Addis Ababa University
Addis Ababa Institute of Technology (AAiT)
School of Civil and Environmental Engineering

Least-cost path analysis and multi-criteria assessment for electric line access planning case study on Aba-Samuel Substation, ETHIOPIA

A Thesis in Geodesy and Geomatics Specialization in Geomatics

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Addis Ababa

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

Least-cost path analysis and multi-criteria assessment for electric line access planning case study on Aba-Samuel Substation, ETHIOPIA

Samson Demissie

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geodesy and Geomatics Specialization in Geomatics.

ADDIS ABABA UNIVERSITY ADDIS ABABA INSTITUTE OF TECHNOLOGY ADDIS ABABA, ETHIOPIA

May 2022

Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

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This is to certify that the thesis prepared by Samson Demissie Tulu, entitled:

"Least-cost path analysis and multi-criteria assessment for electric line access planning case study on Aba-Samuel Substation, ETHIOPIA"

and submitted in fulfillment of the requirements for the Degree of Master of Science in Geodesy and Geomatics with Specialization in Geomatics.

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Chair of Department of Graduate Program Coordinator.

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List of Acronyms

BPR – Business Processes Reengineering

DEM – Digital Elevation Model

EEU - Ethiopia Electric Utility

EEP - Ethiopia Electric Power

GERD – Great Ethiopian Renaissance Dam

GIS - Geographical Information system

GPS – Global Positioning System

GTP – Growth and Transformation Plan

GoE - Government of Ethiopia

LULC – Land Use Land Cover

LV – Low Voltage

MCA – Multi Criteria Assessment

MV – Medium Voltage

NEP - National Electrification Program

ODK – Open Data Kit

TIN - Triangular Irregular Network

Annexes

Factor’s map

Data collection forms in Xlsx format

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Abstract

In Ethiopia, the electric sector is already experiencing considerable rising in generation of power from renewable energy sources like the GERD. Large amounts of new generation are expected in the near-term future, which will require additional distribution planning to properly integrate these resources into the existing electric power supply system. The Distribution expansion planning has an important role in this environment to guarantee the security of the supply with the required levels of quality and price. Therefore, the realization of new distribution lines must be fast and accurate to avoid delays to connect new power sources and potential supply and reliability problems. In this sense, Geographical Information Systems (GIS) can be a powerful tool that provides decision support techniques, which enables a transparent, sustainable, faster and cheaper planning process for in power distribution systems. Manual approach electric line routing based on paper maps, aerial photographs and field visits can generate inconsistent results, besides being a time consuming and intensive labor activity. The application of methodologies based on geographic information system (GIS) combined with multi-criteria assessment (MCA) methods are applied for this study and have proved to be less time taking and cost savings on the electric line planning step. For this Aba-Samuel substation supply area is studied and lower length and lower total cost route is generated via densification and intensification analysis. For route selection, criteria's like proximity to road, land use land cover and household density are considered. ODK data collection method is used to collect primary data.

Keywords: Route selection, Multi-Criteria Decision Approach

CHAPTER ONE

INTRODUCTION

1.Introduction

Electricity after generation from sources like hydroelectric, geothermal, wind or solar power plants travels through a system called *grid*, to substations, transformers, and power lines to supply power to consumers. The electricity generated by power plants is conveyed to end users via power lines called transmission and distribution lines. High-voltage transmission lines, such as those hanging between tall metal poles, transport power to where customers need it over long distances. Transformers at substations step up or step down voltages to adjust to the different stages of the journey from the power plant on long-distance transmission lines to distribution circuits that carry electricity to homes and businesses(EIA, 2019).

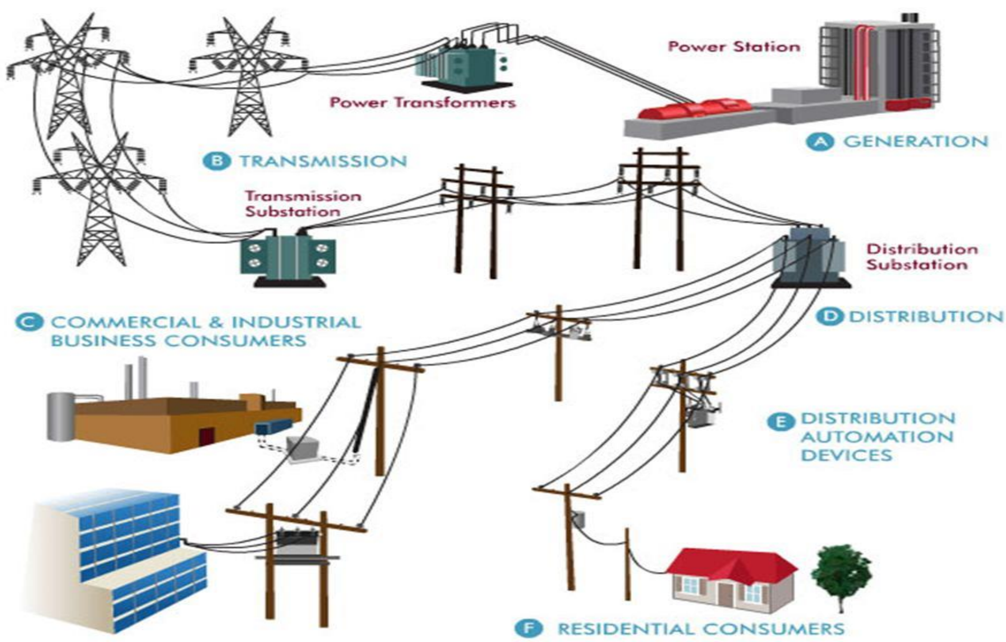


Figure 1 An electric network (Source: engineeringtutorial.com)

Spatial location of assets in utility management system is very crucial and necessity of the time to better visualize and represent the geographical context of a network. With the use of GIS positions of utilities assets can be exactly located and visualized with the help of maps(Foster & McDonald, 2000). Problems of planning in delivery system can be solved by using new methods and specific techniques like GIS because of necessity of accurate up-to-date information of the network. GIS lets utilities learn new things about their assets and possibilities, and enables technological, financial, and environmental variables to be evaluated simultaneously. GIS can have a broad spectrum of solutions encompassing the entire business value chain in the power supply market. Data can be analyzed across a number of spatial attributes, in addition to standard database queries.

With GIS network routing which determines the optimal path that has the shortest and the fastest distance and minimum cost can be generated.

1.1 Background

"In Ethiopia out of over 100 million people over 60 million have no access to electricity that makes the country the second highest energy access deficit in Africa. Currently, the on-grid access rate is about 20 percent and the off-grid access rate is about 10 percent." .

Out of over 350,000 registered customers who have been expecting for a connection for the past many years, of which, about 50,000 have already paid the full connection payment. Currently, it is estimated that of the 14.4 million unelectrified households, about 5 million live within connection-viable the immediate area of the grid network. (World Bank, 2018)

Although efforts are also being made to improve the implementation capability of the utilities implementation of electrification programs, the fast-paced growth of the sector infrastructure in the past decade created capacity challenges for Ethiopia electric power (EEP) and the Ethiopian electric utility (EEU). To tackle this, Indian Power Grid Corporation a management contractor was haired for two years. However, significant improvements were not observed due to the limited scope of the engagement of this corporation being engaged to and with limited higher officials. Capacity constraints of the utilities technical staff has hampered planning of access expansion in the country, as the utilities lack coordinated technical and planning functions like least-cost, nationwide connections rollout program, efficient workflow and supply chain networks, and efficient commercial processes that can support electrification. Many efforts are now under way to address internal organizational and operational issues like complete overhaul of the systems and tools; business process reengineering (BPR); separation of financial accounts; upgrading the billing, accounting, and related management systems; and so on. In the future, the GoE plans to continue the process of internal reform and capacity development of the utilities.

With GTP-II, the GoE's focus is on last-mile connectivity and not just infrastructure growth.(MWIE, 2019) The GoE recognizes the need to focus on connecting households and has put strong emphasis on the rapid scale-up of electricity connections, particularly in areas that are already within the immediate and short-term reach of the network. Under the new leadership and institutional arrangements of the electricity sector, rolling out household connections has become a high priority. The GoE considers on-grid electrification to be a high-impact, low-hanging fruit, which can significantly improve service delivery (World Bank, 2018).

To implement this in November 2017, the Government of Ethiopia launched the National Electrification Program (NEP), that represents the action plan for achieving universal electricity access nationwide by 2025, in a strategic and all-inclusive as well as efficient and transparent manner, for the benefit of all its citizens by 2025. 65 percent of access provision is targeted with grid solutions and 35 percent with off-grid technologies (solar off-grid and mini-grids).

1.2 Problem Statement and Justification

Ethiopia has vast and largely unharnessed clean energy resources, with massive potential for hydro, solar, wind, and geothermal power. The available generation capacity of the country, mostly based on hydropower, has reached 4,256 MW. Other large-scale hydropower project known as Great Ethiopian Renascence Dam (GERD) with capacity exceeding 6,000 MW is now under construction (World Bank, 2018).

Despite major strides in the past decade, Ethiopia's electricity sector continues to fall short of the promise of effective service delivery, with the second highest energy access deficit in Africa (over 60 million people without access). Currently, the on-grid access rate is about 20 percent and the off-grid access rate is about 10 percent (World Bank, 2018). The last-mile connections have not kept pace with infrastructure expansion due to lack of financial resources and inadequate utility capacity, posing a binding constraint to economic growth and social development.

Access expansion has lagged for several reasons, including the absence of a least-cost, nationwide, and comprehensive connections rollout program. In addition, there is a severe lack of dedicated resources to provide electricity access to all households, economic centers, schools, and health centers. There are also capacity limitations at the utility level in planning for access expansion and handling a growing customer base. As indicated on the National Electrification Program (NEP) household connections is a high priority; it is also efficient to reach low-hanging fruit to be reaped in close proximity to the network, given that Ethiopia now has enough generation capacity to support national access expansion to complement its regional goals.

According to world bank international development association program appraisal document report no: 119032-et, there are over 350,000 registered customers who have been waiting for a connection. It is also estimated that of the 14.4 million unelectrified households, about 5 million live within connection-viable vicinity of the grid network (World Bank, 2018). Planning access of electricity for this huge number of people with generation capacity growing so fast requires use of modern technology and techniques.

More over according to this world bank document, capacity constraints of the utilities technical staff and lack of coordinated technical and planning functions like least-cost, nationwide connections rollout program has hampered planning of access expansion in the utilities.

This study therefore aimed to develop a framework that allows for efficient electrification planning and provides, useful insights into identifying this densification and expansion sites through geospatial least cost path analysis and Multicriteria assessment technique.

For this a small substation called Abasamuel is chosen, because it fits for accomplishment of this research's objective due to rural nature of the service delivery area of this substation. Rural service delivery area is preferred because About 96 percent of urban households are connected to the grid (including 99.9 percent in Addis Ababa), while only 27 percent of rural households have access to electricity services(MWIE, 2019).

The size of the network and its proximity to Addis Ababa made this substation ideal for the intended study.

1.3 Research Objectives

1.3.1 General Objective

To develop a prototype for MV electric densification and expansion network planning.

1.3.2 Specific Objective

1. Study the existing electric asset management system and network planning.
2. Design and develop MV Data collection form.
3. Identifying households that could be connected to the existing grid via densification and expansion around Abasamuel substation.

1.4 Research Questions

The following research questions are to be answered to achieve specific objectives of the research.

- What type of technology can be used to better facilitate Medium voltage network planning for densification and exapansion of electric access.
- How will the data sets be collected, compiled ,What type of databases and spatial units must be included in the MV electric database and how will it be structured?
- What are the different data attributes and respective GIS representations of each essential database created for MV electric?

1.5. Significance of the Study

The research is significant especially for Ethiopia electric utility sector. If implemented our society that lived long with electricity access deficiency will see light. And also, there are stakeholders of the utility sector like MoWE that could benefit from proper electric access planning. Proper access planning also means getting out of energy deficiency which could lead to more energy export, which could benefit the government in remittance. The study also has some scientific contributions to the current access planning and electric line data collection.

1.6. Scope of The Study

This study only considered feeders from Aba Samuel substation and its supply area. The households considered are also within the vicinity of this substation.

1.7 Limitations of The Study

The study is limited to only geospatial concepts and methodology to plan new densification expansion networks. After the network is planned in the geospatial platform other study should be conducted on substation and transformer capacity to decide if upgrading is required or not by electrical experts before implementation.

1.8. Organization of The Thesis

This thesis is organized in a precise way that shows the sequential steps in electrical concepts and electrification plans of the country. Chapter two is all about the pertinent literature regarding the previous works related to the title of the research and all the methodologies and the utilities considered for the achievement of the result of the study was discussed in the chapter three of the study. Chapters four and five are about the data analysis and conclusion and recommendation respectively.

CHAPTER TWO

2.LITERATURE REVIEW

2.1 Electric Densification And Expansion

Modern energy facilities are vital to the well-being of humans and the economic development of a nation. For the provision of clean water, sanitation and healthcare, and for the provision of safe and efficient lighting, heating, cooking, mechanical power, transport and telecommunications services, access to modern energy is essential.

According to International Energy Agency (IEA) modern energy access includes

- *Household access to a minimum level of electricity.*
- *Household access to safer and more sustainable (i.e. minimum harmful effects on health and the environment as possible) cooking and heating fuels and stoves.*
- *Access to modern energy that enables productive economic activity, e.g. mechanical power for agriculture, textile and other industries.*
- *Access to modern energy for public services, e.g. electricity for health facilities, schools and street lighting.(IEA, 2020)*

Access to electricity provided to a household is classified as on-grid if it is provided via a local network link (or grid extension) connected to a national transmission network. Usually, grids obtain their power from power plants such as hydro dams or nuclear power plants. Whereas mini-grids established for areas not served by main grids. They are localized power networks, usually without infrastructure to transmit electricity beyond their service area(Henderson et al., 2017).

In addition, electricity access can be provided through stand-alone systems. These are systems that are not connected to a grid and typically power single households.

The GoE is planning through NEP 2.0 program to reach to 6 million household by the year 2030(MWIE, 2019).For this creating connections to households that are near the existing network infrastructure or densification is one of the approaches according to (MWIE, 2019). This are households within 1km of existing MV network and transformer. Reaching out these households only require usually low voltage network-related equipment’s, such as service drops, household metering, and possibly shared pole top transformers

The other power reach mechanism is through expansion which is reaching out to households ranging from 2.5 and 25 km from the existing grid. The GoE plans to serve 8 million households by the year 2030 through its NEP 2.0 program. These households are situated farther away from the existing infrastructure and will therefore involve MV lines construction (MWIE, 2019).

2.2 Electric Network Planning

Routing is the initial stage of the planning process of electrical lines, where the designer decides the best areas to cross, considering existing restrictions. Therefore, According to (Lima et al., 2016) the finest route is the simplest one, with as few of deflection angles as possible, because changes in direction require sturdier structures to support additional loads. And also, this study recommends, the designer should consider other aspects as compensation costs, environmental and social issues, obstacles as bridges, rivers, lakes, urban areas and so on, when defining an optimum route.

This process can be defined as an optimization problem wherein the main objective is to minimize installation and maintenance costs, influenced by strictly technical and geographically depending aspects as accessibility, environment, terrain complexity like slope and relief, geotechnical characteristics of soil, land use like urban areas, forests, agricultural areas etc.(Lima et al., 2016a).

2.2.1 Electric Network Planning Factors

(Monteiro et al., 2005) articulates, computerized line design has been an active study field recently, but most of the efforts have been made in the detailed sizing of all the elements of the new power line, and only a few references include approaches based on realistic line routing. In early published works, geographic information systems (GIS) were identified as the proper computer platform to develop automated routing of underground residential distribution systems. Route selection was based on GIS geographic data manipulation capacity and took in account the essential geographic characteristics of the routing problem, although human designers had to interact with computer systems in order to generate and explore alternative options in the routing process.

Planning of electric route using GIS can consider any number of factors simultaneously in order to determine the shortest route.

Main factors in different studies were roads, land cover, household positions, and slope. Other considerations include rivers (where no access across is possible), environmentally sensitive areas, historical monuments.

A. *Roads*

(Barnard, 2008) suggests road centerline and 2 m on either side and gave maximum rating so as to avoid the planned route running on the road itself. From the estimated road edge to 100 m from the road should be allocated a zero rating as this would be the optimal place in which to build the network.

This study considered road rating considering accessibility for faults, maintenance, line clearing and inspections. Between 100 and 500 m was given a suitability rating of ten as it is still a viable option to build in such proximity, and over 500 m from the road centerline as maximum rating was given.

B. Land cover

Environmentally sensitive areas such as forests, wetlands and other water bodies must be avoided (Barnard, 2008) so this study allocated a suitability rating of 100. To improved grassland allocated nil points as being an optimal area in which to site networks. Ten points allocated to unimproved grassland, degraded, cultivated and urban areas. Thicket, shrubland, barren rock and dongas allocated 20 points due to construction and clearing costs.

C. Households source - *(Barnard, 2008)*

Household (or grouping of houses that would require one connection point) defined by a point; and a radius of 10 m (Barnard, 2008) used by this study to simulate the outer boundary of those households. Points of 100 for inner area allocated to the study so as to avoid running the network through households.

D. Slope

(Barnard, 2008) used DEM (digital elevation model) 20 m point data to create a TIN (triangular irregular network) for each study site. A TIN interpolates DEM height data to create a generalized model which emulates the actual physiology of the ground. The TIN then used to create a slope dataset.

In this study (Barnard, 2008) factors in raster layer format were added together to get suitability ratings for each raster cell ranging.

