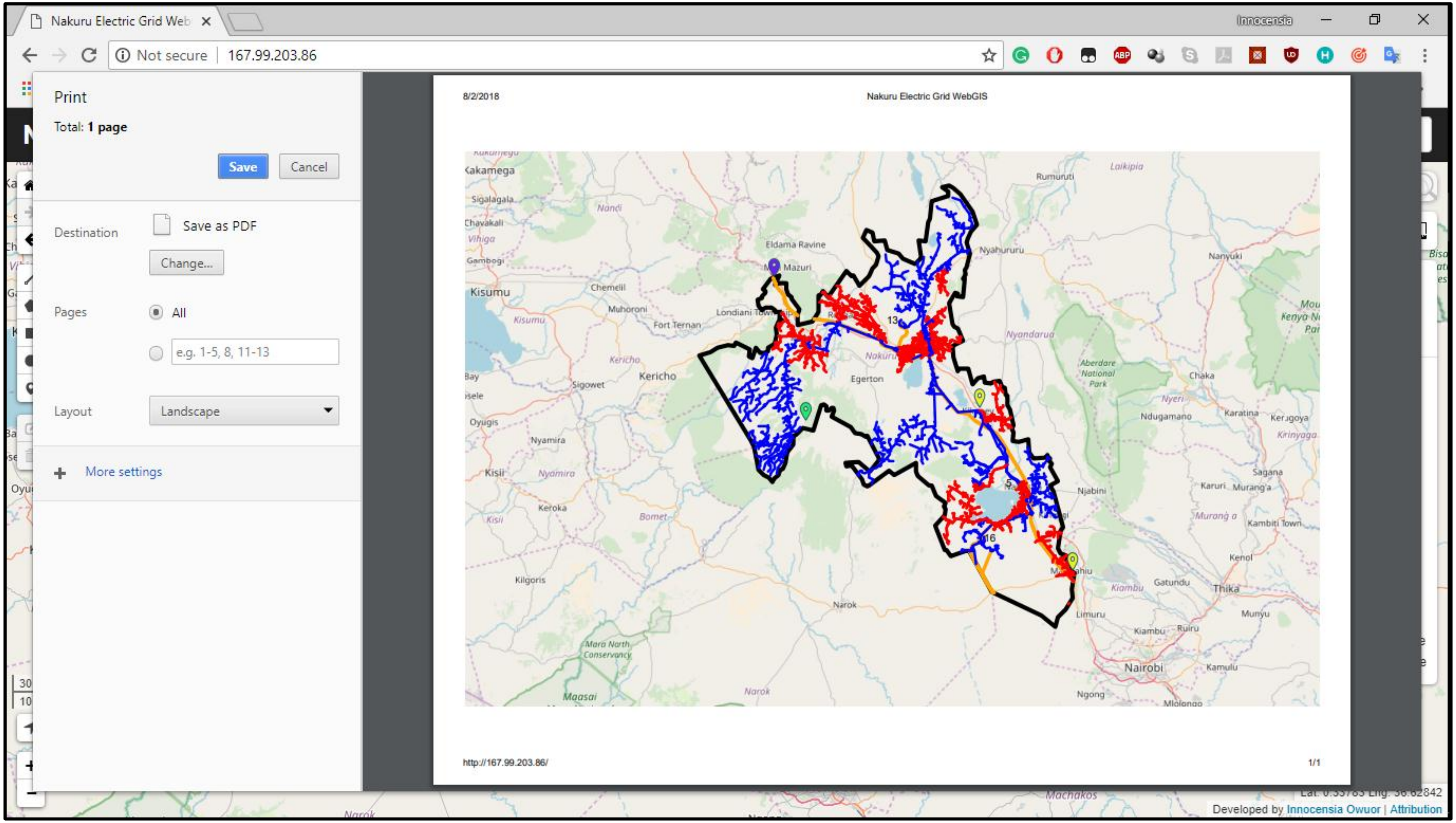


Figure 4.7 Map Printing

4.6. Data Update

The update of data in the application will be carried out by connecting to the PostGIS database on the server to QGIS which has a lot of data editing tools that can be used. Figure 4.8 and Figure 4.9 are screenshots showing the connection of the PostGIS database on QGIS. See Appendix C showing a map created using QGIS capturing the Nakuru Electric Power Grid map.

