

GIS BASED APPROACH FOR ELECTRIFICATION PLANNING AND MODELLING IN CHIRADZULU DISTRICT, MALAWI

DAWNWELL CHIWANDA

Thyolo, Malawi

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DISSERTATION APPROVED BY:

SUPERVISOR:

Title, Initials, Name Signature: _____

ASSESSOR:

Title, Initials, Name Signature: _____

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Abstract

Most of the developing countries confront a challenge of lack of access to consistent electricity supply service. Usually, the common affected sites are rural and peri-urban areas since they occur to be far from town and cities. Geographic information system (GIS) is gradually becoming a preference for energy modelling and planning to enhance electricity distribution in rural areas. Malawi Rural Electrification Program (MAREP) defies the challenge of lack of access to electricity by proposition of electrification models for energy analysis, design and distribution across rural areas. Electrification modelling involves the incorporation of various geospatial datasets as well as attribute datasets for analysis, processing and model development. The datasets including Chiradzulu boundary data, MAREP sites data, ESCOM dataset consisting of Distribution lines and service transformers among others. The data is analysed and processed in ArcMap software tool in order to assess the presence of electricity in the surrounding MAREP sites in relation to the existing electricity grids shown after processing by geospatial processing tool commonly known as buffer tool. Buffer analysis facilitates identification of MAREP sites that lay around within a radius to an existing electricity grid as well as those sites that are beyond the electricity grid. The topography of Chiradzulu district, determined by contours enable identification of potential areas for alternative renewable energy sources including solar, wind and biomass energy. Areas of high elevation tend to receive strong winds necessary for generation of wind energy as a supplement in areas where electricity grid is not practically feasible. In flat lands, the probable energy alternative is solar and in areas of very low elevation usually close to water bodies, the implementation of biomass energy production can prove to be essential. The output data model shows a rural electrification model for Chiradzulu district with information displaying digitized spatial features representing electricity distribution lines extensions along with the alternative sources of energy in their respective spatial locations that ensures just access to electricity across all MAREP sites in Chiradzulu district as a whole.

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ACRONYMS/ABBREVIATIONS

GIS: Geographic Information Systems

MAREP: Malawi Rural Electrification Programme

ESCOM: Electricity Supply Corporation of Malawi

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1. Chapter 1: Introduction

Annual conclusions from the World Energy Outlook Report, shows that over 1.6 billion people situated in rural areas of the developing countries do not have access to electricity in their homes as well as in their surrounding market places. Since electricity is indispensable in most of the daily activities such as lighting, cooking, refrigeration and running household appliances, consequently, it is particularly crucial to improve the quality of life through provision of electricity access to all village and peri-urban areas (Domínguez & Pinedo-Pascua, 2009). Usually, communities without access to electricity are those found in typical remote and scattered areas where grid extension is not always doable in practice. Thanks to lack of access to electricity, these areas remain undeveloped and primitive mostly because of slow progress of daily economic activities due to absence of electricity. Hence, there is a need for the application of GIS techniques to develop an electrification model to ensure un-bias provision of electricity in rural areas as well as providing suggested energy alternatives like solar energy, wind energy as well as biomass energy as alternatives in remote areas at specific spatial points that will easily be accessible by majority of people. The output data model of the research shall depict an electrification model with suggested checkpoints (spatial locations) consisting of electricity distribution pattern typically electricity grid extension, potential solar power sites as well as locations where Biogas energy maybe put to existence and use. Lack of access to electricity drastically affects people's way of life resulting into backward development. Implementation of GIS techniques for spatial planning and modelling will ensure productive incorporation of spatial data, attribute data, existing ESCOM electric grid data, Service transformers data as well as map data for Chiradzulu district to aid analysis during the data processing and electrification model development in ArcGIS software tool namely ArcMap.

1.1. Background

According to the World Bank's collection of development indicators, Malawi's power sector is one of the most severely constrained in sub-Saharan Africa – of which Access to electricity (percentage of population) in Malawi is around 18.02 %. Among 80% population of the people living in rural areas, access to electricity falls at less than 1%(World, 2019). The total installed capacity for power generation in the

interconnected grid of Malawi operated by Electricity Supply Corporation of Malawi (ESCOM) is approximately 362 megawatts (MW), where 351 MW is hydropower and 11 MW is reciprocal diesel engines. Blatantly, the amounting energy present cannot equally be available and sufficient to the whole population for use due to sparse spatial arrangement of population in rural areas. To ensure economic growth in rural areas much focus should be fasted in providing access to electricity mostly on trading centres because that is where majority of villagers associate and their residences reside around the market area. This will ensure development since allot of people will have access to the electric power grids through the market services, hence improved way of life and economic development (Borgstein, Li, Santana, Wade, & Wanless, 2019). Chiradzulu is a district in the Southern Region of Malawi, the district covers an inclusive area of 767 km² and has a population of at least 370, 579 both male and females including children. Less than 10% of the population lives in urban whereas the remaining 90% percent reside in rural areas of the district (Statistics, 2018).

1.2. Problem Statement

There is High demand of electricity in Malawi residential areas than the supply can meet. This usually affects people in the rural areas because they lack access to ESCOM supply grids that leads to scarce of electricity in villages. This plainly shows that Malawi is severely suffering to provide its citizens with access to consistent and reliable electricity for daily use. The lack of access to electricity pose to be a great threat to development of rural as well as peri-urban areas in Malawi. Most of Trading centres also known as MAREP sites in Chiradzulu lack access to ESCOM power grids which is a key drawback to advancing in development activities that involve electric energy i.e. welding, lighting among others. Chiradzulu surfers a great hindrance in socio-economic development of its surrounding areas due to the absence of electric grids in some market areas and in its residential areas. Majority of people in Chiradzulu district are set in typically rural areas where electricity is not present, hence the population living in these places stay primitive such that they cannot acquire electronic devices for home use. This also hinders economic growth and development of the area because no one is willing to invest in places without electricity grids.

1.3. Main Objective

- To develop a geospatial electrification model using GIS techniques for Chiradzulu District.

1.3.1. Specific Objectives

- To assess electricity availability of MAREP sites that exist 2km from ESCOM existing power grid.
- To evaluate the MAREP sites that are beyond visible existing ESCOM power grids.
- To propose electrification technological Model suitable to supply MAREP sites with power grids.

1.4. Research Questions

- Can geographic information systems techniques enable the generation of an Electrification model?
- How will the electrification model help in electricity distribution across all MAREP sites Chiradzulu district?
- Can GIS enhance electrification planning and modelling?
- Will the electrification model help in mapping
- How will the electricity reach all those in surrounding rural areas upon reaching the market place?
- What other electricity option can people opt for unlike ESCOM electricity?
- Which sites and areas are best for each type of electricity supply approach?

1.5. Scientific Significance

Since electricity is perhaps one of the most revolutionary and necessity that needs to be taken both in to peri-urban as well as rural areas. This dissertation elaborates full detail on the development of an electrification model that will enhance sharing of access to electricity in rural areas. The implementation of GIS guarantees the analysis of the lack of access to electricity with respect to the exact spatial location in the rural areas. This

will help planners to make crucial decisions on where to extend the electricity grid line depending on location of population of a particular area so that numerous people can get consistent electricity access. The study will also provide preferable electricity alternatives (options) for example Solar, wind and biomass energy to use in far to reach areas. The study becomes relevant in light of the use of advanced GIS technologies in the enhancement and provision of electricity access to people in Chiradzulu villages as well as across the whole Malawi. All to say, the study outcome will formulate GIS models as well as maps showing information and methods to enhance and help rural areas attain the goal of MAREP to ensure a grant of electricity access for daily use. By systematically following the outlines of this dissertation, one should be able to re-invent the wheel and or re-do the project in a different area on the same study to ensure just sharing of electricity energy to the population in all MAREP sites.