A cost weighted distance raster used to determine value for each cell that relates to the smallest accumulated cost of moving from each cell with reference to a source point. In most cases the nearest transformer on an existing network was used. A combined suitability raster was used to create a cost weighted distance raster radiating out from the nearest source point on a network.

Weighted distance raster was used to determine the shortest path from the source point to the nearest electrification areas. To determine the sphere of 'influence' of a point (house, transformer) Voronoi polygons were used.

An area calculation and household count for each polygon, then the area was divided by the number of households to get an average area. Future rural electrification areas were created by dissolving all Voronoi polygons with an area calculation less than 3,3 hectares.

2.3 GIS In Electrification and Network Planning

GIS technology in the electric utility sector lets for frequent revising and checking. Mapping of the Electrical Network and Customer Database helps in the way of better consumption management, loss reduction, better fee collection, asset and work management and possibly better customer satisfaction.(Nawaz-ul-huda et al., 2012)

In different countries Selection, prioritization, and design of electric path broadly conveyed on political meddling instead of technology facilitated improved and efficient procedures.

Which led to executive influenced network construction which in turn led to overworked networks and wastage in time and money as when priorities change, tasks often need to be deplaned due to changes on standing networks, and within areas on the ground.

Other than mentioned above political interference problem, network planners manual work, using maps and aerial photographs in order to find the optimal routes for network extensions was a challenge(Barnard, 2008).

According to (Rai & Singh, 2016) ,Robust methodologies that combine conventional data conversion techniques with sophisticated project management frameworks to enable efficient workflow management and quality control are necessary to build large-scale electrical network geodatabases. In the generation and transmission fields, technical development is taking place much quicker. Developing countries several power utilities are continuing with old conventional manual systems in the distribution sector where asset maps are not properly updated, the customer bills and related data is inaccurate and the details of network assets and facilities are unavailable and not in an appropriate format so that its proper management are very difficult to the electrical department(Rai & Singh, 2016).

According to (Rai & Singh, 2016) ,many companies and electrical departments could use GIS techniques for asset mapping and consumer indexing, which describe the definition, specifications of the systems and the varied application of this tool in asset management, load prediction, management of delivery systems and customer service, etc. Usage of GIS can simplify easily modified and scalable network databases for tracking needs and ensuring stable quality power supply, efficient Metering, billing and collections, thorough energy audit, recognition of theft and reduction of losses in transmission and distribution. Ultimately, all these steps would advance the overall internal impact and further promote the attainment of commercial viability.

This study's (cited above) showed GIS can be used to priorities' future projects more fairly. Where there are known capacity or reliability issues, GIS could also be used to identify areas of electricity theft, misuse of electricity and renewable energy alternatives in order to source additional supply and continue with the electrification program. Planning network paths using GIS can also result in savings as optimal paths are designed according to a set of agreed criteria from all parties.

2.4 Spatial Multi Criteria Decision Making

Multi criteria decision making techniques can be implemented in various approaches of decision analysis. These methods include clear declarations of decision-makers' expectations. Different quantities, weighting schemes, constraints, goals, utilities, and other parameters reflect certain preferences. Via formal review of alternative alternatives, their features, assessment requirements, goals or objectives, and limitations, they evaluate and facilitate decision-making.(Massam, 1988)

Extension of MCDM ,The spatial multi criteria decision making(SMCDM) is a process that transforms and combines geographical data (map criteria) and value judgments (decision-makers' preferences and uncertainties) to obtain appropriate and useful information for decision making.(Afshari, 2014)

spatial multi criteria decision making have two major consideration components, one is GIS component which deals with from data collection to analysis the other component deals with MCDM which is about aggregation of GIS data to the decision makers preference.

2.5 Analytical Hierarchy Process and Pair Wise Comparison

The Analytical hierarchy process(AHP) is a multiple criteria decision-making tool, which can be used to measure the relative dominance or preference of elements related to a main objective.(Saaty, 1980)

AHP is a comprehensive, logical and structural framework, which allows improving the understanding of complex decisions by decomposing the problem in a hierarchical structure.

In MCDM, AHP is commonly used to assess weights for a set of parameters according to significance. This not only helps decision makers by empowering them to organize uncertainty and exercise judgment, but also enables them to integrate both objective and subjective aspects into the decision-making process.(Al-shalabi et al., 2006)

The incorporation of all relevant decision criteria and their pair-wise comparison allows the decision maker to determine the trade-offs among objectives.

In the context of the Analytical Hierarchy Process (AHP), the system of pair-wise comparisons, also introduced by Saaty (1980), includes pair-wise comparisons to construct a ratio matrix. It takes the parameters' pair-wise comparisons as input and generates their relative weights as output.

2.6 Review on Clustering

Clustering is the process of grouping a set of objects in such a way that objects in the same group are more similar in some particular manner to each other than to those in other groups. It is used in many areas of research like data mining, statistical data analysis, machine learning, pattern recognition, image analysis and information retrieval.(Kumar & Verma, 2018)

Clustering involves data collection, data cleaning, clustering Strategy (choice of clustering algorithm and initial parameters) validation and finally interpretation of results.

The most common types of clustering are:

- Hierarchical clustering - based on the idea of objects being more related to nearby objects than to objects farther away.
- Partitional clustering - algorithms separate the data points into number of different partitions.
- Centroid-based clustering – clusters are represented by a central vector. Eg K-means clustering

  K-means partitions the data space into a structure known as a Voronoi diagram and conceptually close to nearest neighbor classification.

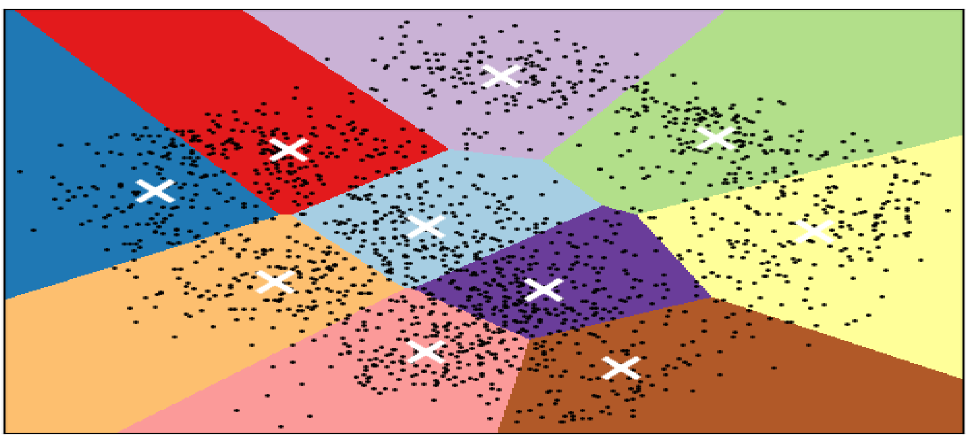


Figure 2 K -mean clustering (source - https://scikit-learn.org)

- Distribution based clustering - clusters objects belonging most likely to the same distribution based on statistics.
- Density-based clustering- clusters are defined as areas of higher density. Eg DBSCAN clustering

  On DBSCAN ,given a set of points in some space, it groups together points that are closely packed together (points with many nearby neighbors), marking as outliers points that lie alone in low-density regions (whose nearest neighbors are too far away).(Saxena et al., 2017)

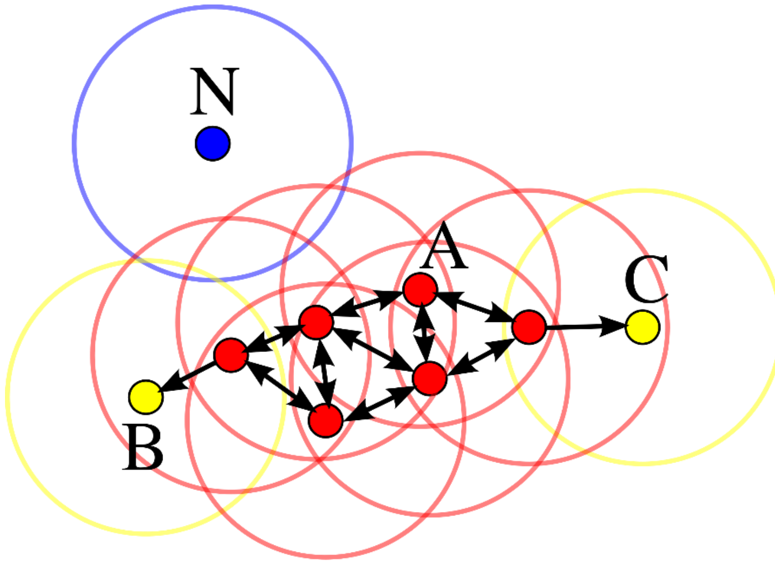


Figure 3 DBSCAN clustering (image source - machinelearningmastery.com)

- Grid-Based Clustering - divides the object space into a finite number of cells that form a grid structure on which all of the operations for clustering are performed.
- Model-Based Clustering: these are approximations of model parameters that best fit the data. They can be either partitional or hierarchical, depending on the structure or model.
- Categorical Data Clustering - These algorithms are specifically developed for data where Euclidean, or other numerical oriented, distance measures cannot be applied.

2.7 Review on Data Collection Method

2.7.1 Mobile Based Utility data collection

Many utilities today are collecting data manually. Which in turn this is a source of many errors. According to (Niro, 2014), this error could be inconsistent data or unreadable paper frequent occurrence of manual entry errors creates utility data problem. Furthermore, According to (Niro, 2014) data from various branches of the same office could be entered into spreadsheets for calculations and reporting at the same time, introducing another source of inaccuracies and ambiguity. Is the data, for example, appropriately inputted or copied and pasted? Is the equation correct? What happens if the data in the spreadsheet does not match the data in the printed report? What happens when numerous versions of the same spreadsheet are stored on different computers and are updated by different people? What's the best way to compare data from different spreadsheets? What happens if your Excel expert quits the company or the permit levels change? Data integrity is challenging to maintain when data is collected and stored using paper and spreadsheets. The resolution to these issues is freely available says (Niro, 2014). Credits to the rapid advancement of mobile technology, the means presented for data collection and analysis have improved substantially in recent years. Smartphones and tablets along with simple, flexible, and affordable applications developed for them that make it possible to streamline every step of the collection, analysis, and reporting of data (Niro, 2020).

2.7.2 The Advantages of Mobile Data Collection Technology

Generally, utilities could use of mobile data collection usage solves the problems produced by paper forms and manual data entry. Mobile technology programs are free, straightforward, and easy to learn, and due to the time and money they save through increased efficiencies. Where mobile technology is employed, less time is spent collecting and entering data and more time is focused on process efficiencies. Errors are drastically decreased, and richer data is collected, including photos, video, GPS coordinates, and automatic date and time stamping. A high level of security can be employed with user verification, password protection, and automatic backups. This means no more lost forms and data can only be viewed and edited by authorized individuals. With a mobile application, data can be instantly confirmed in the field with notices if or when an entry falls outside the normal or expected scope. In addition, since real-time data is immediately uploaded, authorities can be informed when new information is available, or action needs to be taken. Notifications can also be set to send text messages and emails alerting staff (Niro, 2020).

2.7.3 Handheld GPS For Utility Data Collection

Handheld GPS receiver can be used for rapid data collection. These data have the ability to transfer rapidly from the GPS environment to the GIS environment. The maps and plans which are obtained by using handheld GPS and GIS software's can be used effectively for getting information, querying and analyzing the feature classes(Ayday,2020). The problem that raise due to hand held GPS for utility data collection is that it involves manual data entry from paper formats. This could lead to errors and inconsistencies. Also, since this method is not more technology enabled could be time taking and inefficient.

CHAPTER THREE

MATERIALS AND METHOD

3. Material and Method

3.1 Study Area Description

This research is done in Oromia region East Showa zone, in rural kebeles in between Addis Ababa and Gelan town where Abasamuel substation medium voltage lines supply power. The substation is located on 8.755, 38.718 geographic coordinates. The area covered is around 30,000 ha land mostly covered with agricultural land. The main economic crops grown in this Area is 'teff'.

Considering the objectives of the research, the study area is choosen due to its rural nature which indicates less provision of electricty according to statistics as decribed in the significance section of this proposal. so unlike the citys where electricity supply have reached more than 90%, in such areas its possible to find rural housholds without electricity connection despite the fact that they live around grid connection which can be expanded with less cost. Its proximity to Addis Ababa also makes it ideal to complete this reasearch with the allocated budjet.

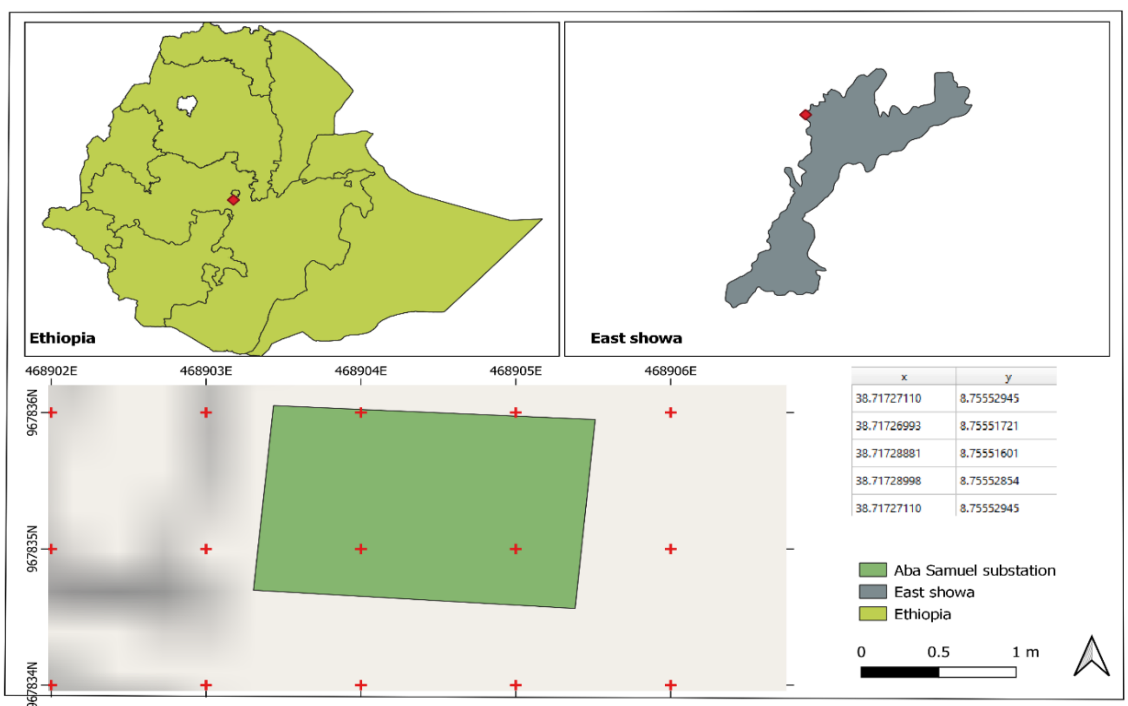


Figure 4 Study Substation location

3.2. Method of the Study

3.2.1. Data Sources

3.2.1.1. Primary data sources

The primary data MV line network of the substation and transformers are collected by android based application called Open data Kit, ODK collect. For this 31.4km of MV line is collected as shown below.

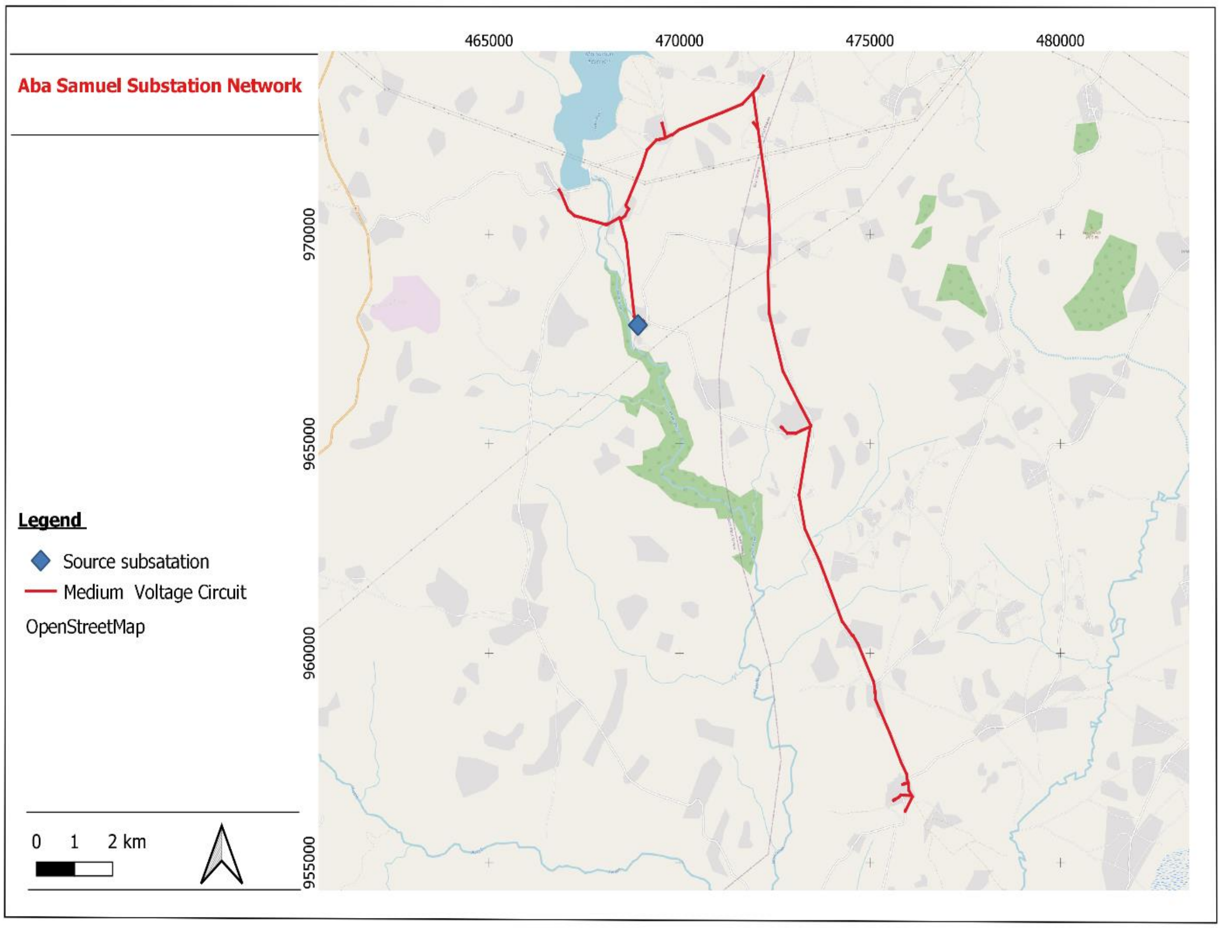


Figure 5 Medium Voltage circuit

3.2.1.2. Secondary data sources

For Densification and Expansion analysis existing housing structures of settlements and roads are digitized from google earth. Land use land cover map is also generated from google earth image.