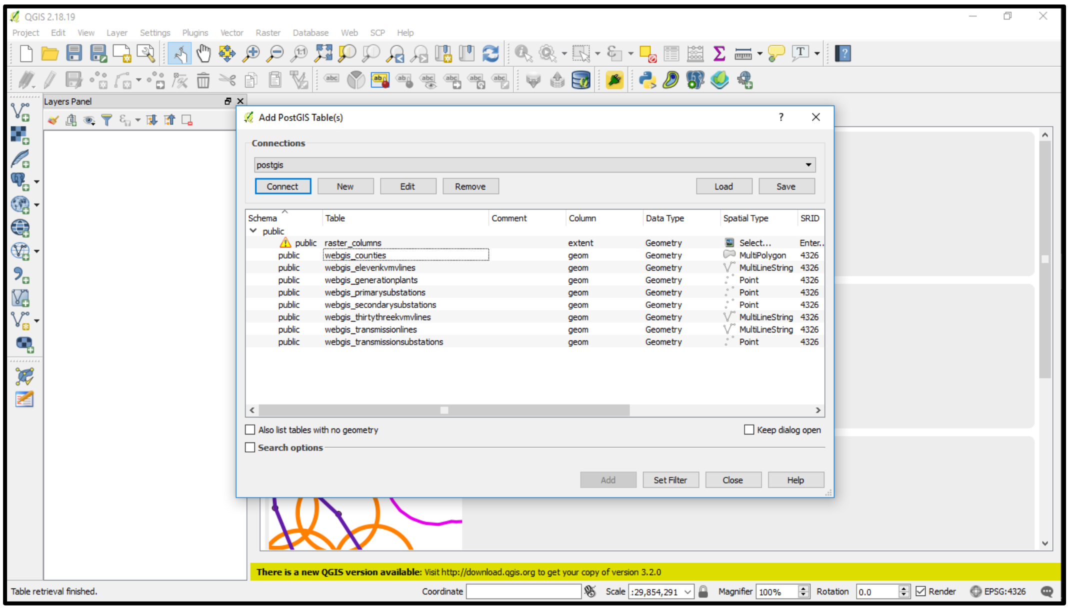


Figure 4.8 Connecting to the PostGIS database on QGIS

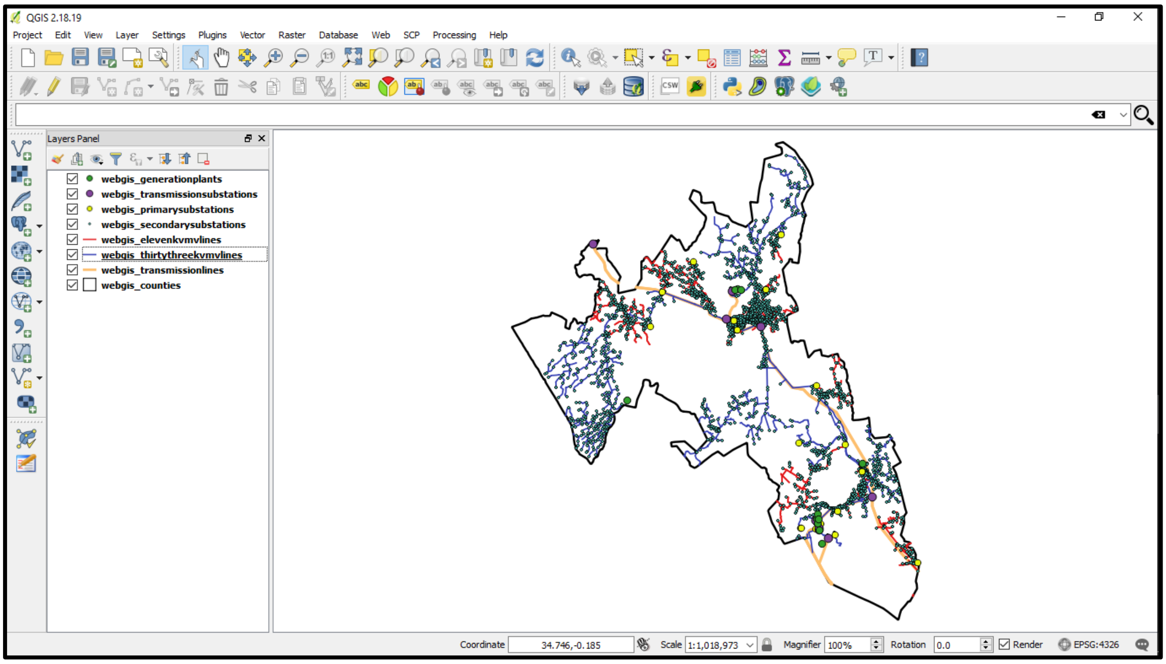


Figure 4.9 PostGIS database data displayed on QGIS

CHAPTER FIVE

5. Conclusions and Recommendations

5.1. Conclusions

The web GIS system provides a platform that is an avenue for accessing electric grid spatial data in Nakuru County provided a user has an internet connection. It facilitates the move from desktop GIS where decision support is provided at an individual level to group decision making support. This level of decision support is necessary for the Power sector players in the country who have intertwined responsibilities and are now making every effort to achieve universal access to electricity by the year 2030.

User needs assessment, Database design and Web GIS development facilitated the execution of this project. User needs assessment helped to consolidate user requirements and also informed the Database design. The Web GIS development involved using GeoDjango, JavaScript, HTML and CSS to create programs that enabled the application to display data, enable data download, data querying and map printing. Interactive features such as zoom controls, drawing tools, distance and area measuring tool, scale and geocoder are also available in the web GIS application.

Update of the infrastructure data is also possible through connecting the PostGIS database to QGIS software which exposes the application to more advanced desktop GIS data analysis, data editing and manipulation tools. Web GIS complements desktop GIS in that it facilitates GIS data access to a variety of users in different locations but a lot of geoprocessing functions are available in a desktop GIS.

Data accessibility and distribution facilitated by this web GIS application is critical especially because of the interrelation between power sector agencies in Kenya. It will help to minimize resources spent on data collection by each agency, manage the electric grid data for the whole sector in an organized manner and avail electric grid spatial data to users across the power sector agencies free from the bureaucratic procedures in the current status quo. This project therefore, acts as a prototype that will guide large-scale development of a web GIS application that includes the electric grid data for the whole country.

5.2. Recommendations

This study was restrained to a specific time period and this affected the number of functionalities that could be availed in the application even though the ones available are very valuable. Software was a huge component in this project and for large scale implementation of this project, software that have reliable support services should be considered. Improvements that can be considered in future related studies are below.

5.2.1. Software