2. Chapter 2: Literature Review

2.1. Geographic Information System (GIS)

Geographic Information System is a conceptualized framework that enhances the ability to capture, manage, analyse and visualize spatially referenced data. Rooted in the science of geography, GIS integrates various types of data that has a spatial reference on the earth surface. Typical GIS operation for instance Geo-processing is a major toolset for manipulating spatial data together with it associated attribute data to allow definition, management and analysis of data layers for various processes for example geographic feature overlay, topology processing among others. GIS capability of incorporating both spatial, temporal as well as attribute data enhances and eases the analysis of spatially related problems in the real world. It analyses the spatial location and organizes layers of information into visualizations using maps and models in order to aid a Decision making process(Yuan, 2008). Geographic information system (GIS) is a modern asset for integrating and analysing numerous spatial processes where in turn it facilitate several advantages for example, the use of spatial data to analyse electricity demand at a particular location with the aid of projections that takes into account the location's unique characteristics.

2.2. Electricity Distribution

Access to electricity remains an economic hindrance in many regions of African developing countries. To achieve a swift electricity access for large geographic regions alternative electrification pathways apart from grid Connection need to be put to account and in practice. Therefore, sophisticated GIS planning tools to determine techno-economic optimized electrification pathways are necessary. An approach for such a contrivance prove to be present and up-to date as it combines GIS aspects and energy system tools for electricity distribution and access. The approach focuses on the identification of consumer clusters (spatial location), determination of status of electrification (attribute data) and assignment of a suitable electricity supply option in surrounding rural areas (Borgstein et al., 2019). On national level, a significant challenge to rural areas is the lack of electrification development schemes due to absence of potential investors and associate economic infrastructures (i.e. maize mill and Markets among others) built in the area that act as drive force for provision of an electricity grid line. Village areas surfer a great concern on the inaccessibility of electricity that leads to backward or slow development. Most developing countries face challenges on rapid urbanization as well as high unemployment rate since majority of people from rural areas come seeking for improved way of life in urban areas(Griffith, 2007). Electricity is a factor that facilitates economic growth as well as symbolizing social-economic wellbeing of people. Generally, electricity is an impetus enhancing economic growth strategy nowadays with the influence of technology advancements in different sectors. However, access to the electricity grid is always a problem in rural areas since the spatial location of residential areas sparsely scatter across an unreasonably large area. This tends to stir an inverse relationship between people living with access to electricity are usually those situated very closed to an existing electricity grid line unlike those in far places beyond the electricity grid line.

2.3. Data Accessibility, Management and Visualization

ArcGIS tool namely ArcMap is essentially a geographic information system software capable of accessing, manipulating as well as visualizing geospatial referenced datasets. Arc-Catalogue, is a tool for data management, it is an additional tool in ArcMap for data accessibility from the computer storage. It connects the directory containing the

map data to ArcMap through the Catalogue for easy data acquisition and accessibility. Map data for Chiradzulu district was loaded from the Arc-Catalogue on to the map data view window together with the associated data that includes Chiradzulu MAREP sites, ESCOM distribution lines, service generators as well as village dataset for visualization and analysis. Data from the Arc-catalogue is susceptible to modifications upon loading the files to ArcMap data frame to ensure data consistency by checking for map data type, map projection among others. This ensures that the data in the ArcMap data view window is free from discrepancies during manipulation. For instance, map data with different coordinate systems causes a problem when digitizing spatial features in the data frame. Connecting Arc-Catalogue facilitates easy data management and handling during data processing. The superimposition of thematic map layers in the table of contents enables combination of data features so that it gives meaning when visualizing in the data view window. Map layers show the main area of study as well as its current state, in this case the presence of already existing Distribution lines, service transformers in relation to the MAREP sites. This helps analysts to conduct visual as well as digital analysis to make sure that there is data consistency within the datasets before running geo-processing tools. Table of contents holds map data layers, allows analysts to edit data layers properties, enable switching on and or off the data layers so that they appear and disappear in the data view window. Data of different projection coordinates poses a hindrance during editing for example digitization of shapefile data requires shapefile data referencing with the base map or other data sources in the data panel. Overall, the data contents retrieved from Arc-Catalogue shows map contents that facilitates analysis and electrification model design to aid decision-making process during electricity distribution across Chiradzulu district.

2.4. GIS Electrification Modelling

Over the past decades, GIS has been a vanguard approach that employs spatial planning process in rural electrification mapping and modelling. GIS provides a framework that enhances comprehensive electrification analysis and provides useful insights into the technological options and investment requirements necessary to boost electricity access at all levels. A quantitative approach is significant during electrification model planning

which makes it essential to map the estimate of the growing electricity demand in a most cost-effective way across rural areas. It also ensures efficient mapping of the alternatives of renewable energy resources including solar and biomass to supplement the electricity grid line supplying the area under study (Parker & Asencio, 2008). Seemingly, most of the shortcomings in current energy system research planning set their base on the topological models that clearly show the lacking in geospatial planning activities during location analysis. In other words, electric energy systems largely decouple from the real world (in a geographical point of view) as they mostly only consider topological relationship within the existing grid network, disregarding the actual topographic and geographic relationships. This perennial challenge incurs the incorporation of spatial nature of all potential energy systems, and not only considering energy relating parameters but also the entire geographical phenomena including the population of people in the surrounding area (Korkovelos, Bazilian, Mentis, & Howells, 2017). The GIS approach in support of planning for electrification model as well as the analysis of potential energy alternatives including solar energy, biomass energy and wind energy will establish an elaborative and informative procedure for integrated data quantification with its associate data visualization, to aid decision making. It also leads to the generation of a set of sequential steps that include renewable energy potential estimation, energy self-sufficiency analysis and composite map preparation using Geographic information system(Crampton, 2010). This approach takes one-step further from previous tasks that only dealt with GIS-based site selection and so it takes into account the long awaited energy self-sufficiency possibilities in all potential sites at regional level. To attain this goal, there is a need for an integration of spatial planning concepts that contain guidelines for carrying out a significant spatial planning process during data analysis and manipulation.

2.5. Demographic Analysis and Electricity Access

There is an inverse relationship between population of people living with access to electricity and those that are not, to the distance that these populations are living from the existing electricity grid as well as the presence of alternative energy systems. It emanates out to be true that the shorter the distance from the existing electricity grid the high the possibility of having consistent electricity access and the vice-versa(Resch &

sagl, 2014). In rural areas, often many villages reside at longer distances from peri-urban areas hence this setting poses a drawback to potential investors who are planning to undertake an economic project that requires dependable electricity access provision and grant. Commonly, despite being far away these villages are also scattered across a large space in a specific rural area. To achieve just provision of electricity access, planners take advantage of the presence of market places as a convenient location from where everyone can access the electricity for daily services. Generally, electricity in villages is more profound to be in use mostly for lighting and driving electronic appliances like radios that plainly depicts low consumption of energy from the electricity grid as compared to urban areas consumption rate.