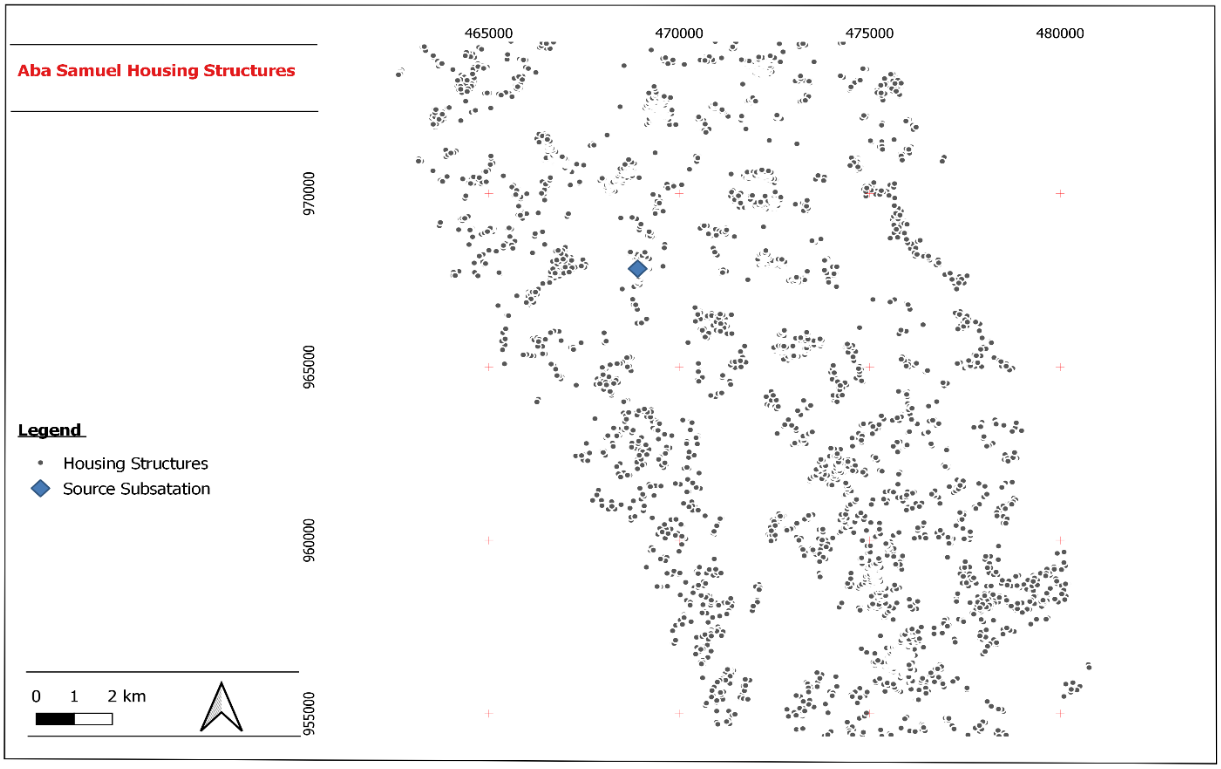


Figure 6 Housing structures

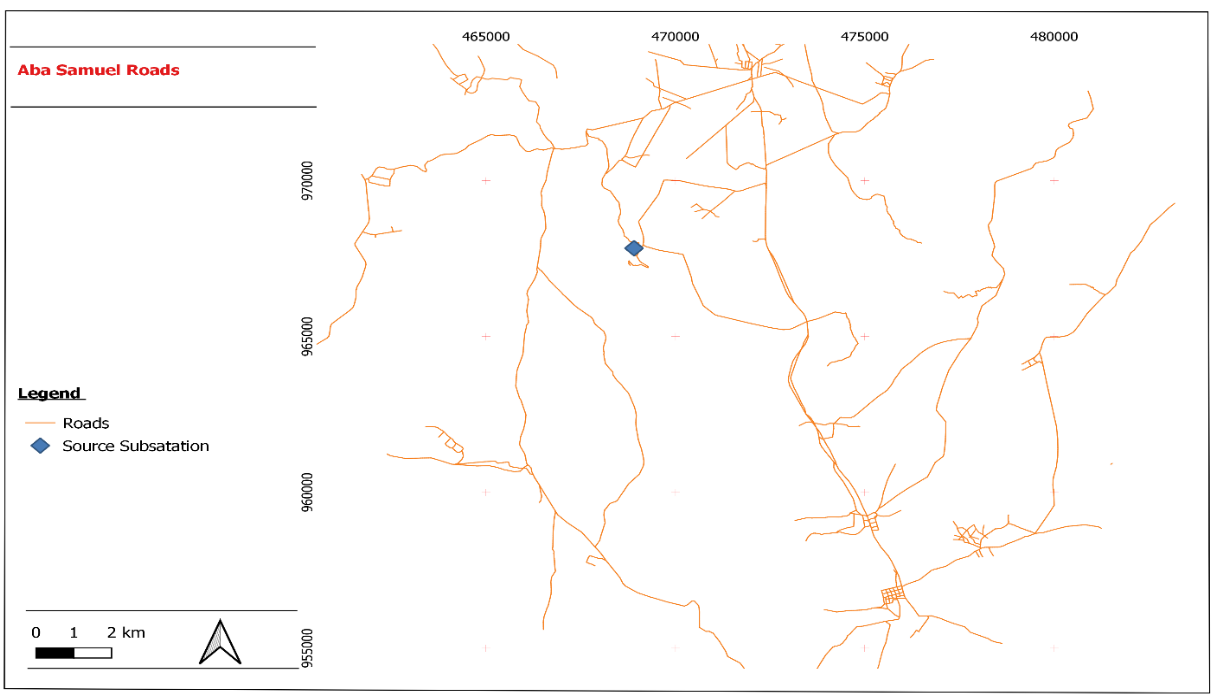


Figure 7 Roads

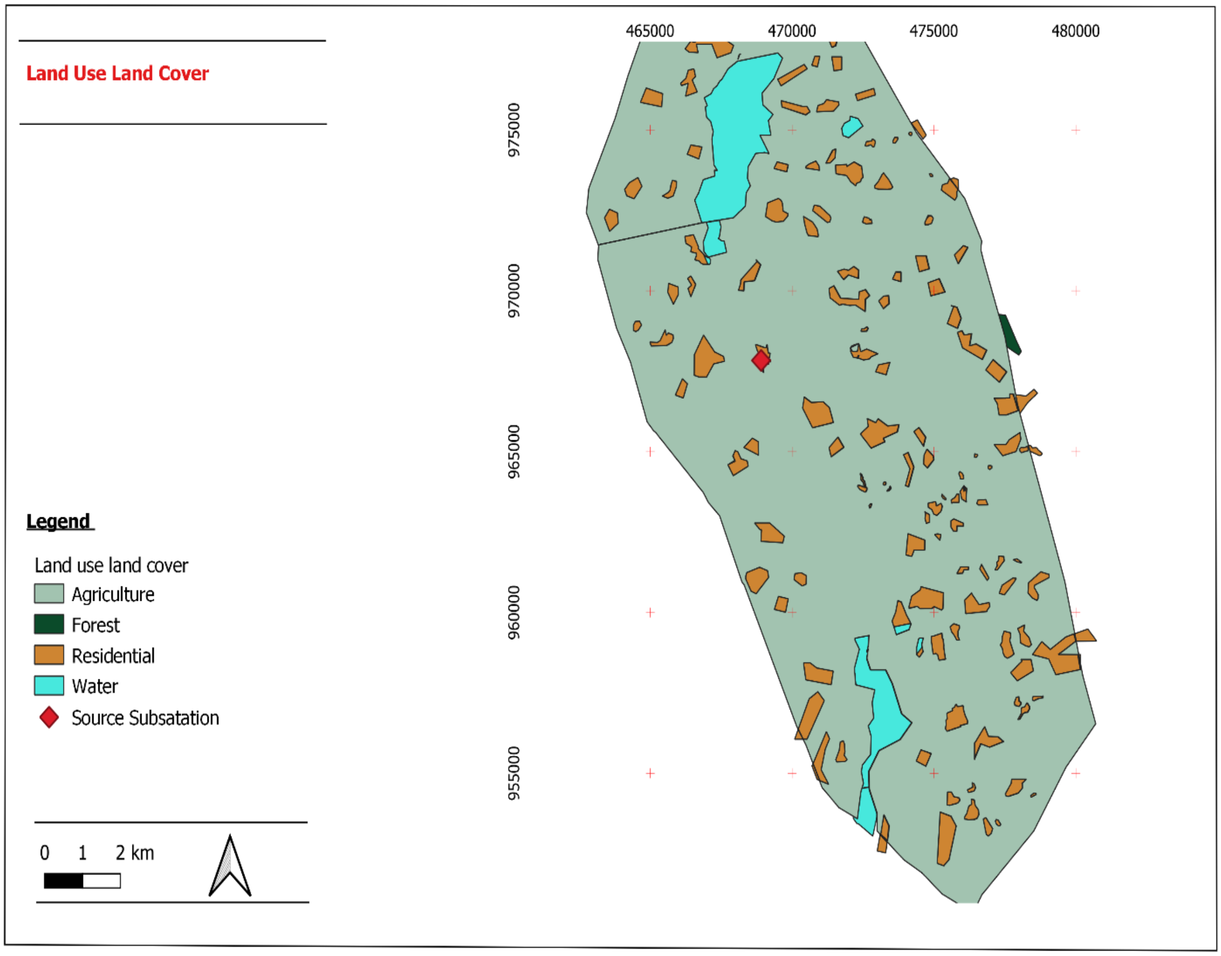


Figure 8 Land Use Land Cover Map

3.3 Open Data Kit (ODK) data collection form development

Since the data collection is done using open data kit, ODK, android based application at first it required developing a form. For developing the form xlsx format is used.

Hence, for the data collection task two forms are developed. The first form is MV survey form to survey the electric line in line format and the second form is equipment survey form which is used survey equipment's along the line in point format.

With the equipment survey form, equipment's that exist on the network like transformers, capacitors, regulators could be collected.

This forms after being developed in xlsx format they are converted to XML and letter used for data collection using mobile based application called ODK.

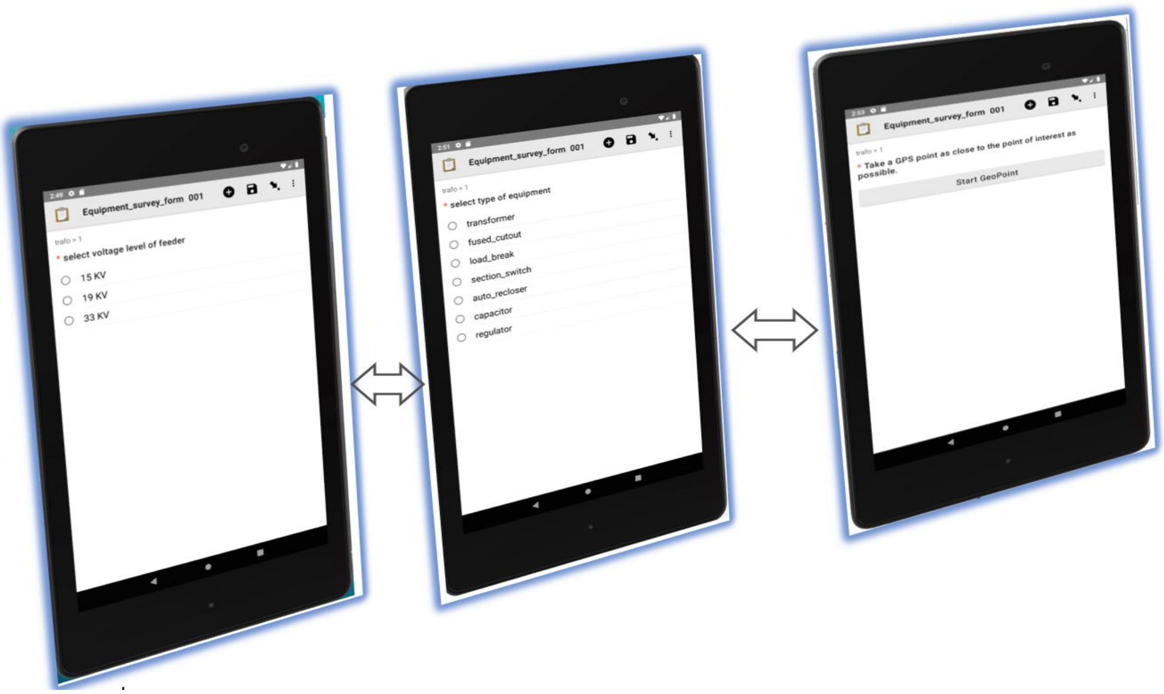


Figure 9 Form in ODK layout

Data collected on the field is sent to free server directly, prepared using only Gmail account and associated google sheet file.

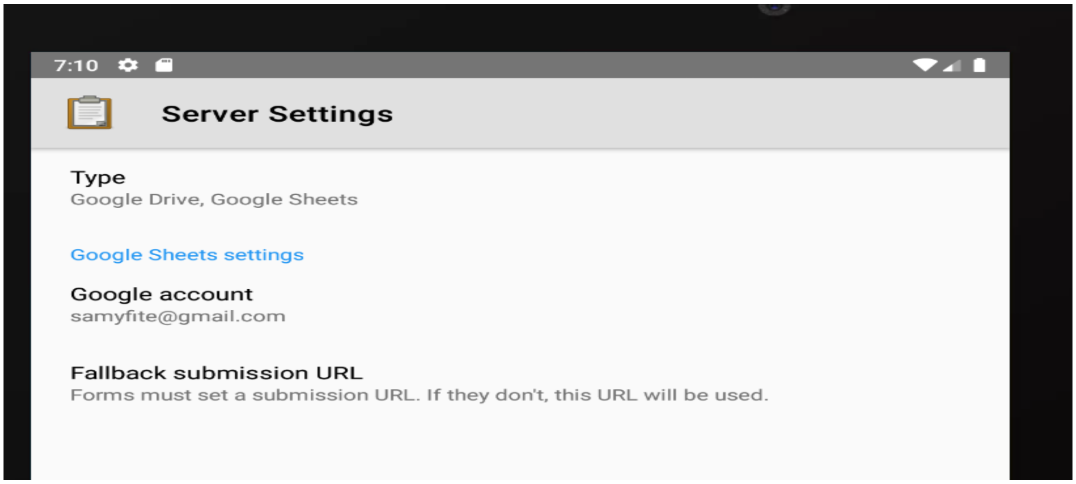


Figure 10 Server Setup

3.4 Methods for Densification Analysis

According to literature (MOWI 2019) 63% rural households do not have access to electricity. Based on this statistic the study identifies this households using spatial analysis technique. This rural households could also be electrified using just lv, also known as densification. Because households are within 600m radius of existing transformers they can easily have electricity access using LV connection.

Hence after digitization of the house strictures and Geolocation of this existing transformers by field data collection a buffer of 600m is run using QGIS software. The buffer area of 600m is average length Ethiopian utility uses to connect transformers to customers. This length varies from 100m which could be used in densely populated area with high energy consumption, up to 1200 meter which can be used in rural areas with low energy consumption. For this there is no written guideline in the utility company but the researcher acquired this numbers by interviewing utility experts.

3.5 Expansion Analysis Steps

The first step in expansion analysis is to determine factors affecting medium voltage network route planning. This section presents method and techniques applied for analyzing the data as well as for route selection. The details of computational scheme are presented below.