1. Implement the application on proprietary software such as ArcGIS which comprises of the ArcMap, ArcGIS server, ArcGIS JavaScript API and ArcGIS online. Proprietary software provides better support services necessary for large scale projects and have functionality already built in the software thus make programming is easier.
2. Employ a JavaScript library such as Mapbox which has been around for a number of years and is more stable with rich source of plugins.

5.2.2. Functionality

1. Capabilities for spatial filters which are useful for querying data within a particular user drawn geometry. This can be useful when data such as population is included in the application to find the number of people living within a particular area of interest and the electrical infrastructure supplying them with power.
2. Enable users to overlay data from external sources on the platform. This can help in creating rich maps that meet the particular needs of a user.
3. Avail routing functionality that can assist users in locating entities of interest when they are on the ground. This functionality will be useful especially when power sector agency staff are inspecting the electrical infrastructure.
4. The date of installation attribute can be included in the datasets in order to enable spatio-temporal analysis that can help in analysing the rate of infrastructure development.

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APPENDICES

Appendix A: JavaScript Function for Loading Datasets onto the Web GIS application's Interface

```javascript
var generationplants = L.geoJson(null, {
  pointToLayer: function (feature, latlng) {
    return L.marker(latlng, {
      icon: L.icon({
        iconUrl: "static/img/genplant2.png",
        iconSize: [24, 28],
        iconAnchor: [12, 28],
        popupAnchor: [0, -25]
      }),
      title: feature.properties.name,
      riseOnHover: true
    });
  },
  onEachFeature: function (feature, layer) {
    if (feature.properties) {
      var content = "<table class='table table-striped table-bordered table-condensed'>" + "<tr><th>Name</th><td>" + feature.properties.name + "</td></tr>"+  "<table>";
      layer.on({
        click: function (e) {
          $("#feature-title").html(feature.properties.name);
          $("#feature-info").html(content);
          $("#featureModal").modal("show");
          highlight.clearLayers().addLayer(L.circleMarker([feature.geometry.coordinates[1], feature.geometry.coordinates[0]], highlightStyle));
        }
      });
      generationplantSearch.push({
        name: layer.feature.properties.name,
        capacity: layer.feature.properties.capacity,
        source: "Generationplants",
        id: L.stamp(layer),
        lat: layer.feature.geometry.coordinates[1],
        lng: layer.feature.geometry.coordinates[0]
      });
    }
  }
});
$.getJSON("http://167.99.203.86/generationplants_data", function (data) {
  generationplants.addData(data);
  map.addLayer(generationplantLayer);
});
```