2.6. ArcGIS Software Analysis

GIS comes along with various aligned software tools that enhances the analytical processes done during spatial planning, analysing, manipulation and visualization of data. In this case, ArcGIS software is one of the major tools that play a huge part in tasks that involve spatial as well as attribute data analysis to aid decision making. Relationship distance that occurs between people living in a village (in rural area) from an existing electricity grid is often assessable using GIS tool kits, potentially, buffer analysis tool is more preferable to measuring distance in a specified distance value (often; radius). Buffer analysis is the most important function of spatial analysis in Geographic Information Systems. The basic idea of buffering is to create a zonal area of a certain specified distance around its boundary namely buffer zones, that will support analysts in identifying the impact range and service provision range to the surrounding environmental proximity (Esri, 2004). Upon data assessment using buffer tool, the output data shows the distance of a feature under consideration to the reference feature in the area of study. In this case, the distance of villages living at a close proximity to an existing electric grid will fall within the specified linear distance value in the buffer tool on the output display. Those areas far beyond the specified linear distance value does not appear within the buffer zones since they are off the electricity grid. Visual analysis also aid the evaluation of areas that exist outside the buffer zones to enhance a sound decision making process. These incur either an extension grid to reach the population in far areas or by simply applying any energy alternatives including solar

and wind energy depending on their spatial location and topography. Buffer analysis usually help determination of distance of a feature from the nearest reference point specifically given by the linear distance value(Dong, Yang, Rui, Zhang, & Cheng, 2003).

2.7. Renewable Energy Alternative Sources

Electrification plans go by a number of names in literature, with variants namely; rural electrification master plan and national electrification master plan. These plans not only considers the provision of electricity through electric grid lines but they also include the alternative energy sources such as solar energy, wind energy as well as biomass energy systems. Implementation of least-cost planning supported by Geographic Information Systems is recommendable for analysis because in usually ensures the information is nearly up-date unlike classic or traditional approaches that involve paper documents of which some render out-of-date for spatial processing (Borofsky & Perez-arriaga, 2020). The choice of an electric energy source is mostly dependent on the physical topography of an area. Some of the far to reach areas (Villages) are geographically flat, while other areas are mountainous in nature and some are located in low lands. These factors play a great role in assignment of an efficient energy alternative in relation to the location characteristics. For example, Flat areas have an advantage of providing a full surface for sun radiation reflectance and absorbance to occur in relatively large amounts, hence, usability of solar energy. It is therefore reliable to suggest the use of solar panels to harness the energy from the sun and converting it into electric energy. This usually works better during summer season since the sun is overhead as it sprouts a lot of energy through the clear sky to the earth surface. Introduction of solar energy in rural areas also enhances improved agricultural practices, be it solar water pumps among others.

In lowland areas, mostly there is less access to efficient sun energy for solar panels, so a suggestion of an alternative energy source perchance is biomass energy in supplement of Solar and electricity energy. Biomass derives from livestock dungs and biological plants as well as animal remains enclosed in an airtight depository. These decaying components produces flammable Biogas that is a utility for cooking, lighting and heating in homes. The lower lands are fond of swampy areas with enough dead plant material together with animal remains are essential materials that are key factors for energy

generation locally. Malawi national policy on Biomass energy strategy emphasizes the transformation of the country's economy from high dependency on biogas energy to more eco-friendly energy system particularly hydropower, but at the same time government has recognized that more pragmatic approach to the biomass energy sector is required(Peterson, 2009).

Areas situated in high lands pose a chance of using wind as a drive force for electricity generation at a reasonably low local cost. GIS spatial planning and analysis ensures detection of areas in high lands so that potential sites for wind energy generation are into account.

The presence of a complimentary energy sources in addition to the insufficient electricity from the grid eventually leads to just provision of electricity in rural areas through the implementation of GIS techniques and spatial planning process. The electrification model shows the population with access to electricity from the grid as well as the supplement of renewable energy sources in their respective locations beyond the existing electricity grid. The map output of an electrification plan help to facilitate the allocation of electricity services having in mind the spatial settlement of the surrounding villages. This will ensure social economic development of the rural area and in turn reduce rapid urbanisation that usually happens when people from villages are migrating to town areas in search for improved way of life.

3. Chapter 3: Methodology

3.1.1. Study Area

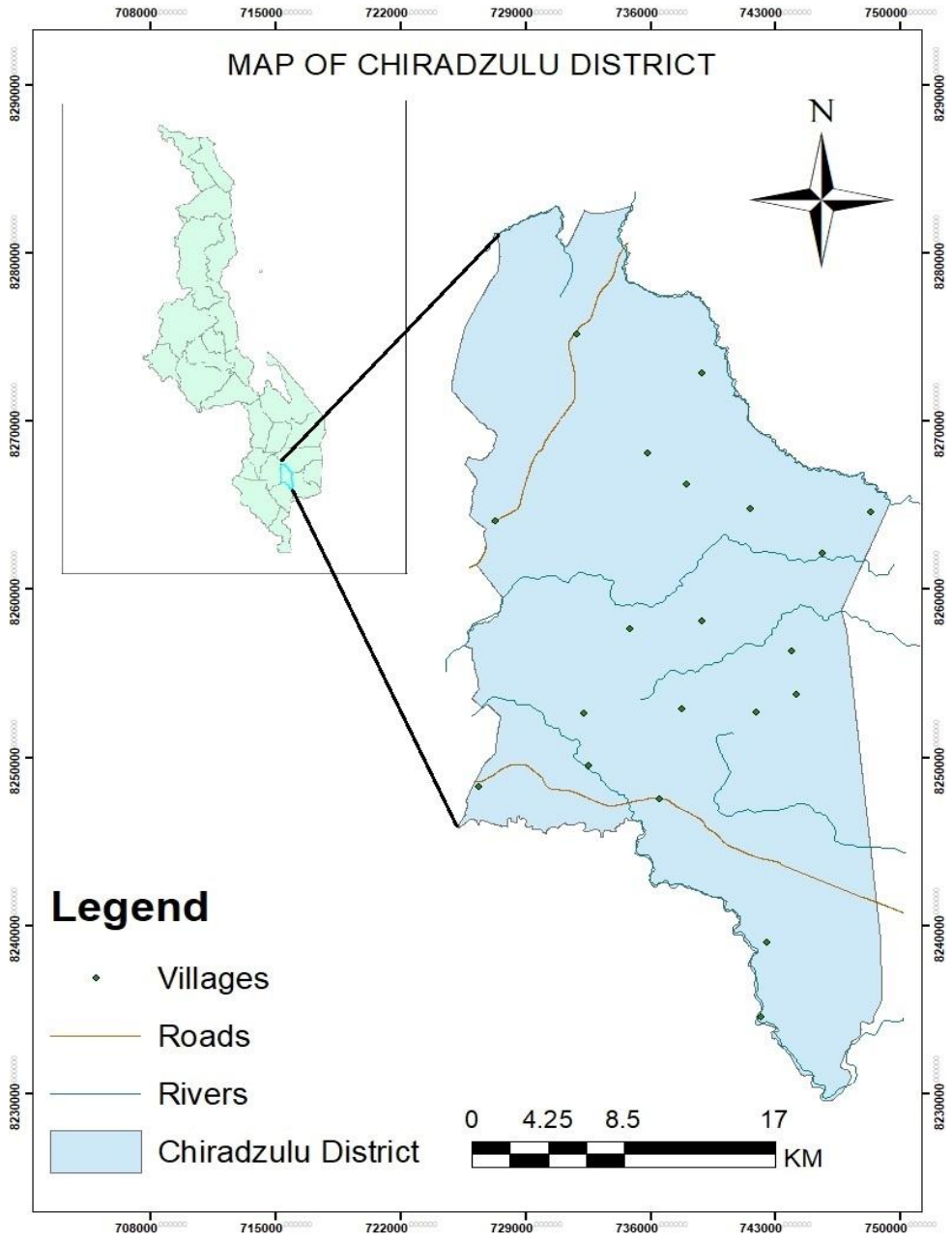


Figure 1.0 shows Map of Chiradzulu district

3.1.2. Research Design

A qualitative GIS approach is indispensable to carry out the proposed project since energy system planning is essential in order to enable equivalent match in supply with growing demand usually in the most cost-effective way across rural areas. In addition, moving from planned, centralized, and expensive energy carriers toward fluctuating,

decentralized, and cost-effective renewable energy production necessitates considerable modifications in energy infrastructure as well as critical planning is carefully put to practice for optimal results during a long run electrification project. These modifications most often prioritise the utilization of geospatial datasets as a major input dataset for modelling and processing, therefore spatial data are of key importance to help identify the most effective electrification strategy. Geographic information techniques will ensure probable data processing to acquire minimal results to guide the research project with its associated objectives of the study. With the help of ArcMap software, incorporation of map data as well as MAREP sites data as well as ESCOM data will enable data analysis, processing which involves digitization among other processes. This dissertation will outline key aspects of electrification modelling with all associated energy resources to ensure consistency in electricity access to population across the entire Chiradzulu District.