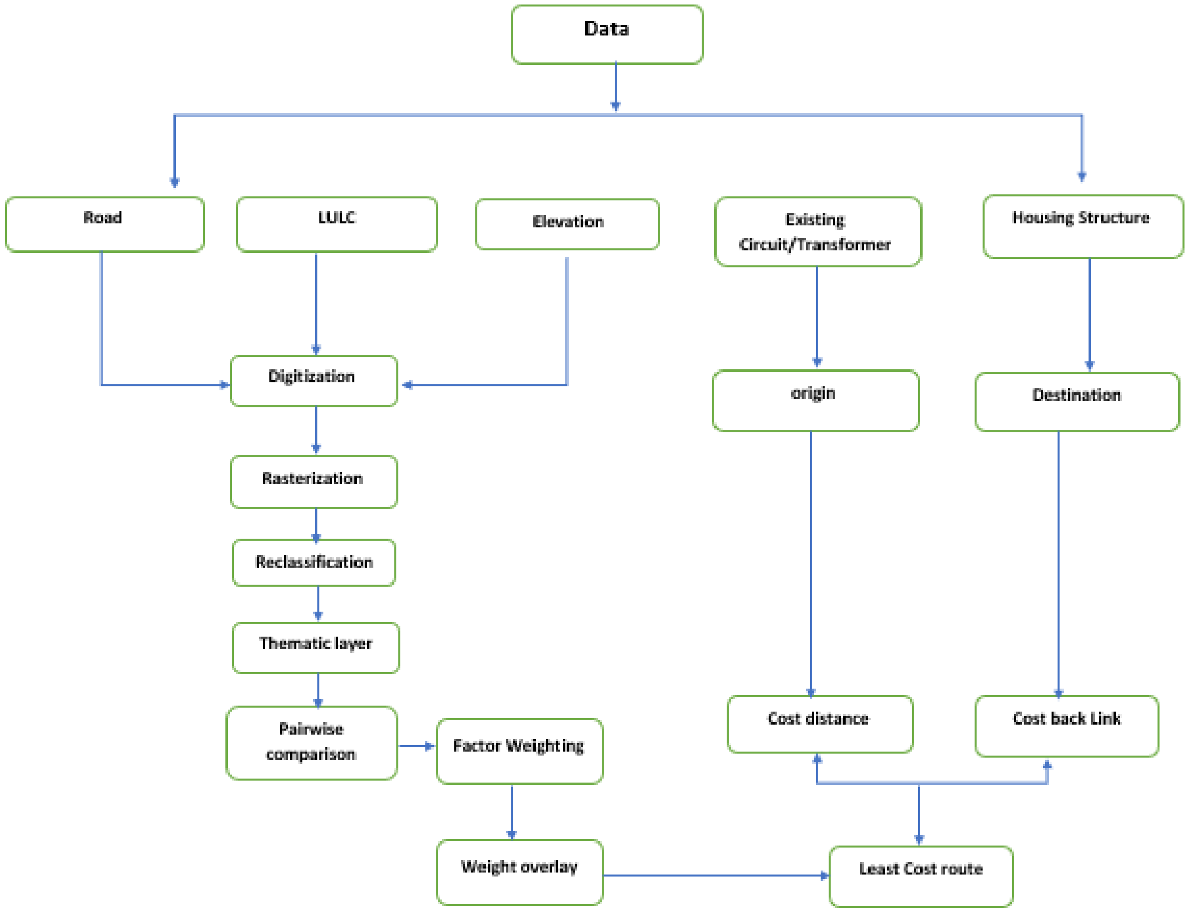


Figure 11 Methodological Framework

DB scan or Density-based spatial clustering of applications with noise (DBSCAN), non-parametric algorithm based on density is used to cluster household structures. After the households are clustered to propose transformer location for each cluster centroid points are generated. MV routing based on multi criteria evaluation is run toward this cluster centers from existing MV line.

3.6 Multi criteria evaluation of MV route to cluster centers

Most of the work presented in the literature that employs GIS tools for route optimization is based on the concept of 'cost surface', defined as a raster file type, where the values associated to each pixel are used as weights to calculate the least-cost path between two points. So, the factors are aggregated to produce maps that show the rating of land for MV electric route.

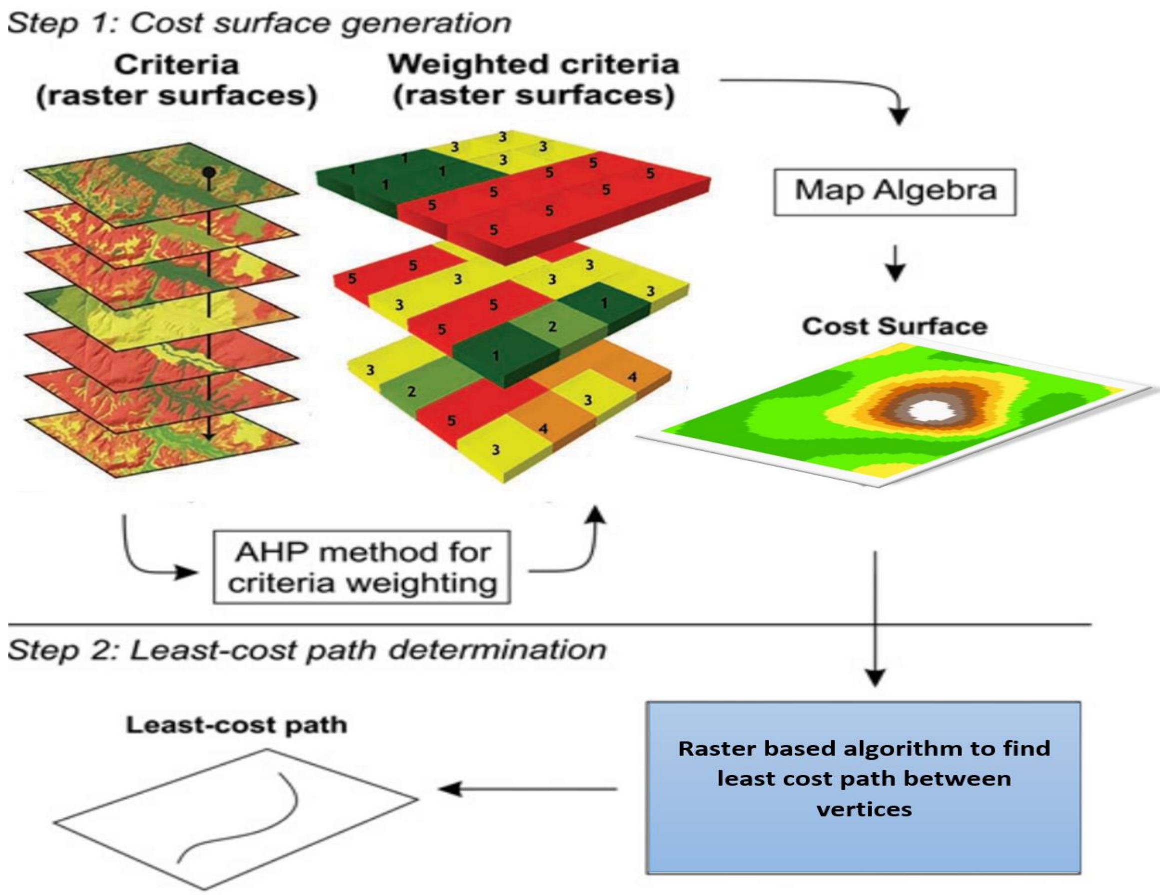


Figure 12 Cost surface generation methodology (source - (de Lima et al., 2016)

Literatures showed four sets of components that influence implementation and maintenance costs. These are slope costs, associated with the local slope of the terrain; direction change costs; and geographic factors, which are:

(i) accessibility costs: represented by the costs of equipment transportation, installation and maintenance, depending on the quality and type of the existing access routes.

(ii) land use; costs of pole foundations according to soil type; costs associated with vegetation, for example, need for insulated conductors to cross forested areas with significant ecological importance, vegetation suppression and/or pruning costs; additional maintenance costs in areas susceptible to decaying of poles.

(iii) terrain complexity: slope and relief complexity influence on determining the types of poles and conductors, where flatter lands are more favorable.

3.6.1 Weighting with AHP

The AHP (Analytic Hierarchy Process) is a multiple criteria decision-making tool, which can be used to measure the relative dominance or preference of elements related to a main objective.(Saaty, 1980). Each element (criterion) weight is determined by using paired comparisons, wherein each element is compared with all others according to their importance.

For this study the pairwise comparison matrix using Saaty's (1980) nine-point weighing scale was applied.

Table 1 Nine-point weighing scale Saaty's (1980)

Intensity of importance Definition	Intensity of importance Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong to extremely strong importance
9	Extremely importance

To develop a pairwise comparison matrix different criteria are required to create a ratio matrix. These pairwise comparisons are taken as input and relative weights are produced as an output.

Table 2 Ratio matrix

No	Criteria	Pairwise comparison matrix				
		Slope	Proximity to road	Land use	cost	Normalized cost
1	Proximity to road	1	3	7	2.758924176	0.669416869
2	Slope	1/3	1	3	1	0.242636922
3	Land use	7	3	1	0.362460124	0.087946209
	Sum				4.121384301	1

Estimation of the consistency ratio

To eliminate bias in the calculation of criteria weighting the consistency ratio (CR) was used.

To get consistency ratio first consistency index is calculated.

first consistency index (CI) = $\frac{\lambda avg - n}{n-1}$ (1)

The value for lambda(λ) is simply the average value of the consistency vector

$$\begin{pmatrix} 1 & 3 & 7 \\ 1/3 & 1 & 3 \\ 7 & 3 & 1 \end{pmatrix} * \begin{bmatrix} 0.669416 \\ 0.242636 \\ 0.087946 \end{bmatrix} = \begin{bmatrix} 2.012951 \\ 0.72959219 \\ 0.2644479 \end{bmatrix}$$

$$\begin{bmatrix} 2.012951 \\ 0.72959219 \\ 0.2644479 \end{bmatrix} / \begin{bmatrix} 0.669416 \\ 0.242636 \\ 0.087946 \end{bmatrix} = \begin{bmatrix} 3.007021768 \\ 3.006929804 \\ 3.006928716 \end{bmatrix}$$

Avg = 3.006960096

(CI) = $\frac{\lambda avg - n}{n-1}$

(CI) = $\frac{3.006960096 - 3}{3-1}$

= 0.003480048

Consistency ratio = $\frac{\text{Consistency Index}}{\text{Random Index}}$ (2)

Random index is the consistency index of a randomly generated pairwise comparison matrix of order 1 to 10 obtained by approximating random indices using a sample size of 500 (Saaty, 1980).

Table 3 Random Index (source (Saaty, 1980)

Order Matrix	1	2	3	4	5	6	7	8	9	10
Random Index	0	0	0.58	0.9	0.12	1.24	1.32	1.41	1.45	1.49

Hence the study has three factors the random index is 0.58.

So, Consistency ratio = $\frac{0.003480048}{0.58}$

= 0.006000083

The consistency ration showed above is less than 0.1 which shows the weight calculated is acceptable.

3.6.2 Cost surface

Weighted thematic maps for each factor were created after determining the comparative weight of factors, derived weights from a pairwise matrix in Multi-Criteria Analysis (MCA), and inserting the particular value to the map layers. The thematic cost map is a raster map, with each pixel's value representing the anticipated relative cost of route upgrade across that pixel (Saha et al, 2005). It is determined by the terrain's complexity, closeness to a road, and land use land cover.

As per the weighted values are given in the pairwise matrix and ranked values given, all those cost maps were produced. The final thematic map is presented by adding this weighted raster.

3.6.3 Raster Direction

The cost distance raster shows the least aggregated cost of each cell to the nearest source, but it doesn't tell you how to get there. The direction raster generates a road map that shows how to get from any cell to the nearest source by using the least-cost approach. The Spatial Analyst tool provides access to this feature. The origin and the weighted raster calculator are the input data for this direction raster. The least cost path was determined using the above cost raster surface information and cost backlink. The cost is determined by a number of variables that were considered in the analysis. The least accumulative cost distance should be computed for each cell to the nearest source over a cost surface when specifying the cost distance. The cost of traveling from one point to another is determined by the spatial orientation. Furthermore, the cost of travel will be affected when the cells are connected. This is known as the 'node travel cost' (Understanding Cost Distance Analysis, 2012).

3.6.3 Least Cost Path Analysis

The destination raster, cost distance raster, and direction raster are required input data for determining the least cost path. Following the preparation of all essential inputs, the spatial analyst tool is utilized to generate the least cost path and the analysis results.

CHAPTER FOUR

4.RESULTS AND DISCUSSION

4.1 Current Electric Asset Data and Planning Technique Findings

The researcher went to Gelan EEU service center and made interview with staff member to grasp and understand the existing electric asset management and planning technique and found out that paper-based asset management and network planning techniques are implemented. The asset management sometimes uses excel based data handling. Free sketch of MV network are also used to understand geographic coverage and do network plan for approved customers.

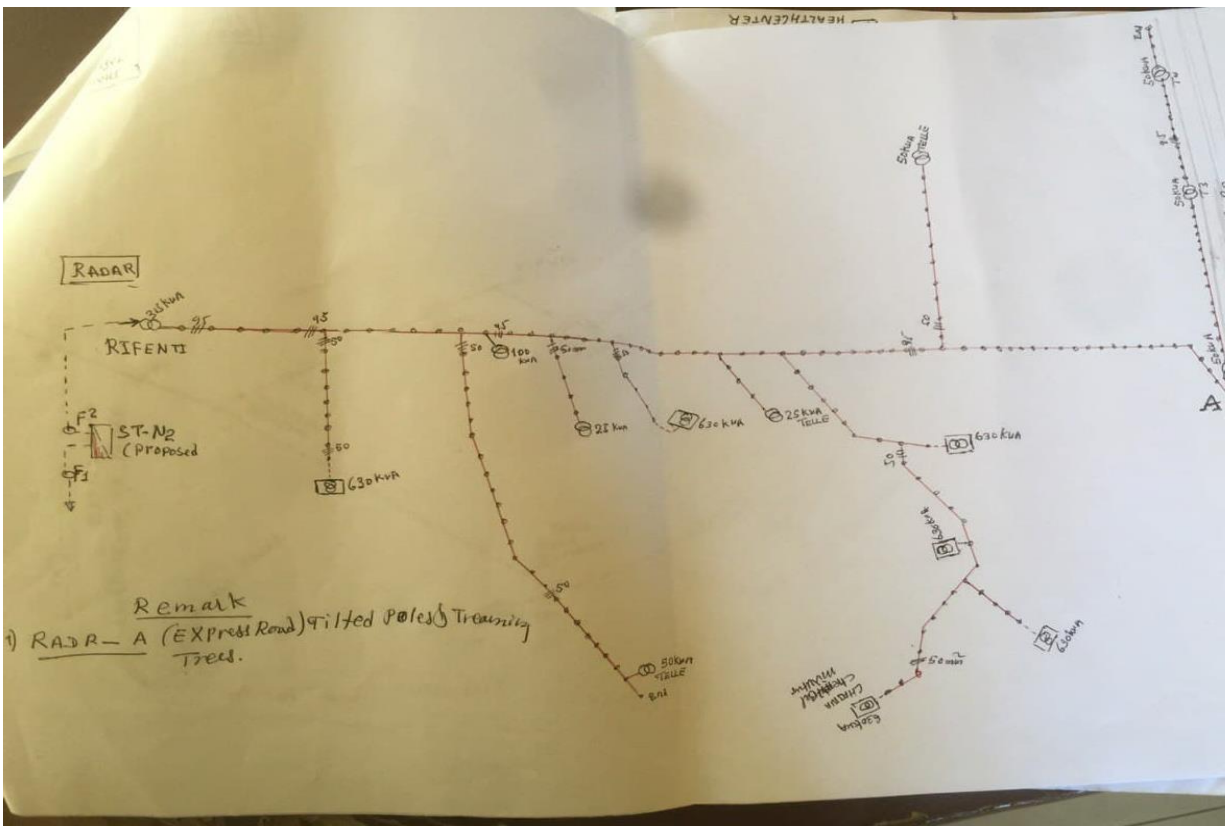


Figure 13 Free sketch of a MV network with Planning (Source -Gelan Service Center)

The excel data is filled and reported when EEU head office ask for it and usually this is done annually.

The data contains very basic and limited information regarding the network as shown below.

Ethiopian Electric Utility

Central region Distribution Network Data

No	Electrifid Town of village	political Region	Political zone	political special wereda	system	Name of substation	Year of Electrif (EFY)	Year of Intercon (EFY)	Street light	voltag level	Number of Transformer by (kvA) Name of SERRVIC CENTER — Numeber of Transformer by (kva) servic center													Total
1										15/33kv	10	25	50	100	200	315	500	630	800	100	1250	2000		

Figure 14 Excel data components (source – Gelan service center)

4.2 Densification Analysis Results

During data collection 50 existing transformers are identified on Aba-Samuel substation. According to Minister of Water, Irrigation, and Energy (MWIE, 2019) only 63% of rural households have electricity access. This means of all digitized structures that are within 600m buffer radius of this existing structures, 37% of them could be connected to these transformers with only LV lines.

The ones that intersect this 600m buffer area are categorized as Densification households. But on some cases as shown on below figure 600m transformer buffer areas overlap when the transformers exist close to each other.