Appendix B: Attributes for Data Querying

Generation Plant Name
Olkaria I Geothermal Power Station
Olkaria II Geothermal Power Station
Olkaria III Geothermal Power Station
Olkaria IV Geothermal Power Station
Olkaria V Geothermal Power Station
Akiira One Geothermal Power Station
Menengai I Geothermal Power Station
Menengai II Geothermal Power Station
Menengai III Geothermal Power Station
Biojoule Thermal Power Station
Baringo Thermal Power Station

Tranmission Substation Name
LANET SUBSTATION (132 / 11;33 KV)
NAIVASHA SUBSTATION (132 / 33 KV)
OLKARIA I (33 / 132 KV)
OLKARIA II (132 / 220 KV)
MAKUTANO 132/33 SUB STATION (132 / 33 KV)
NAKURU WEST (SOILO) SUBSTATION (132 / 33 KV)
MENENGAI (NONE / 132 KV)
OLKARIA 1AU 200KV (33 / 220 KV)
OLKARIA 4 11/ 200KV (11 / 220 KV)

Transmission Line Name
JUJA-LANET 132 LINE 2
JUJA-LANET 132 LINE 1
JUJA-LANET 132 LINE 1
JUJA-LANET 132 LINE 2
OLKARIA II-OLKARIA I 132KV
OLKARIA II-N/NORTH 220KV LINE2
OLKARIA II-N/NORTH 220KV LINE1
OLKARIA I-NAIVASHA 132 KV
LESSOS-LANET 1 132
LESSOS-LANET 2 132

Primary Substation Name
GILGIL (33 / 11 KV)
MARULA (33 / 11 KV)
DCK (33 / 11 KV)
SUBUKIA (33 / 11 KV)
NAKURU DEPOT (33 / 11 KV)
RONGAI (33 / 11 KV)
ELBURGON (33 / 11 KV)
MAI MAHIU 66/11 SUB STATION
MWARIKI 33/11KV (33 / 11 KV)
KIHOTO SUBSTATION (33 / 11 KV)
WELLHEAD 043 (NONE / 33 KV)
WELLHEAD037 (NONE / 33 KV)
WELLHEAD 914 (NONE / 33 KV)
EBURU GENERATION POWER
ORPOWER INC (220 / 220 KV)

33 KV Primary Feeder Name
GILGIL INTERCONN 33KV EX SUSWA
DCK NAROK 33KV EX SUSWA
NYAHURURU/MARALA L 33Kv L1
GILGIL /MARULA EX LANET
INTERCONNECTOR 1 EX LANET
LANET RONGAI ELBURGON 33K
RONGAI OLENGURUONE33K EX SOILO
KINANGOP FEEDER 33KV
K.P.C. STATION 33KV EX SOILO
EBURU MARULA 33KV LINE

11 KV Primary Feede Name
GAME PARK 11KV E MWARIKI
KIHOTO SOUTHLAKE 11KV
MOLO 11KV EX ELBURGON
KIRENGERO 11KV EX SUBUKIA
RACE TRACK 11KV EX MWARIKI
NORTH SHORE 11KV EX MARUL
GILGIL TOWN 11KV EX GILGI
CAMP EX LANET
MAILI SABA TOWNFEEDER EXBAHATI
NAKURU TOWN 11KV EX NAKURU
MENENGAI 11KV EX NAKURU
SATELITE EX MAGUMU
SOUTH LAKE SHORE 11KV EX
CAPTAIN 11KV EX OLKALOU

Secondary Substation Name
5399
5405
5414
5415
5425
5433
5443
5464
5465
5467
5472
5479
5481
5482
5484
5496
5497
5510
5512
5513
5514
5517

Appendix C: Nakuru County Electric Power Grid Map