3.1.3. Material

This research project involved personnel, data, hardware and software as part of input material where personnel were GIS experts, geospatial datasets in table 1.0. Hardware includes computers with minimum of 4GB RAM and 500GB ROM, where software includes ArcGIS software-ArcMap and MS office. The following table shows hardware and software requirements.

TYPE	Material	Properties
hardware	Computers	4GB RAM 500GB ROM
Software	ArcMap Arc-Catalogue MS office	Compatible on Windows and IOS

Table 1.0 shows hardware and software material required for electrification modelling

3.1.4. Data

No.	Data label	Data type
1	Service transformers	Point
2	Chiradzulu MAREP sites	Point
3	Chiradzulu Distribution Line	Polyline
4	Chiradzulu boundary	Polygon
5	Contours	polyline
6	Chiradzulu River data	polyline
7	Service transformers	Point

Table 2.0 shows data types required for the electrification-modelling project

3.2. Data Handling In ArcGIS Software

ArcGIS software namely ArcMap was opened from computer start menu of applications. In the ArcMap window, the new map project was opened to a blank window. On the ArcMap toolbar, Catalogue window was opened and the data directory containing the project data was connected to ArcMap for data access. Upon loading the datasets to the map window, map data projections were checked and transformations were made to data that had different projection system where it was transformed to WGS84 36S. Chiradzulu map boundary data was loaded from the Arc-Catalogue window on to the blank map project. The ESCOM distribution line for Chiradzulu district was also loaded to the project on top of the boundary data. MAREP sites data of Chiradzulu district was also loaded in the ArcMap and over-layered to the project data in the map window. Service transformers data Shapefile was also loaded in the ArcMap project window. To ensure data consistency, the map data layers in the table of contents enables cross checking by switching ON and OFF to make sure that

the required data features are practically loaded in the ArcMap. The data frame window enhanced data visualization for feature identification among other feature classes in the map data. Data overlay inspection was conducted to ensure that the data loaded is specifically for the electrification model for Chiradzulu district.

3.3. Data Processing in ArcMap

3.3.1. Buffering Process

On the main ArcMap window, Geo-processing tab was clicked and buffer analysis tool was opened. With all datasets loaded in ArcMap, the buffer tool on the input features drop-down, Chiradzulu MAREP sites feature class was selected. Automatically, the Output Feature Class directory was created to hold the buffer results contents after processing. A distance value of 2KM was specified in the linear distance field of the buffer tool. The drop-down button to the right of the linear value was set to kilometers. The buffer tool was executed by clicking OK at the bottom of the buffer tab. Data layer containing buffer zones was created in the table of contents as a temporary layer Visual analysis was made to identify the MAREP sites existing within 2KM close to the electricity grid. The MAREP sites existing beyond the existing electricity grid were also identified on the buffer model generated after processing.

3.3.2. Electricity Grid Extension

To extend the electricity grids to nearest MAREP sites, digitization method plays a key functionality on this phase of processing whereby it is used to add new features to the map model. In the ArcToolBox, editor function was opened and editing mode was enabled. In the ArcCatalog under the folder containing map data, polyline Shapefile for Electricity distribution line was created. On Editor's toolbar, create feature tab was opened and Chiradzulu Distribution line was selected for editing. On the map data frame, the existing grids were extended by editing the line feature to the nearest MAREP sites that lay beyond but nearly close to the electricity distribution grid. The line feature extension was digitized up to reaching the buffer zones of the nearest MAREP sites so that they can have access to electricity. For addition of service transformers to the extended electricity grids, point Shapefile feature was created in the catalogue window for service transformers. On the editor's tab, create feature was opened and service transformers was selected for editing. In the map view area, service transformers were

digitized on the extended electricity distribution lines across Chiradzulu district in the buffer zones. The edits were saved and the editor was stopped. The final output model contains pre-existing electric grids, freshly digitized extension grids as well as service transformers are present on the map model.

Map data was switched to map layout view for cartographic analysis and design. To begin with, the map title was written as electricity grid extension. The legend of the map was generated consisting of the Chiradzulu boundary, extended electric grids, additional service transformers, buffer zones, MAREP sites as well as existing service transformers and electric distribution lines. The map was generated to a scale that was set to be in Kilometers.

3.3.3. Topographic Analysis

Shapefile data for Chiradzulu district boundary and villages was loaded from Arc-catalogue. Data Shapefile for Chiradzulu elevation properties in form of contours was loaded in the ArcMap project on top of the loaded data layers. In the table of contents, contour properties was opened and the symbology tab was selected. Under categories, unique values were added and the value filed was set to height with a specific colour lamp as well as labels. The properties tab was closed after applying the changes to the contours layer in the map data. Visual inspection was conducted on the map view frame to identify areas of high elevation and those of low elevation. Areas of lowlands, flatlands, high to steep slopes were identified on the map model by checking the presence of sparsely spaced contour lines across the area. Areas situated in high lands were identified by the presence of closely spaced contours in Chiradzulu district. In map layout view, legend was added showing elevation of an area with respect to the colour lamp generated from the contour dataset. Analysis was done to identify the location relationship existing between the villages to the topography of the surrounding area with respect to the presence of an electric grid within or beyond the MAREP sites. This is essential in order to select most probable sites for specific energy alternative in Chiradzulu district.

3.3.4. Alternative Energy Sources Mapping

In order to map and assign the alternative energies in Chiradzulu district map model, the digitisation functionality present in ArcMap played a huge role during the process of electrification modelling. This phase also involved river dataset as a lead to identifying probable sites for biomass energy sources. To start with, data for main rivers in Chiradzulu district was loaded to ArcMap from the data catalogue. It was loaded and layered on top of the existing data together with Chiradzulu contour data so that all datasets appears in the data frame. Inspection of river flow was done by identifying areas consisting of closely spaced contours to sparsely spaced contours to detect areas of high as well as low elevation, respectively.

Flat land was identified on the map data through the presence of contours that are sparsely spaced across the district. This clue enhanced a decision of using solar energy as an alternative source of energy in flat lands. To assign the solar stations on the map model, editor tool in ArcMap was started and the point feature Shapefile for solar energy feature class was created in Arc-Catalogue under the folder containing the map data. Solar energy generation locations were assigned in the flat areas by digitizing the solar stations using sun graphic on specific flatlands across Chiradzulu district. The edits were saved upon completion of sketch digitisation. These solar stations cover almost 30% of the area compared to other alternative energy sources.