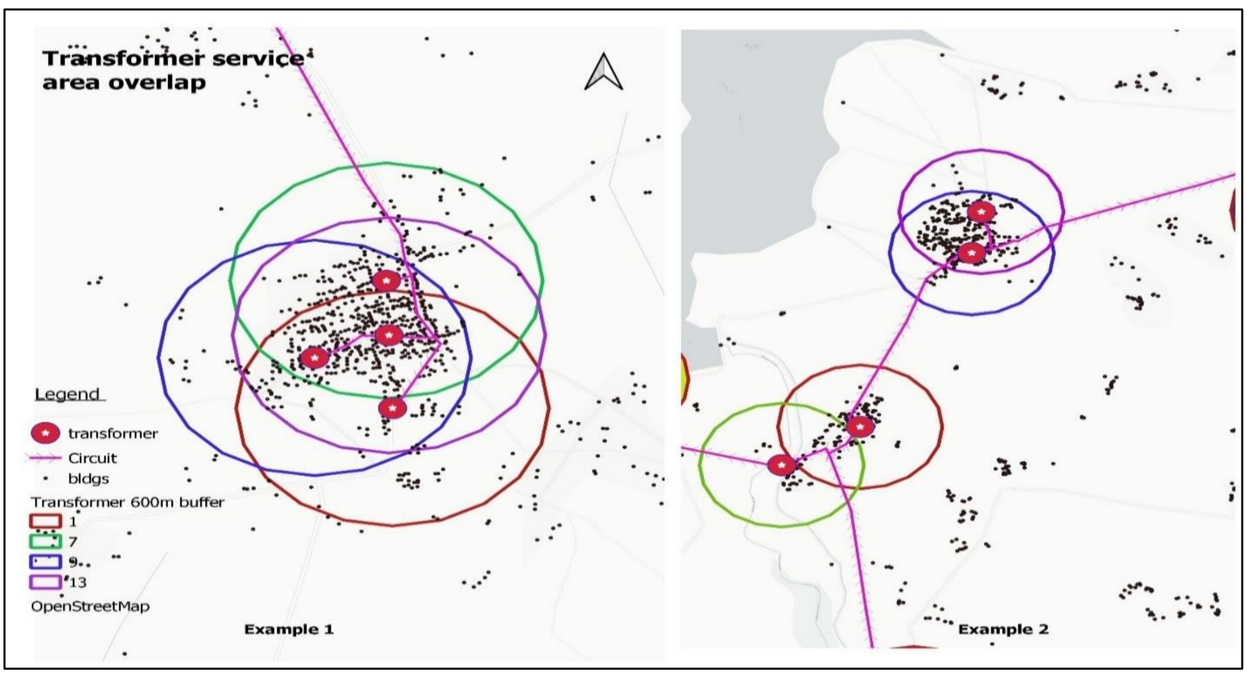


Figure 15 Transformer service area overlap examples

To solve this problem and identify household's connection per transformer via densification a spatial technique called Voronoi polygons or Dirichlet tessellation are used. This polygon identifies each transformer influence area until break off by the other transformer's 600m area.

By clipping the Voronoi polygons using the 600m buffer area the correct service area of this transformers is identified.

Figure 16 Transformer influence using Voronoi polygon

Hence, following densification procedures described in previous chapter these 1384 households are identified.

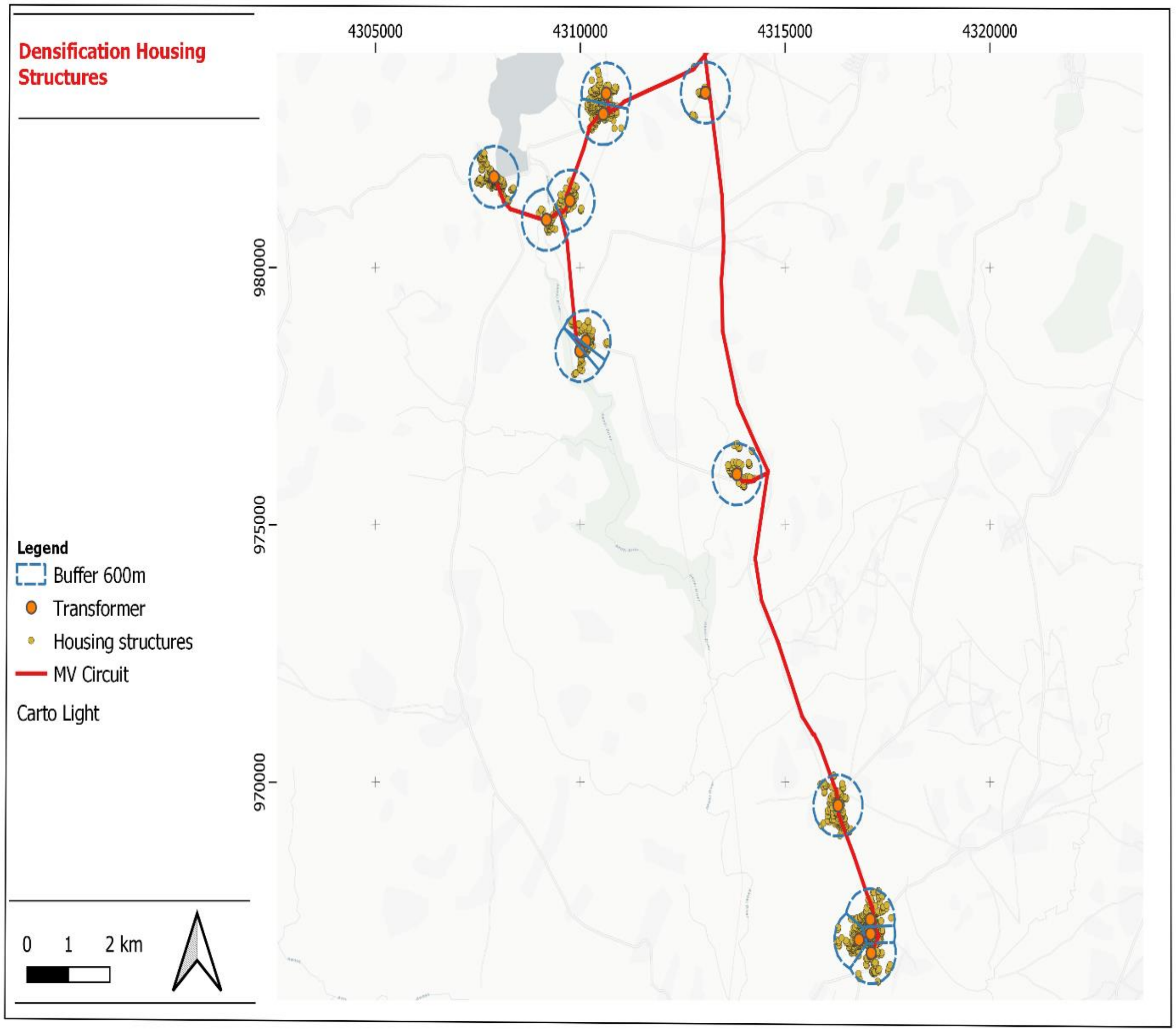


Figure 17 Densification Results

4.3 Expansion Analysis

4.3.1 Density based scan clustering

For clustering the households based on density (number of households close to each other) is crucial and it won't be economical to but transformers without properly analyzed location. To cluster the house holds using this technique average distance of 600m and apart is used. This is the average length the utility company uses to connect transformer to consumers.

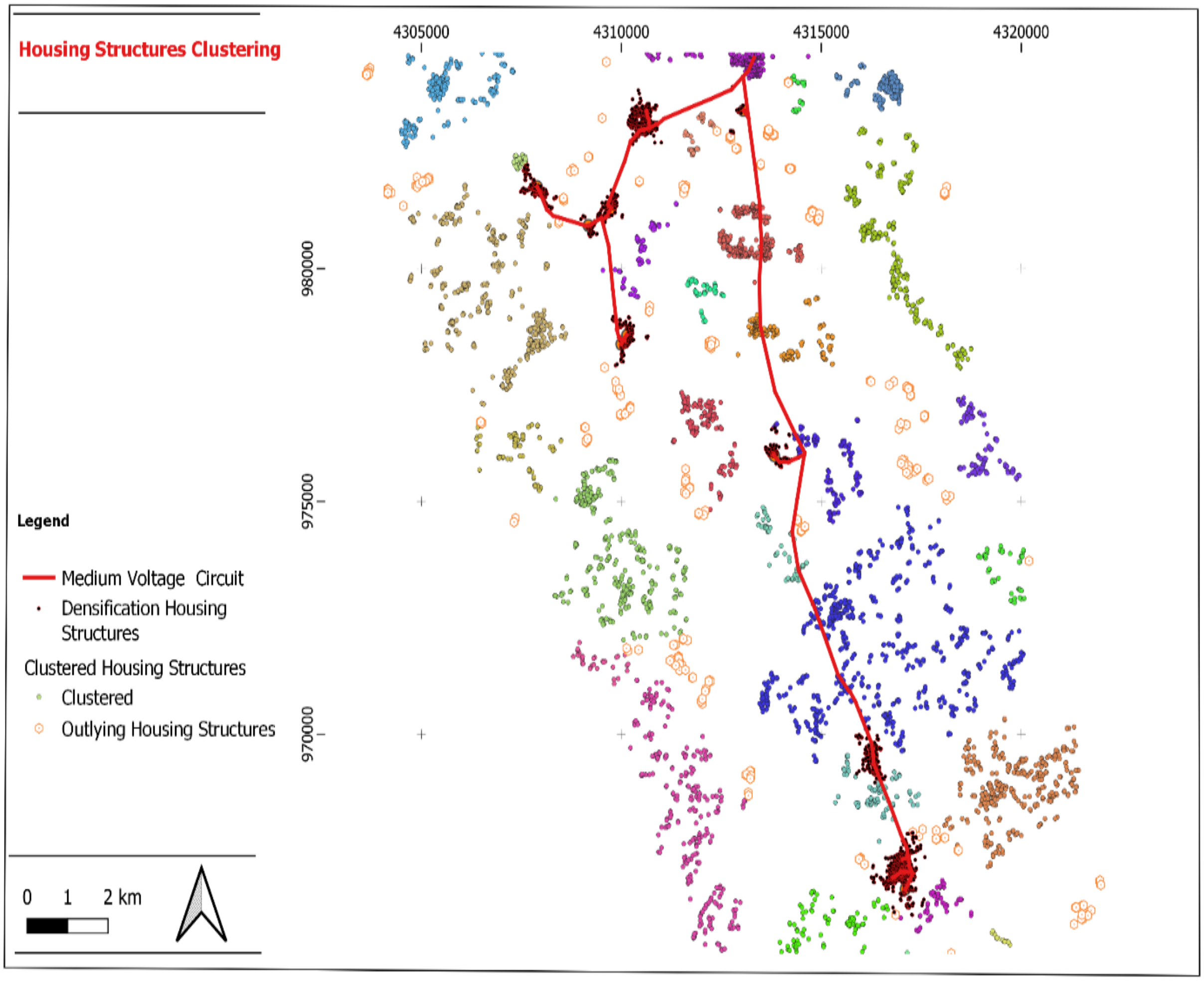


Figure 18 DBSCAN clustered structures

4.3.2 Identifying proposed transformer location via cluster centers

For every cluster deciding where to put the transformers is very important because further connecting each household from this need to economically viable. Hence a center of each clusters is proposed to put transformers because connecting LV to each household from the structures center is the least cost.

Minimum bounding box (convex hull) for each cluster is identified and then center of each cluster is found by centroid finding spatial technique.

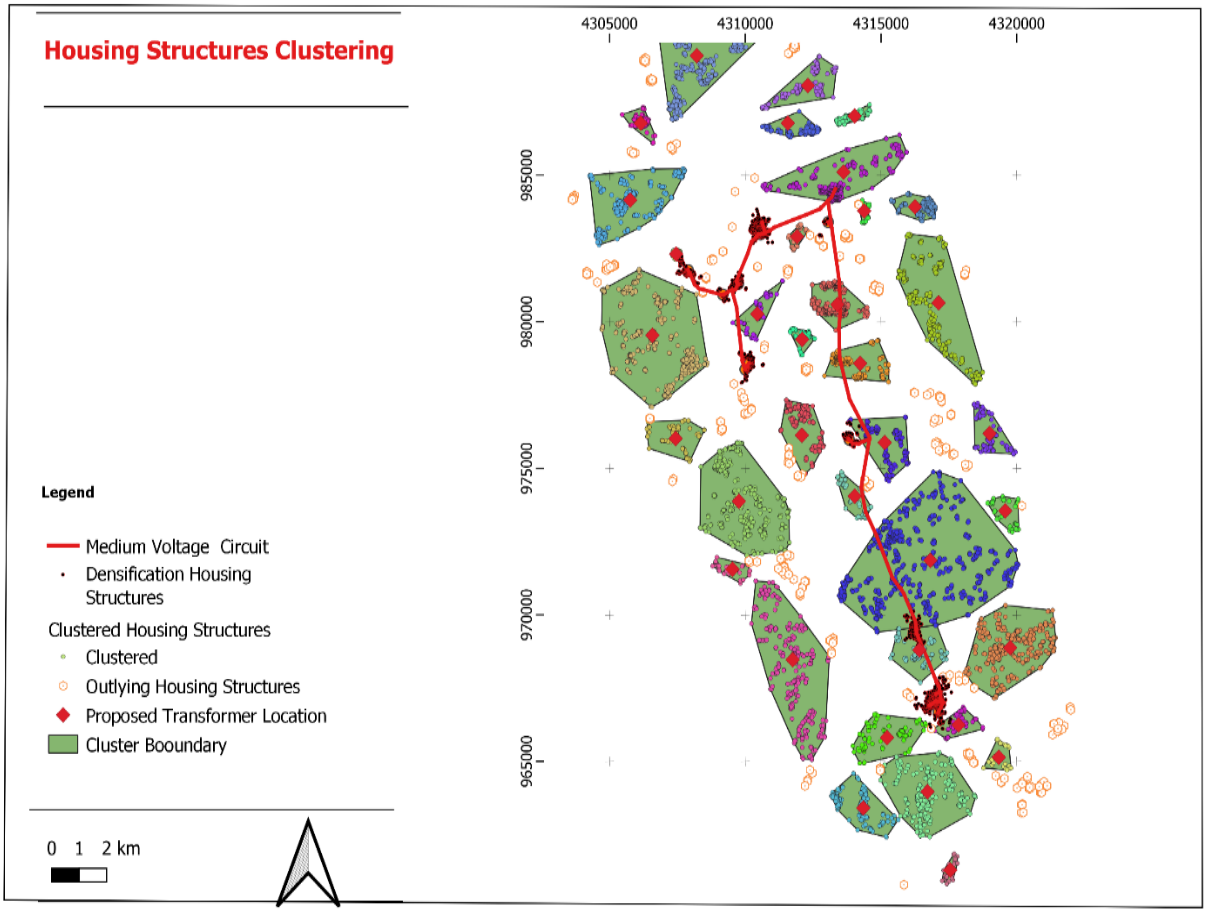


Figure 19-Transformer placement location

As discussed in the previous chapter density-based clustering algorithm is used to cluster households according to their closeness to each other. This resulted 35 clusters of digitized 8830 structures within the vicinity.

Table 4 Clustering results

Structure	Length(m)
Minimum number of structures in cluster	20
Maximum number of structures in cluster	700
Not clustered(outlier)	450
Average Number of structures in cluster	181
Total cluster	35
Total structure	8830

4.3.3 Road Proximity classification

According to (Barnard, 2008), to avoid the proposed path running on the road itself, the road centerline and 2 m on either side should be given the maximum rating. The area between the estimated road edge and 100 meters from the road are given a zero rating since this would be the best spot to install the network because it would be the most accessible for faults, maintenance, line clearing, and inspections. Between 100 and 500 m from the road centerline received a ten-point appropriateness rating, indicating that it is still a viable option to develop in this region, while above 500 m from the road centerline received the highest rating.

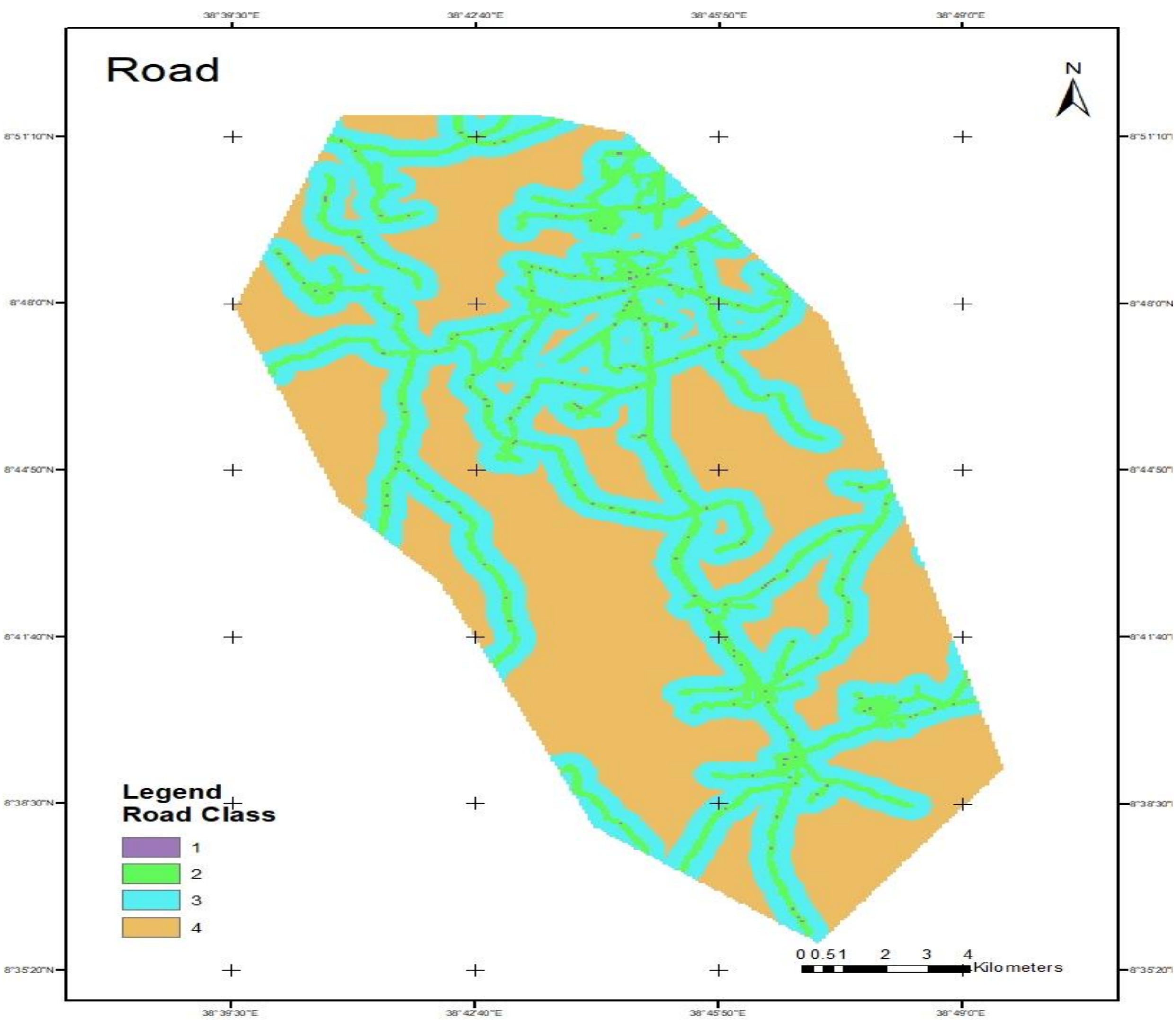


Figure 20 Road classification raster

4.3.4 Land Use Land Cover Layer classification

LULC with higher value indicates costlier and therefore less suitable for road construction. Environmentally sensitive areas such as forests, wetlands and other water bodies must be avoided and therefore were allocated a suitability rating of 100. Settlement and agricultural areas were allocated one and two points as being an optimal area in which to site networks.