Areas of high elevated land were identified by having contours that are closely spaced together across Chiradzulu district on the map model. Wind energy was suggested and point Shapefile was created in the Arc-Catalogue. Suggested wind energy point sites were digitised on the map model across Chiradzulu district. The very low elevated areas were also identified by contour lines space further apart as well as those areas near Rivers. These areas were assigned an energy alternative of Biomass which is a naturally renewable energy source. Shapefile for Biomass energy was created in the Arc-Catalogue and its point features were digitised on the map data in the data frame window. The edits were saved and the editor was stopped. In the layout view, map elements were added, these consist of all alternative energies, Chiradzulu boundary data, MAREP sites, Villages data together with rivers dataset. The output model was exported showing the alternative sources of energy across Chiradzulu district.

3.3.5. Electrification Modelling

In the ArcMap data frame, all the contents of the map were loaded and checked in the table of contents. These were Chiradzulu boundary, Chiradzulu distribution line with its associate extension line, Chiradzulu MAREP sites, Chiradzulu villages, service transformers with the added transformers as well as all alternative energy sources including solar, wind and biomass energy. The electrification model was constructed by combining numerous outputs of the research project to summarize the whole concept in one model. In the layout view, a model was generated with a legend containing all the above-mentioned datasets on the electrification model. These features on the model were accompanied by map elements to aid interpretation and decision making.

3. Chapter 4: Results and Discussion

3.1. Data accessibility, analysis and processing

Data layers loaded in ArcMap software are available for analysis from the table of contents and the data frame provides a data view window for all datasets. This research project involves datasets for instance vectors such as shapefile data (polygons, polylines and points among others). The data contains Chiradzulu district boundary, MAREP sites data, Chiradzulu Electricity distribution lines and service transformers. Table 1.1 shows data inputs in ArcMap software. These datasets are key inputs in ArcMap software to aid analysis and processing as well as digitization of additional output features of the research project for example extension grids. The dissertation encompasses processes such us buffering, digitization (electricity grid extension), topographic analysis and model development of an electrification plan for Chiradzulu district.

To begin with, Buffer tool enhances the analysis of availability of electricity in MAREP sites of Chiradzulu district. Buffer model output shows the MAREP sites that lay within the existing Chiradzulu electricity distribution line as well as MAREP sites that exist beyond the visible electricity grids. These MAREP sites are enclosed in buffer zones of radius 2 kilometers surrounding the area where electricity grids are distributed in the Chiradzulu district. Electricity distribution line extensions were extended using the functionality tool commonly known as the editor to facilitate electricity grid digitization. The digitization phase results into generation of a model showing suggested

grids digitised towards the MAREP sites found beyond the existing electricity grid. Service transformers are also placed along the extended grid lines in the MAREP sites during digitization. Figure below shows the extensions with respect to the MAREP sites beyond the existing grids with respect to the buffer zones.

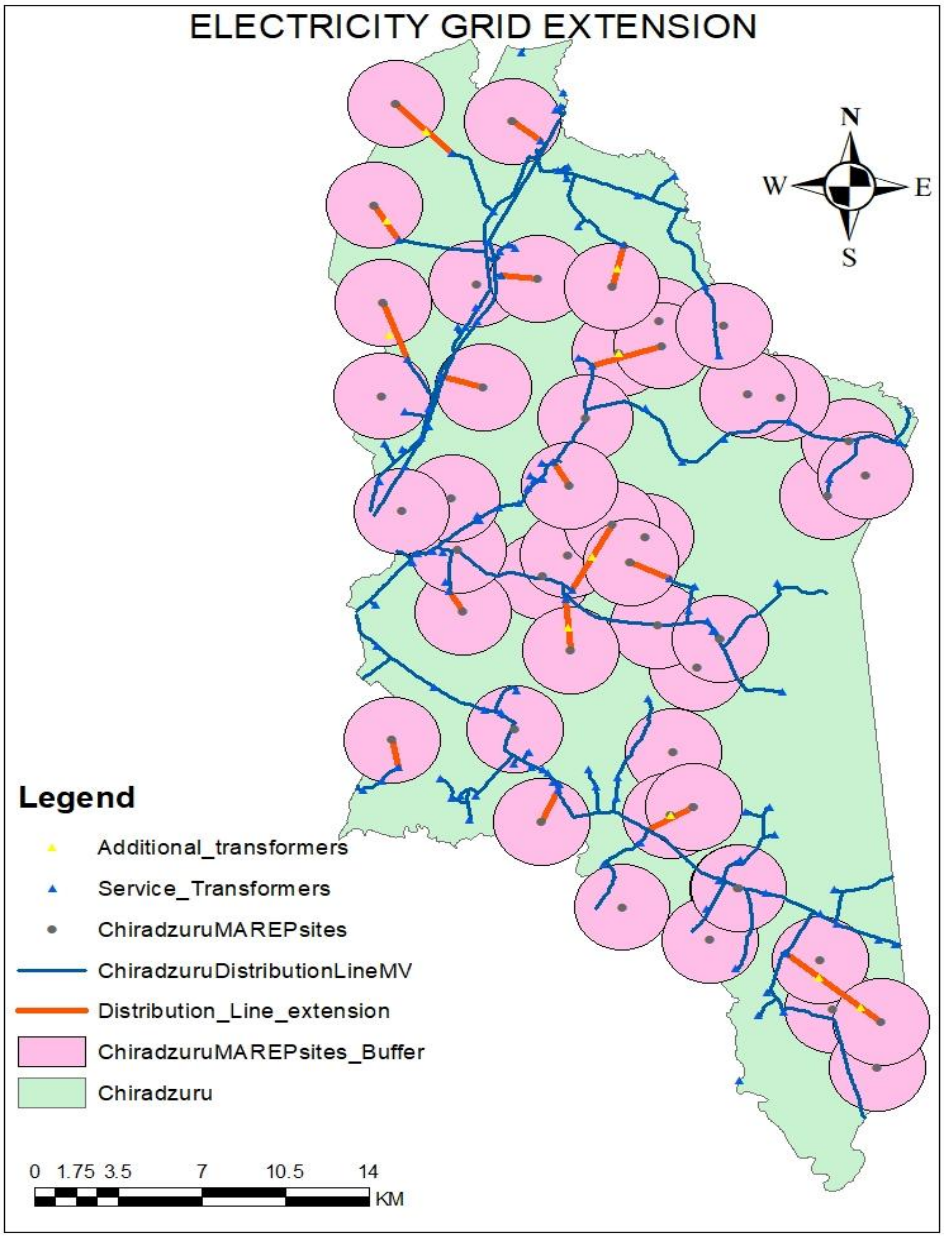


Figure 2.0 shows the extension of the grid lines towards the MAREP sites in Chiradzulu district.

The commonly used spatial data processing tool, Buffer, which is a proximity function tool enhances the generation of an output Model showing buffer zones that appears on a map in form of circles or other polygons. The buffer tool uses a specific linear

distance value when creating the buffer zones, in this case 2KM distance ensures that the output model show only those features (MAREP sites) that fall within the specified distance value as well as those beyond it. The zones shows the model depicting distance of the MAREP sites that are within 2KM from the existing ESCOM electricity grid. The buffer zones that contain an electricity distribution grid accentuates the presence of electricity access to the MAREP site, hence people have access to electricity. Visually, electricity distribution grids that fall within the linear distance value radius of the buffer zones depicts the electricity accessibility in the MAREP sites that have electricity grid in its proximity. The model gives a quick preview of the extent coverage in terms of electricity availability in the MAREP sites consisting of electricity distribution grids in their buffer zones vicinity. On the other hand, the model also shows the distance of MAREP sites that are beyond the existing ESCOM electricity grids. The occurrence of electricity distribution grids outside the buffer zones implies that the MAREP sites are yonder the electricity grid and have no access to electricity. Most MAREP sites in the Villages exist nearly close to the boundary marked by the buffer zones. Some of the MAREP sites are clearly out of reach for electricity distribution because most of these areas reside in typical rural. The overlapping buffer zones graphically portrays an intersection that eases electricity distribution simply because the MAREP sites exist in close proximity to each other. The presence of an electricity grid within these intersected MAREP sites ensures that the population from these areas accesses electricity from common sources.

3.2. Grid Extension (Digitization)

Significant uses of Arc-catalogue are mainly data management as well as manipulation. It also enables analysts to create other feature classes of different data types for example shapefile. In this case, the catalogue facilitates the creation of Shapefile data for electricity grid extension in the directory containing the project map data. Shapefile of vector type specifically a polyline is a feature class that is holds edits done to electricity distribution grids during digitization. The extensions of the electricity grids connects the existing distribution grids that are close to MAREP sites occurring beyond the linear distance value of the buffer zones. Editor tool also enables point feature creation on the map data to add service transformers along the extended electricity grid to facilitate

reliable electricity access to the MAREP sites. The resulting output model shows the extension grids with their associated additional service transformers. Electricity distribution grid extensions are doable only in those MAREP sites existing relatively close to the already existing Electricity grids because it is cost effective to do so than extending the grids to far places where population of sparsely spaced across the area. Shapefile data layer consisting of the extended grids show area coverage of the electricity distribution to the MAREP sites that previously had no access to electricity. Extending the electricity grids on the map model facilitates electricity distribution towards the suggested locations in Chiradzulu district.

3.3. Topographic Evaluation

Topographic analysis and evaluation of Chiradzulu district involves the incorporation contour data together with the MAREP sites data, village Shapefile data. After analysis and processing of the elevation data, output model showing elevation of Chiradzulu district was generated to aid decision making. This model contains information on elevation with colour lamp to show areas of low, flat, high lands as well as steep slopes across Chiradzulu district. Areas that have contours occurring very close together symbolizes area characterized by high land meaning that the area contains hills, steep slopes among others. Those areas with contours further from each other shows that the area is branded as flat area without presence of steep slopes or hills on its surrounding. Very packed contours in an area on a map depicts the presence of very steep slopes in the area under study. Topography of an area is a factor that influences distribution of electricity in an area. It is more concerned about the analysis of the earth surface configuration in order to determine the efficient energy alternative to use in a particular area. Elevation of an area determines the type of alternative energy the area can accommodate depending on topographic characteristics of the area. The elevation model for Chiradzulu shows the combination of Flat land, high elevation as well as low elevation areas. This model facilitates judgement of an area during assignment of alternative energy sources to ensure efficient distribution of electricity in Chiradzulu district. Figure below shows elevation model containing contours of Chiradzulu district.

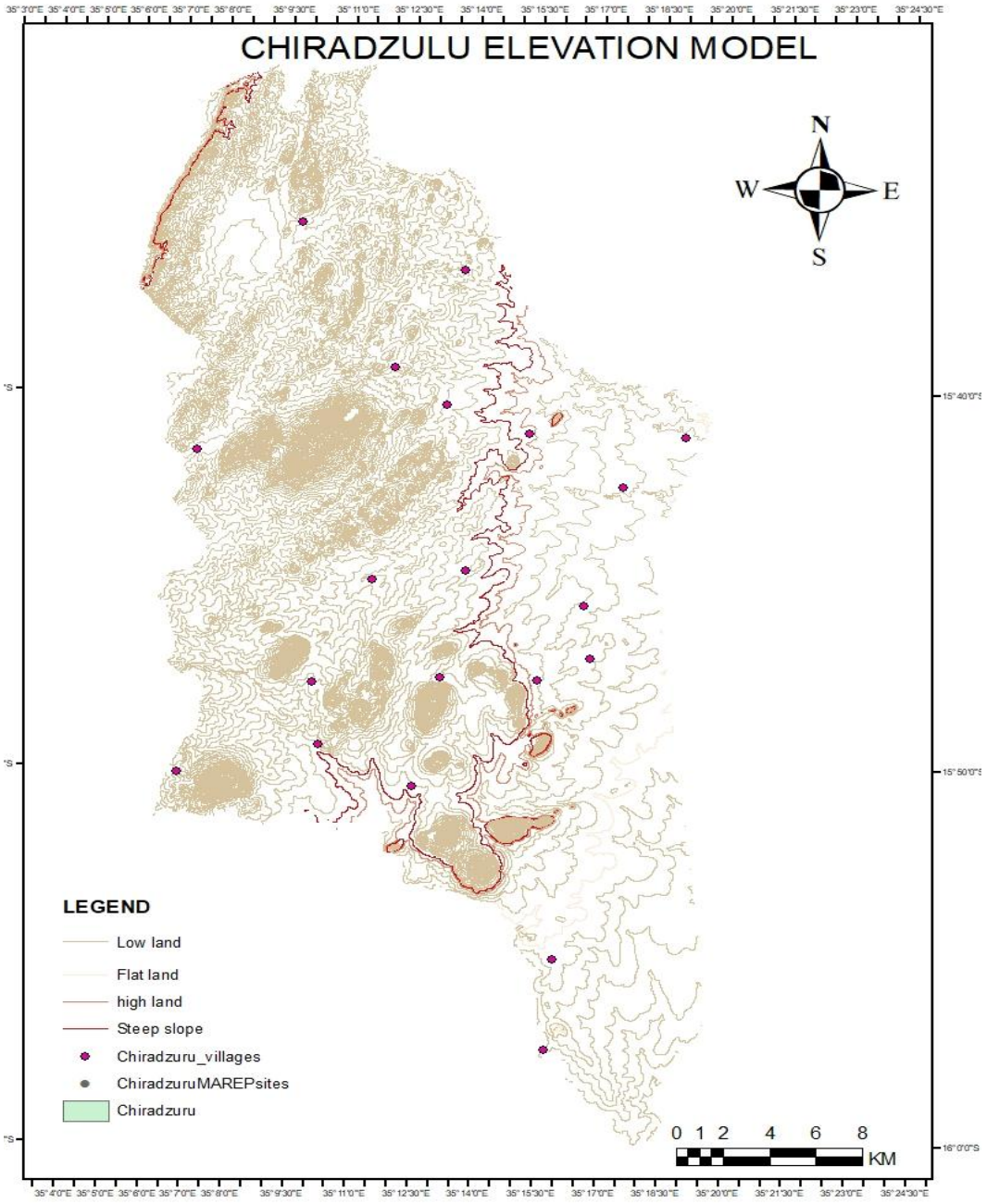


Figure 3.0 shows topographic model of Chiradzulu district

3.4. Evaluation Alternative energy sources

The generated electrification map model show areas that are far beyond the existing ESCOM grids, some of which exist in areas of high elevation where electrification projects are a huge problem in terms of electricity grid extension. The presence of closely spaced contours on the map symbolizes that the area is of high elevation from the sea level. Hence, the application of wind energy alternative is a key factor to enable the capture of wind for electricity production at a household level. Elevation of these areas makes it hard for ESCOM personnel to supply electricity through grids because of

uneven ground and presence of steep slopes. The model incorporates an alternative form of energy, wind energy in some parts of Chiradzulu district. This is because most areas situated in high elevated locations tends to experience strong winds that are almost constant, this plays an important role in generation of electricity locally using wind as a driving force for windmills. These sites would act as supplements to the ESCOM electricity of which a few people have access to the grid in the surrounding areas close the existing MAREP sites.