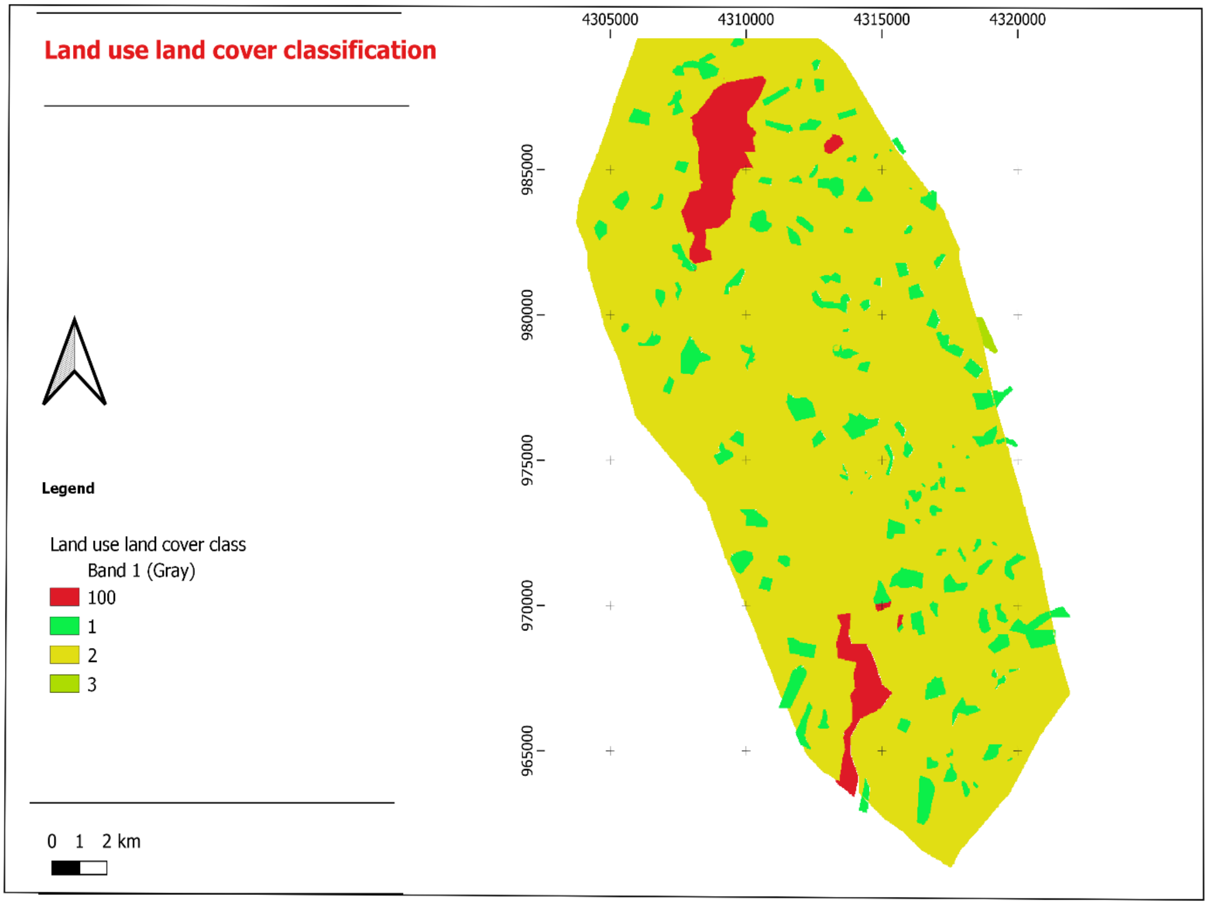


Figure 21 Land Use classification raster

Raster calculation to generate the cost raster that considers proximity to road, slop and land use according to their influence is generated and presented in the following suitability map.

4.3.5 Slope Classification

Steep slopes are disadvantageous for construction. Steeper slopes increase the construction cost of the network and also make operation and maintenance difficult(Barnard, 2008). Hence 0 to 10° slopes are given lowest cost and the slope level is classified as presented below.

Table 5 Slope Classification

Slope	Suitability rating (Scale: 0 -100)
0 - 10°	0
10 - 20°	5
20 - 30°	10
30 - 40°	50
40 - 100°	100

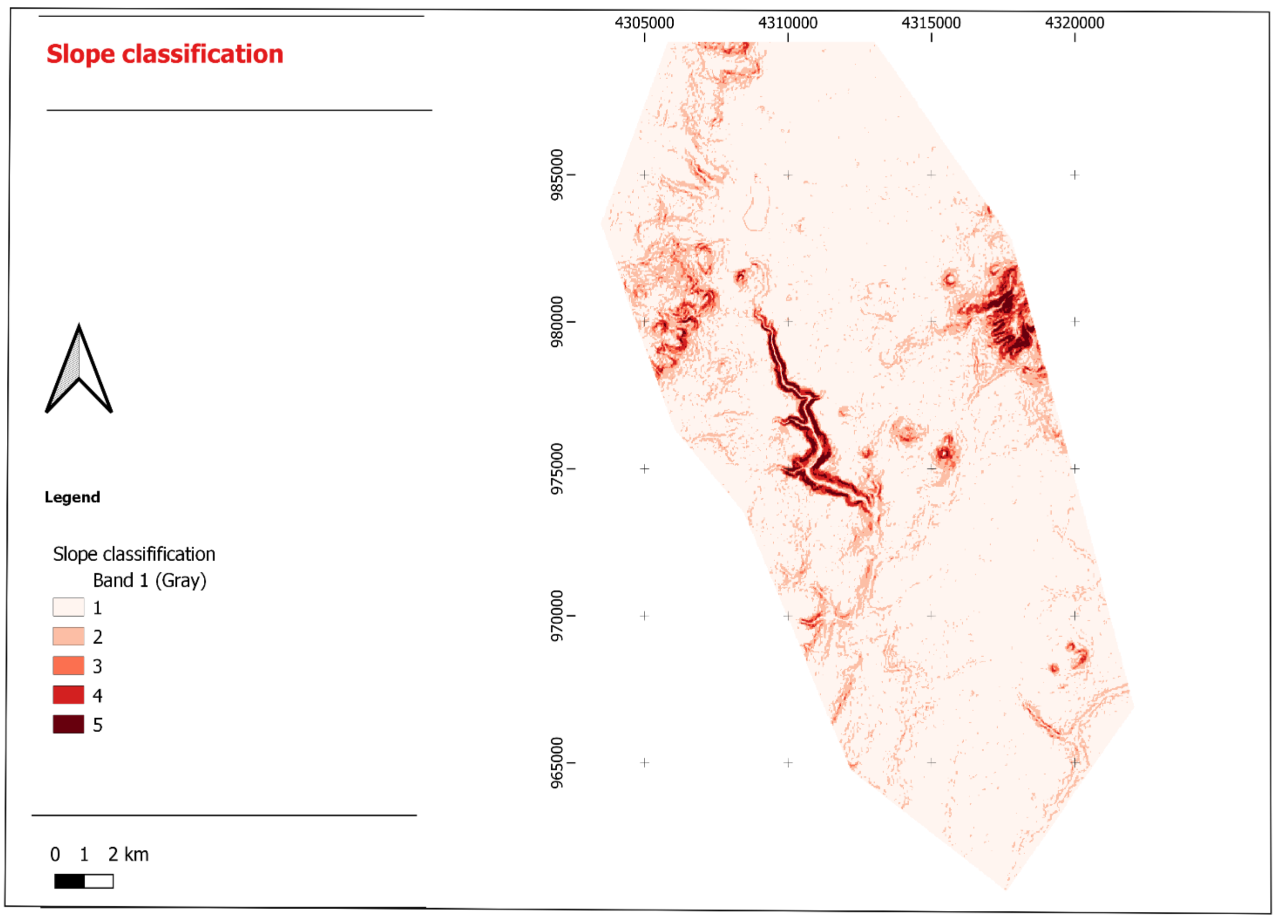


Figure 22 slope classification raster

4.3.6 Cost map generation

Weighted Linear Combination and Multi – Criteria Evaluation methodologies can be used to find the interrelation among the weights and to accumulate various data layers

The thematic cost map is calculated using the following equation.

Thematic Cost = ∑Weight ∗ Thematic Data Layer (attribute)   (Bennema et al., 1984)

Therefore

Thematic Cos = ∑(0.669 ∗ road , 0.242 ∗ Land use, 0.088 ∗ Slope)

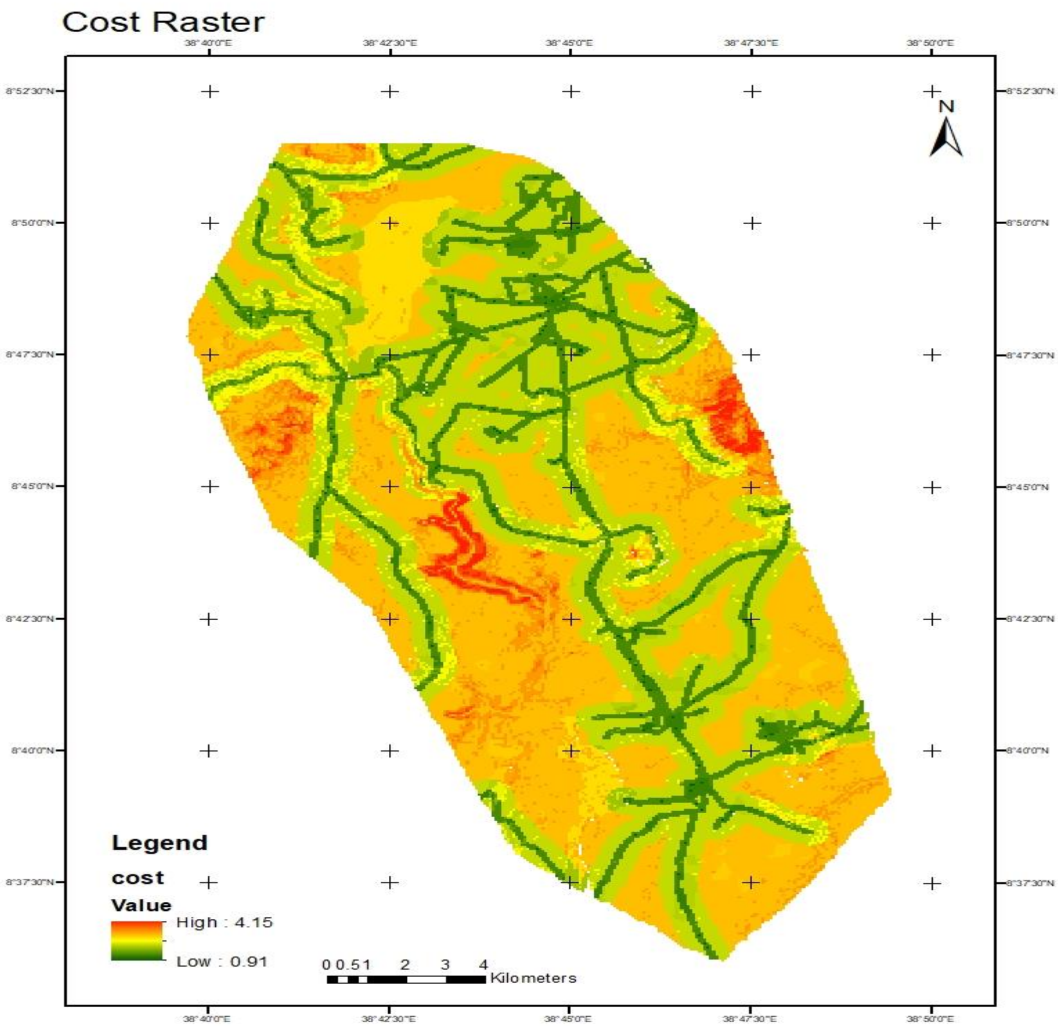


Figure 23 cost raster

The results of a methodological approach including the thematic cost factor, distance factor, and direction component for route planning, as well as least-cost route selection, are shown in the next section.

4.3.7 Cost Distance

The cost weighted distance function provides an output raster in which each cell is allocated a value that identifies the least accumulative cost distance over a cost surface to the recognized source raster locations using the weighted overlay layer and the source.

Each cell in the cost-weighted raster was given a value equal to the total of the fewest travel costs that could be obtained by returning to the nearest source raster, It does not, however, specify how to get there (Suleiman et al., 2015)

The weighted overlay raster layer and the source point feature, existing circuit vertices are the input layers for cost distance in this study.

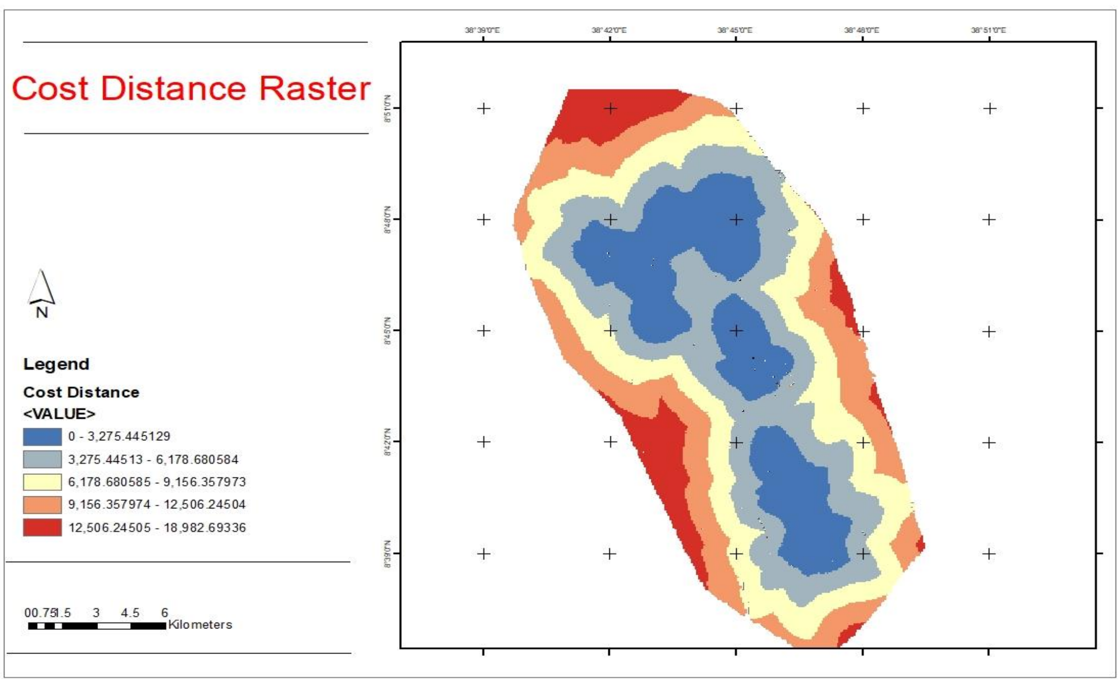


Figure 24 Cost Distance Raster

4.3.8 Cost Direction

Raster called backlink raster, also makes use of cost raster and source feature cost in doing weighted distance raster. The direction raster gives a suggestion that shows the quickest and cheapest way back to the nearest source from any cell(Suleiman et al., 2015). The value zero is used to symbolize the source raster locations. The values from 1 through 8 encode the direction.

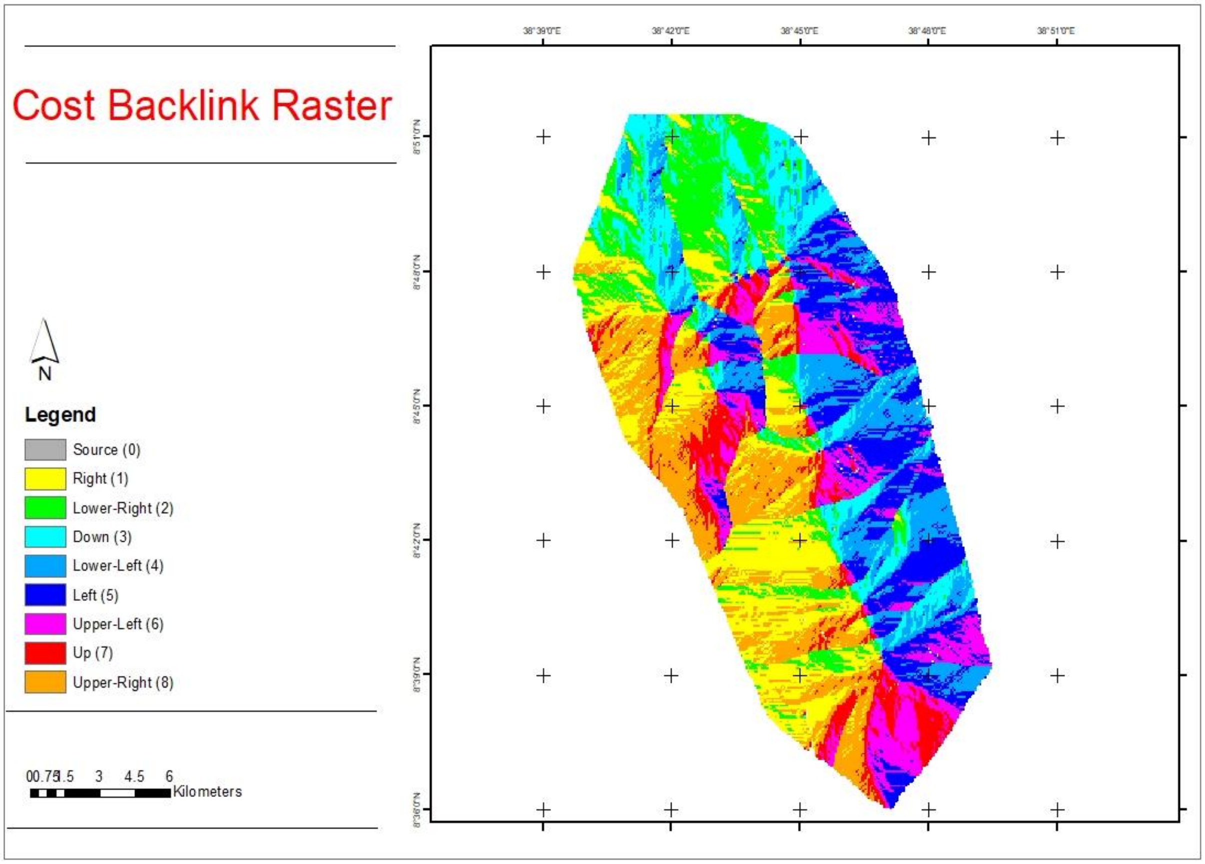


Figure 25 Cost Back link Raster

4.3.9 Least Cost Path Analysis

The MV routing from vertices of existing MV lines to the cluster centers using GIS least cost pass technique considering cost raster in background resulted the shortest and economically feasible new proposed routes.

The sum of the road, land use and slop raster's according to their influence is the background coverage used as cost. The result which is the optimal route obtained in the least cost path generation algorithm, crosses the surfaces with the lowest cost and avoids areas with high geographic costs.

Centers of the clusters and existing MV line vertices from the substation under study are used to find least cost point to point paths.

Table 6 Expansion route findings

Medium voltage circuit	Length(m)
Maximum proposed	7794.17
Minimum Proposed length	36.54
Average proposed length	869
Total proposed MV length	89459
Number of Proposed Transformers	35

As indicated in the table above 89 km of new MV line with 35 transformers could give electricity access to 6699 households. From the total 8830 digitized structures only 450 structures are considered outliers from the proposed clusters and that are not going to be connected to the grid.

This circuit lengths could be multiplied with current conductor and other related equipment's cost in the market to find total cost which in turn that could generate finical plan.

As discussed above, here, densification structures that are within 600m of existing transformer and outlier structures are neglected.

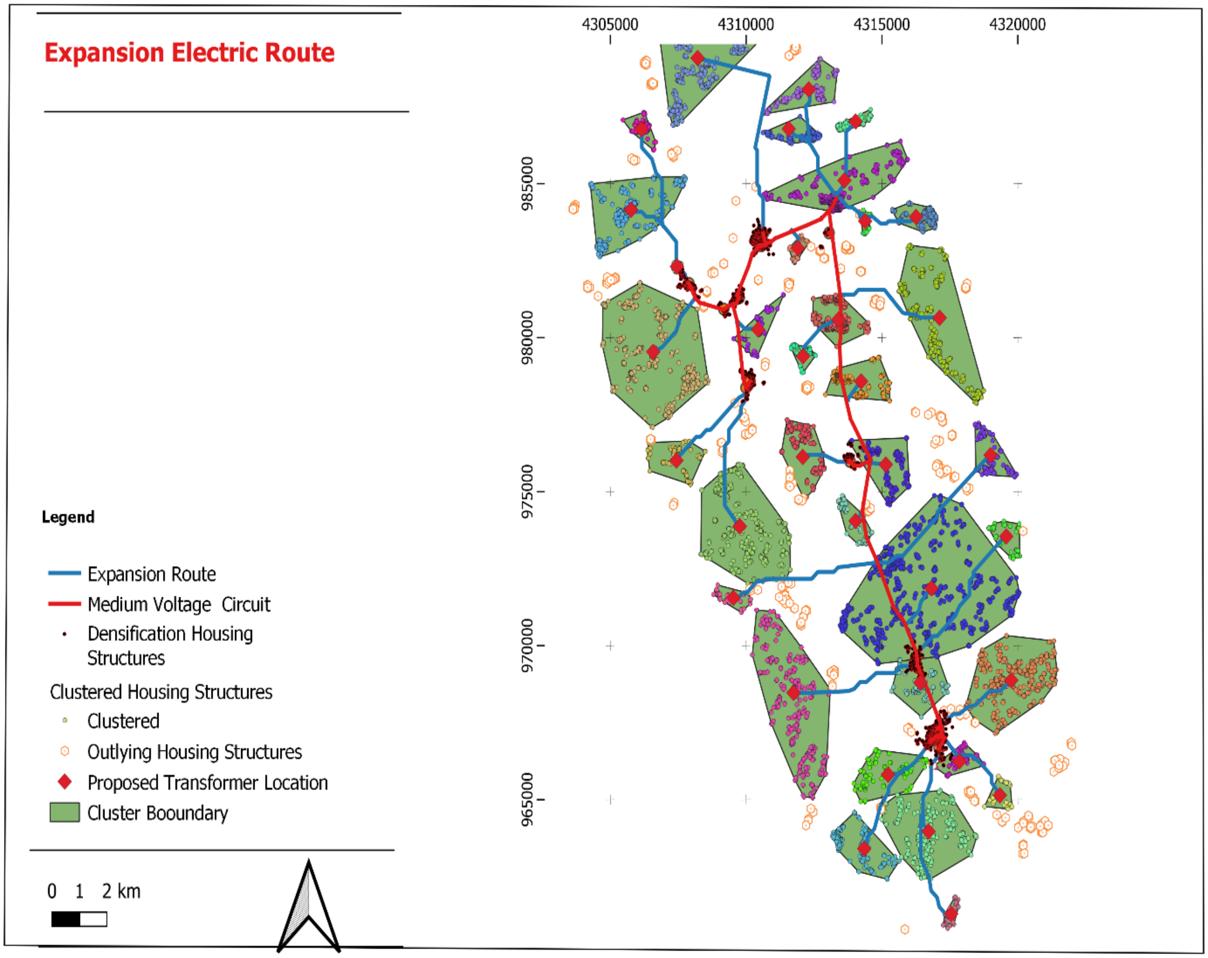


Figure 26 Expansion route

The number of study's in utility planning and specifically on electric network planning and management is very low. This researcher mainly found and used study's focusing specially on transmission lines and extended this study's to medium voltage distribution lines. This approach is supported by (de Lima et al., 2016) study made on transmission line planning.

According to (de Lima et al., 2016), the transmission line planning should also consider highly valued cultural and recreational sites, visibility from highly valued cultural and recreational sites, visibility from residential buildings, aspect, distance from infrastructure corridors. But, since this study is proposing medium voltage planning approach and since medium voltage related equipment's like pole and electric current field do not have effect on residential cultural, recreational historic sites, these factors are excluded. Other Matching factors proposed by (Monteiro et al., 2005) and (Barnard, 2008) like road ,population density , land use and slope are considered in this study and found optimum route for the clusters. Unlike (Monteiro et al., 2005),which proposes MATLAB for clustering this study used QGIS ,and found it to be effective platform as well.

Other researches mainly by (Rai & Singh, 2016) proposes GPS data collection the electric utility lines. This method is prone to errors due to the use of paper to collect further attributes. This creates error during data collection. Against that, this study proposes use of ODK data collection method using built in GPS in tablets or phones. Which allows simultaneous attribute data collection along with geographic coordinates. Since this method used cloud servers as data storage means loose of data is not a problem.

Proposed route and transformers could be further merged or split depending on the size of transformer capacity the utility uses for different clusters. Further the need for substation capacity upgrade should be studied by electrical experts to handle the proposed clusters load.

4.3.10 Model Validation

The proposed expansion routes validation has been made on randomly selected cluster routes based on their spatial location. These routes are checked by tracing the lines on google earth. The results show that the proposed expansion routes are situated on location that fit the considered factors. The proposed lines are near to roads and avoid difficult terrain.

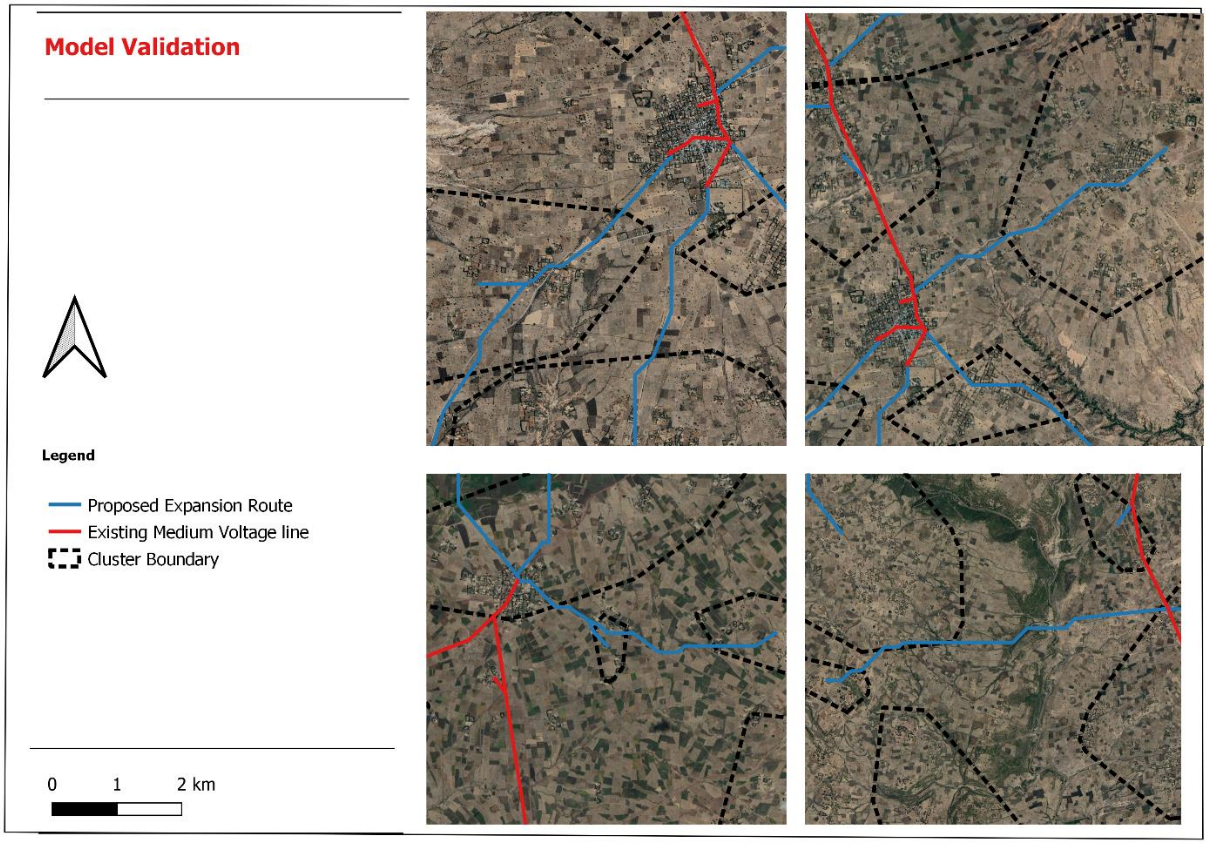


Figure 27 Model Validation

CHAPTER 5

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Achieving universal access to electricity in Ethiopia by 2030 in a cost-effective manner requires a combination of grid-connection and off-grid technologies.

The main goal of the study which is presenting a working prototype to MV line network planning have been achieved. This automated technique for new MV electric route can easily be extended to national level electric routing. The methodology is useful for the automated selection of the most economic route to build new lines.

These lines are feasible routing areas that link two particular points (origin and destination of the electric line) and keep associated line costs below a limit value determined by the planner; moreover, the line costs like the operating, maintenance, and investment costs for a given electrical conductor size can be calculated easily within new field.

The other goal which was developing technology enabled electric line data collection using the ODK has proved easy, reliable and free means to collect any utility related data.

The current practice in asset management and network planning using very backward paper means will hinder the country's electrification process and customer satisfaction will problem could prevail as always.

Although this methodology has been developed to route medium voltage electric power lines, it can be easily extended to other line routing problems, such as high and low voltages, and takes advantage of the processing and viewing capabilities of GIS to proper data management.

The proposed new expansion lines can be used as the starting point for advanced negotiation processes among different stake holders like other utilities, local and national authorities, environmental protection authorities, and other donor or investment banks who should reach a consensus on the best route to build this new expansion lines.

5.2 Recommendation

Based on the findings of this research, recommendations on the use of least-cost path analysis and multi-criteria assessment for electric line access planning the following recommendations are indicated:

- GIS- based MCE techniques for least cost path analysis are easy to use and understand and also proved to be working methodology for decision making, so implementing this technique not only in the electric sector but also in other utility organs could improve the business process and drastically grow customer satisfaction.
- It is also recommended to EEU and other utility sectors to include GIS in their business process and hire GIS professionals in their institute.
- Finally, this research has presented a working prototype least-cost path analysis and multi-criteria assessment of MV electric line access planning but, further researches in the electrical domain are still needed because the results also further need existing substation and transformers capacity study to decide whether upgrade of this equipment's is necessary or not.

References

Afshari, A. R. (2014). *A review of Spatial Multi Criteria Decision Making. International Symposium on Advances in Science and Tecchnology, Malaysia*. *May*.

Al-shalabi, M. a., Mansor, S. Bin, Ahmed, N. Bin, & Shiriff, R. (2006). GIS Based Multicriteria Approaches to Housing Site Suitability Assessment. *XXIII FIG Congress. Shaping the Change. Munich, Germany, October 8-13*, 1–17.

Ayday, C., & Ayday, E. (2020). The Use of GIS and Handheld GPS Integration for the Preparation of Quick Plans. *Methodology*, 1–5.

Barnard, J. (2008). Using GIS in Electrification and Network Planning. *GIS Technical, Planning, Network Specialist, GIS Distribution, Eskom*, *1*, 1–6.

Bennema, S., van Setten, A., 't Hoen, H., & Voogd, H. (1984). Multicriteria evaluation for regional planning: Some practical experiences. *Papers of the Regional Science Association*, *55*(1), 59–69. https://doi.org/10.1007/BF01939844

de Lima, R. M., Osis, R., de Queiroz, A. R., & Santos, A. H. M. (2016a). Least-cost path analysis and multi-criteria assessment for routing electricity transmission lines. *IET Generation, Transmission and Distribution*, *10*(16). https://doi.org/10.1049/iet-gtd.2016.1119

de Lima, R. M., Osis, R., de Queiroz, A. R., & Santos, A. H. M. (2016b). Least-cost path analysis and multi-criteria assessment for routing electricity transmission lines. *IET Generation, Transmission and Distribution*, *10*(16), 4222–4230. https://doi.org/10.1049/iet-gtd.2016.1119

EIA. (2019). *Electricity explained*.

Foster, J. A., & McDonald, A. T. (2000). Assessing pollution risks to water supply intakes using geographical information systems (GIS). *Environmental Modelling & Software*, *15*(3), 225–234. https://doi.org/https://doi.org/10.1016/S1364-8152(00)00008-6

Henderson, M. I., Novosel, D., & Crow, M. L. (2017). Electric Power Grid Modernization Trends, Challenges, and Opportunities. *IEEE Technology Trend Paper*, *November*, 17.

IEA. (2020). *Defining energy access*. https://www.iea.org/articles/defining-energy-access-2020-methodology

Kumar, M., & Verma, A. (2018). Text Clustering Techniques A Review. *International Journal of Computer Sciences and Engineering*, *6*(6), 1091–1099. https://doi.org/10.26438/ijcse/v6i6.10911099

Massam, H. (1988). Mdti-criteria (MCDM) Decision Making Techniques in Planning. *Progress in Planning*, *30*(Mcdm), 1–84.

Monteiro, C., Ramírez-Rosado, I. J., Miranda, V., Zorzano-Santamaría, P. J., García-Garrido, E., & Fernández-Jiménez, L. A. (2005). GIS spatial analysis applied to electric line routing optimization. *IEEE Transactions on Power Delivery*, *20*(2 I), 934–942. https://doi.org/10.1109/TPWRD.2004.839724

MWIE. (2019). *National Electrification Program 2.0*. 1–216.