Some of areas in Chiradzulu district exist beyond the existing ESCOM grid lines where the whole population is scattered across the large surface area that is usually flat land. Population in such areas is sparsely scattered to an extent that electricity grid lines can cost a lot to reach every settlement in the area hence, the use the sustainable energy alternative of solar is an effective proposition. Flat land of which is symbolized by presence of sparsely spaced contours on the map view area of chiradzulu district. These areas on the map fall in areas of quite low elevation from the sea level but high enough to receive enough sun radiation during the whole day. Flat areas are more suitable for implementing solar energy generation devices including solar panels among others that is why solar power stations are located in these areas. Practically, efficient radiation from the sun is highly experienced in areas of flat lands where surface area for reflection is relatively large. In return, solar driven panel harnesses enough heat energy and converts it into electric energy for use in in various local tasks for example lighting. The map model shows numerous checkpoints where solar power generation ensures that the community can have access to electricity.

Coarsely, majority of the villages in Chiradzulu district occur in relatively lower areas, for instance in lower lands close to water bodies for example rivers. People tend to locate in lower lands because of an added advantage of the presence of water for irrigation purposes. These areas hardly have access to electricity since they exist beyond the existing ESCOM grid lines usually due to their presence in the hardly to reach lower lands. Using topology model, the presence of sparsely closed contours along a river line symbolises a very lower land and these places have consistency biomass accumulation in its surrounding. The electrification map model portrays areas where biogas can readily act as an alternative source of energy for heating and lighting among others.

Briefly, the energy alternatives take up certain percentage across Chiradzulu district with respect to the topographic characteristics of the area. Alternative energy model was generated after series of digitization of Shapefiles created for solar energy, wind energy and biomass energy in flat lands, high lands as well as lower lands across Chiradzulu district, respectively. The figure 4.0 shows the alternative energy model with suggested energy sources that can supplement ESCOM electricity in Chiradzulu district.

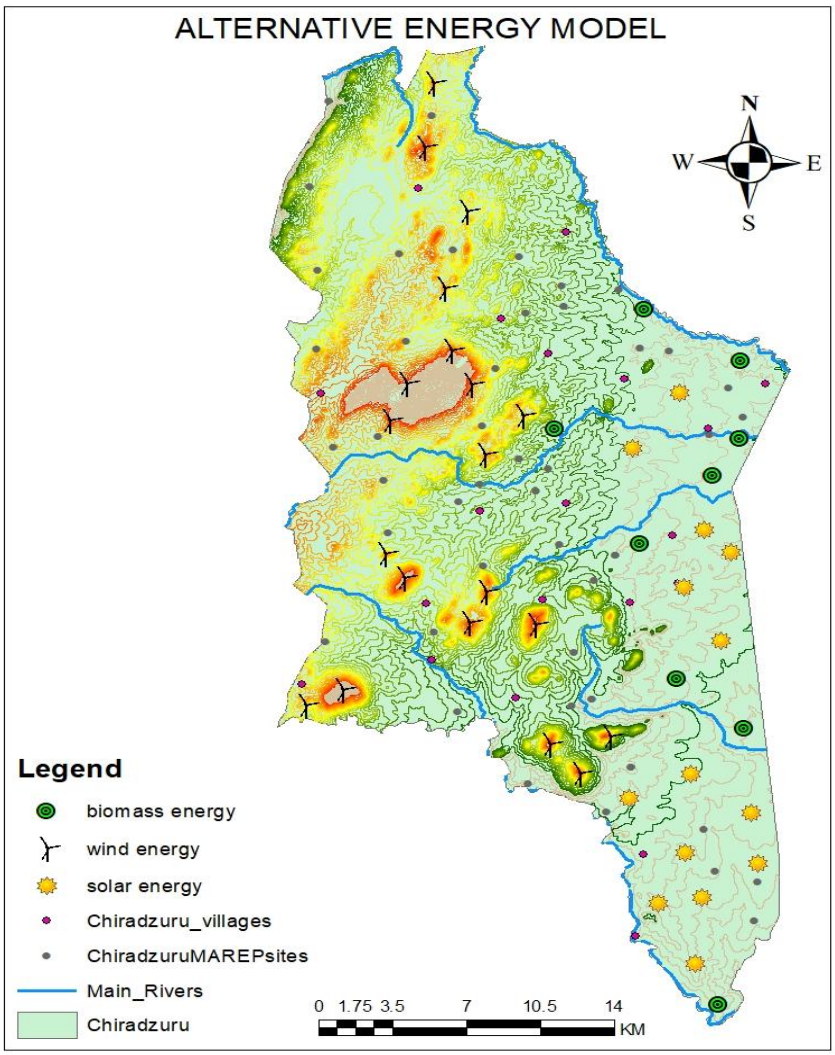


Figure 4.0 shows alternative energy sources with respect to topography of an area.

3.5. Electrification Model

Rural electrification modelling encompasses all the map data elements as well as data processing tools in ArcMap to generate information for users in form of an output data model. These datasets include Chiradzulu boundary data, village shapefile data as well

as ESCOM dataset composing of Electricity distribution lines, service transformers with their associated extension distribution lines and additional service transformers digitized towards the MAREP sites that exist close to the electricity grid. It also contains data for the suggested alternative energy sources assigned on to specific spatial areas depending on the topographic characteristics of that particular location.

For instance, wind energy is favourable in situations characterized by high elevation with presence of hills, mountains among other features. These places are umpired to analysts by the occurrence of map contours that are closely spaced together on a map model. High elevation locations are a major drive for wind energy generation in places that are far from the electricity grid line. The advantage of such Areas is that they tend to receive strong winds of high speed that is capable of driving a wind turbine to produce electricity. This is the reason the wind generation stations appear in areas of high elevation on the output electrification model. Since electricity grids barely passes across the mountains, highly elevated areas usually have no access to electricity. This implies that areas that are on high or hilly location will not surfer a burden of lack of electricity due to the implementation of wind energy system. Wind energy stations estimate percentage electricity coverage is 48% in Chiradzulu district. Most of the wind stations are locale in North-West of Chiradzulu district. The model on figure 4.0 shows the suggested wind stations in form of windmills on specific location depending of characteristic of the area having a high elevation status.

Areas situated in flat lands tend to receive much sun radiation across a wide area. These are discoverable on the contour map of Chiradzulu by identifying areas where contours are far apart from each other. The flat land Locations are constructive for solar power generation because they receive ample sun's heat energy. The mechanism implemented is the use of solar panels designed to harness heat energy and converting it into electricity for home use. When the sun is overhead, flat areas receive sun radiation throughout the day hence essential for solar energy generation. Solar energy stations reside in the South-East of Chiradzulu district because of the presence of flat lands. The model on figure 4.0 shows the suggested wind stations in form of miniature sun graphic symbolizing solar power stations.

An alternative energy source namely Biogas energy is usually encouraging in very low elevation areas usually close to water bodies such as rivers, swampy areas, wetlands, catchment areas among other examples. Lowland areas have contours very far apart showing that the area occurs in lower land. Biogas generation stations are identified by the presence of a green round circles on the electrification model. Since majority of lowlands occur near to water body, these areas have abundant biomass from dead plants as well as animal dung and all organic decomposable materials that are raw materials for biogas production.

The electrification model portrays all the map data contents to scale and the legend elaborates the feature classes on the map output and other associate models. The rural electrification model is a major tool for ensuring probable ways of certifying that electricity distribution across the entire Chiradzulu district, hence, enhancing socio-economic growth among people living in rural areas. The rural electrification model contains all potential datasets modelled on a single representation to aid analysis. Following figure shows the electrification model of Chiradzulu district.