Nawaz-ul-huda, S., Burke, F., Azam, M., & Naz, S. (2012). GIS for power distribution network: A case study of Karachi, Pakistan. *Geografia - Malaysian Journal of Society and Space*, *8*(1), 60–68.

Niro, S. (2014). *The Benefits of Using Mobile Technology for Data Collection and Reporting*. https://www.woodardcurran.com/the-benefits-of-using-mobile-technology-for-data-collection-and-reporting-2/

Niro, S. (2020). *he Benefits of Using Mobile Technology for Data Collection and Reporting*. 3. https://www.woodardcurran.com/blog/the-benefits-of-using-mobile-technology-for-data-collection-and-reporting

Rai, P. K., & Singh, C. (2016). Gis in electrical asset mapping: The case of bhadohi, India. *European Journal of Geography*, *7*(4), 19–33.

Saaty, R. W. (1980). The analytic hierarchy process-what it is and how it is used. *Mathematical Modelling*, *9*(3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

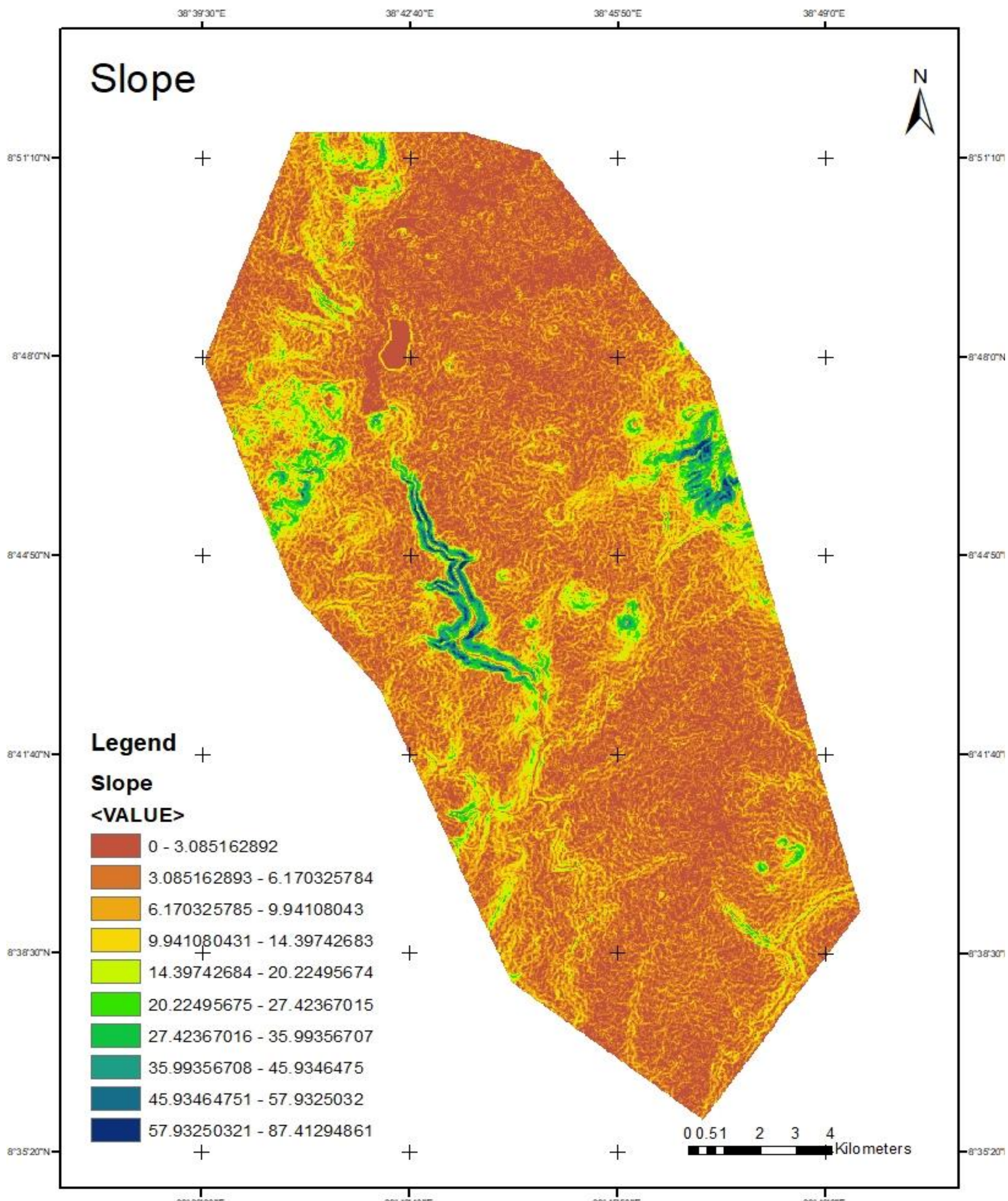
Saxena, A., Prasad, M., Gupta, A., Bharill, N., Patel, O. P., Tiwari, A., Er, M. J., Ding, W., & Lin, C. T. (2017). A review of clustering techniques and developments. *Neurocomputing*, *267*(May 2018), 664–681. https://doi.org/10.1016/j.neucom.2017.06.053

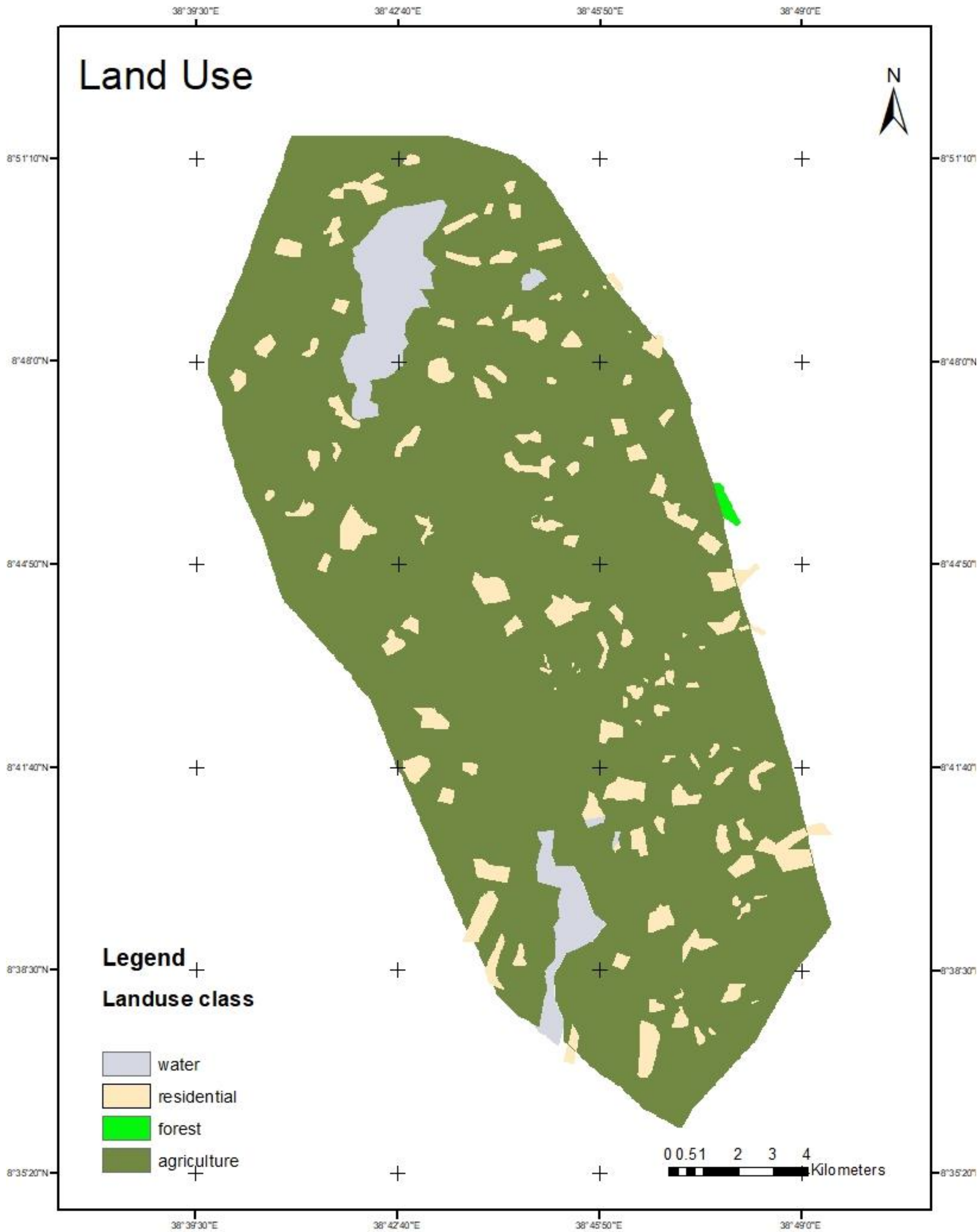
Suleiman, S., Agarwal, V. C., Lal, D., & Sunusi, A. (2015). Optimal Route Location by Least Cost Path (LCP) Analysis using (GIS), A Case Study. *International Journal of Scientific Engineering and Technology Research*, *04*(44), 9621–9626.

World Bank, W. (2018). *Addis ababa, ethiopia*. *July*.

Annexes

1. Factor




Land Use
N
Legend
Landuse class
water
residential
forest
agriculture
0 0.5 1 2 3 4
Kilometers
38°39'30"E
38°42'40"E
38°45'50"E
38°49'0"E
8°51'10"N
8°48'0"N
8°44'50"N
8°41'40"N
8°38'30"N
8°35'20"N

1.1 MV collection form xlsx format

dateTime	inventory_date	Inventory Date	The date and time of	yes						now()			
text	user_ID	User ID	Provide yc	yes			(regex(., "[0-9]{6}"))						
type	name	label::English	hint::Englis	required	read_only	default	constraint		relevant	calculatior	choice_filt	appearanc	repeat_count
start	start												
end	end												
dateTime	inventory_date	Inventory Date	The date and time of	yes						now()			
text	user_ID	User ID	Provide yc	yes			(regex(., "[0-9]{6}"))						
select_one choices_region	region	Region	Select regi	yes									
select_one choices_district	district	District	Select dist	yes							region= ${region}		
select_one choices_service_center	service_center	Service Center	Select serv	yes							region= ${region} and district= ${district}		
text	town_city_village	Town/city/village	Mention tl	yes									
text	net_point_name_of_node_start	Net Point Name of Node Start	Special na	yes									
geotrace	seg_path	Segment Path	The GPS d	yes									
decimal	seg_distance	Segment Distance			yes					distance(${seg_path})			
text	net_point_name_of_node_end	Net Point Name of Node End	Special na	yes									
select_one choices_description	description	Description / Pole Type	Select the	yes									
select_one choices_pole_structure	pole_structure	Pole Structure	Identify pc	yes					(selected(${description}, 'wooden')) or (selected(${description}, 'steel')) or (selected(${description}, 'imported')) or (selected				
text	additional_description	Additional Description											
select_one choices_no_of_circuits	no_of_circuits	No. of Circuits	Select the	yes									
begin repeat	circuit_detail	Circuit Detail											if(${no_of_circuits}='single',1,if(${no_of_circuits}='double',2,if(${no_of_circuits})
calculate	circuit_detail_ID	User ID			yes					${user_ID}			
select_one choices_source_of_power	source_of_power	Source of power	Used to id	yes									
text	source_of_power_2	Other source of power	Select oth	yes					(selected(${source_of_power}, 'other'))				
select_one_external choices_substation_name	substation_name	Substation /Source of Power Name	The name	yes							region=${region} and district= ${district}		
select_one_external choices_feeder_name	feeder_name	Feeder Name	The name	yes				constraint_message			region=${region} and district= ${district} and substation_name= ${substation_name}		
select_one choices_voltage_level	voltage_level	Voltage level (15,19,33) KV		yes									
select_one choices_arm_type	arm_type	Arm Type	The type c	yes									
select_one choices_type_of_conductor	type_of_conductor	Type of Conductor	Describing	yes									
text	type_of_conductor_2	Type of Conductor	Describe the type of material conductor has been produced from.						(selected(${type_of_conductor}, 'other'))				
select_one choices_size_of_conductor	size_of_conductor	Size of Conductor (in mm square)	Select the	yes									
integer	size_of_conductor_2	Size of Conductor (in mm square)	Describe the cross sectional area of the conductor in mm square						(selected(${size_of_conductor}, 'other'))				
select_one choices_insulation_of_conductors	insulation_of_conductors	Insulation of Conductors	Bared or I	yes									
select_one choices_type_of_insulator	type_of_insulator	Type of Insulator		yes									
end repeat													
select_one choices_pole_length	pole_length	Pole Length / Height (in Meter)	Select Pol	yes					(selected(${description}, 'wooden')) or (selected(${description}, 'steel')) or (selected(${description}, 'imported')) or (selected				
select_one choices_pole_strengh_dan	pole_strengh_dan	Pole Strength (daN)	Select pol	yes					selected(${descriptio description=${description}				
select_one choices_type_of_pole_foundation	type_of_pole_foundation	Type of pole Foundation	Foundatio	yes					(selected(${description}, 'wooden')) or (selected(${description}, 'steel')) or (selected(${description}, 'imported')) or (selected				
select_one choices_pole_treatment	pole_treatment	Treatment of poles (Wooden)		yes									
select_one choices_visual_inspection_of_pole	visual_inspection_of_pole	Visual Inspection of Poles		yes									
select_one choices_pole_erection_condition	pole_erection_condition	Erection Condition of Pole		yes									
select_one choices_visual_inspection_of_insulator	visual_inspection_of_insulator	Visual Inspection of Insulator		yes									
select_one choices_visual_inspection_of_arm_type_and_accessories	visual_inspection_of_arm_type_and_accessories	Visual Inspection of Arm Type and Accessories		yes									
select_one choices_visual_inspection_of_conductors	visual_inspection_of_conductors	Visual Inspection of Conductors		yes									
integer	number_of_poles_from_node_to_node	Number of Poles from Node to Node	Describing	yes									
select_multiple choices_type_of_node	type_of_node	Type of Node	The type c	yes			count-selected(.)<=4						
select_one choices_type_of_switch	type_of_switch	Type of Switch	The opera	yes					(selected(${type_of_node}, 'switch'))				
decimal	grading_factors	Grading Factors (from 20 to 100)			yes					if(${pole_treatment}=1 or ${pole_treatment}=3 or ${pole_treatment}=5,${pole_treatment}*4,0)+ if(${visual_ins			
text	status_of_line	Condition / Status of Line			yes					if(${grading_factors}<0,"Error", if(${grading_factors}<=30,"Poor",if(${grading_factors}<=60,"Fair",if(${grading_fa			
decimal	network_acquisition_value	Nework Acquisition Value	Costs of erecting the distribution network per unit										
date	in_service_date	Capitalization (In Service) Date	the inservice/operation start date of the network										
select_one choices_service_of_line	service_of_line	Service of Line		yes									
text	owner_of_line	Owner of Line	Name of t	yes		EEU							
text	remark	Remark											

2.2 Equipment survey form xlsx format

read_only	default	required	appearance	bind::saveIncomplete	type	choice_filter	repeat_count	relevant	constraint	calculation	name	label	hint	constraint_message	image	audio
	"A-06"	yes	2		text				regex(., "^[A-Za-z]{1,2}-[0-9]{1,3}-?[0-9]{0,3}$")		id	your ID		Invalid ID		
					begin repeat						Eq	Equipment				
		yes	quick	yes	select one region						region	Select region for circuit				
		yes	quick	yes	select one substation	region=current()/../region or region='other'					substation	Select substation for circuit				
		yes	quick	yes	select one feeder	sub=current()/../substation or sub='other'					feeder	Select feeder for circuit				
		yes			text			${feeder}='other'			feeder_other	Enter feeder name manually				
		yes			select one source_of_power						source_of_power	select source of power for substation				
		yes			select one Voltage_level						Voltage_level	select voltage level of feeder				
		yes			select one Equipment_type						Equipment_type	select type of equipment				
		yes			select one choices_trafo_have_plate_no			selected(${Equipment_type},'transformer')			choices_trafo_have_plate_no	Does the transformer have plate number?				
		yes			select one choices_trafo_positioning			selected(${Equipment_type},'transformer')			choices_trafo_positioning	select trafo_positioning				
		yes			select one Transformer_pole			selected(${Equipment_type},'transformer')			Transformer_pole	select the transformer pole the trafo is mounted on.				
		yes			select one Manufacturer			selected(${Equipment_type},'transformer')			Manufacturer	select Manufacturer of the transformer				
		yes			text			selected(${Equipment_type},'transformer') and selected(${Manufacturer},'other')			Manufacturer_other	Enter transformer Manufacturer manually				
		yes			select one Transformer_capacity			selected(${Equipment_type},'transformer')			Transformer_capacity	select transformer capacity				
		yes			text			${Transformer_capacity}='other'			Transformer_capacity_other	Enter transformer capacity				
		yes			select one phases_output			selected(${Equipment_type},'transformer')			phases_output	select phase out put				
		yes			select one cap_rating			selected(${Equipment_type},'capacitor')			cap_rating	select capacitor rating				
		yes			select one switch_rating			selected(${Equipment_type},'section_switch')			switch_rating	select switch rating				
		yes			select one fuse_rating			selected(${Equipment_type},'load_break') or selected(${Equipment_type},'fused_cutout')			fuse_rating	select fuse rating				
		yes			geopoint						loc	Take a GPS point as close to the point of interest as possible.				
					end repeat						id					

3.Data collection pictures