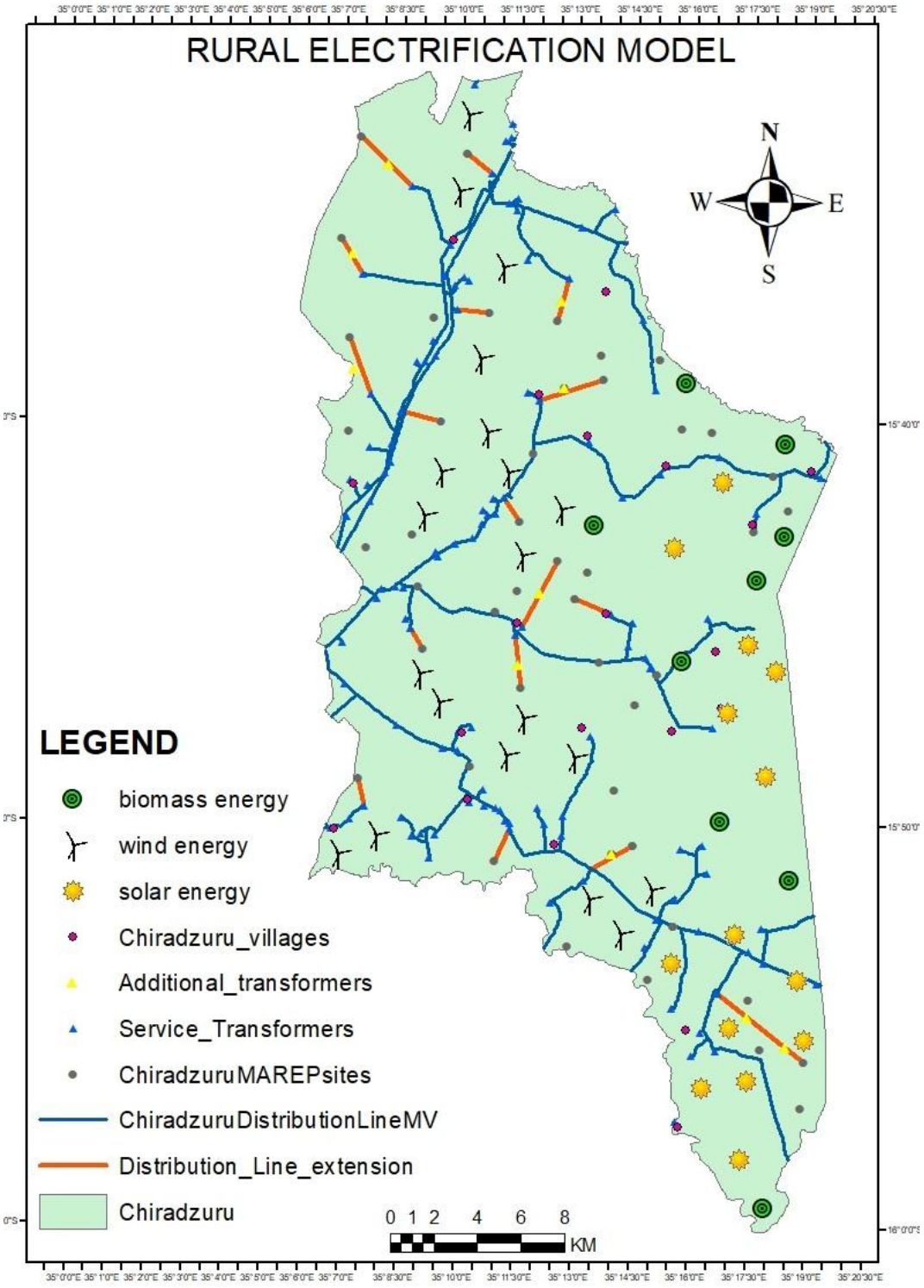


Figure 4.0 shows the rural electrification model for Chiradzulu district.

The electrification model graphically shows the alternative energy systems were marked on the map model depending on the location as well as topographic characteristics of the area. The table 3.0 summarizes the number of potential sites across the Chiradzulu district.

ALTERNATIVE ENERGY	ELEVATION	NO. of SUGGESTED SITES
SOLAR	Flat land/high land	13
WIND	High land	19
BIOMASS	Lower land	8

Table 3.0 shows alternative energy sources

Electrification model incorporates all possible attributes of geographic information systems as well as spatial datasets to lay out a foundation of an electrification model that depicts the distribution of electricity across Chiradzulu district. In addition to already existing ESCOM electricity grids in the area, alternative energy sources were implemented to sustain the availability of electricity across Chiradzulu. Solar energy covers 15% of Chiradzulu district compared to other alternative energies in the area, whereas wind energy covers 25% and biomass energy covers the remaining 10% of the area. ESCOM electricity grids covers a huge area of 50% since it is they supply electricity to numerous locations across Chiradzulu district. The self-explanatory electrification model for chiradzulu district is a major tool that can be used by ESCOM as well as Malawi Rural electrification programme to facilitate sufficient distribution of electricity across the entire chiradzulu district thereby improving economic development and socio wellbeing of people.

4. Chapter 5: Conclusion and Recommendation

4.1. Conclusion

The dissertation presents the application of GIS techniques on rural electrification modelling using GIS software particularly ArcMap. Geographic information system facilitates data acquisition, analysis, manipulation and visualization of spatial and attribute data to aid Decision making process. Rural electrification modelling is a scientific approach for planning the distribution of electricity across rural or far to reach areas in underdeveloped communities. The electrification model portrayed the

arrangement of MAREP sites in relation to the existing ESCOM power grid. Areas that are close to the MAREP sites are those that gain access to electricity since the electricity grids are usually at market places where people utilize the electricity on various socio-economic activities. The generated buffer zones show the linear distance at which the villages are situated, these zones gives a clear outlook of the association of people as well as electricity access in the area. Unlike those villages that lie beyond the existing power grids usually surfer access to electricity availability within their reach.

However, due to high demand of electricity, not everyone can have access to electric energy within their reach and so the research paper has suggested alternative forms of energy to deploy in rural areas that exist in far-to-reach places. The sources of energy includes solar energy, wind energy as well as biomass energy for daily economic or domestic use. Some MAREP sites have population of people sparsely arranged across a large area making it hard to extend the ESCOM grid lines to accommodate the scattered population, hence, be it a flat topographic area solar energy is highly an alternative. Generally, people in such areas can use solar energy for domestic purposes including lighting, charging electronic devices thereby improving their social life.

In hilly areas, an alternative of wind energy proved to be effective because elevated places receive reasonably strong winds that drives wind generators to produce electricity. Wind and solar energy can supplement each other depending on the type of weather, for instance, during summer season there is abundant solar energy through the clear sky. In times of winter, is it more efficient to utilize wind for electricity generation since the winds are abundant in such season. Some part of rural areas lay in lower lands close to water bodies are good sites for biomass energy generation because of the presence organic material. The research paper emphasises on adapting the use of biogas as a source of energy in areas where Electricity is hard to extend. In brief, the dissertation elaborates the development of an electrification model to tackle the lack of access to electricity across Chiradzulu district.

4.2. Recommendation

The dissertation provide empirical information model output showing an electrification plan that elaborates the distribution of electricity across Chiradzulu district. The use of spatial data for problem analysis and model design facilitates probable implementation of GIS processes to solve the challenges with respect to the actual location on the earth surface. Utilization of geographic information system tools and techniques allows the incorporation of spatial as well as attribute data to aid data processing. GIS has the capability of associating datasets from various sources to generate maps and models, hence it is recommendable to use its software tools for instance ArcMap to aid generation of a rural electrification model. Model development in GIS software tools attaches spatial elements of an area under study thus ensuring sound the decision-making process with respect to exact place on the ground. It is recommendable to employ the use of geographic information system for energy planning systems because of the engrossment of spatial data during the analysis and designs. The output electrification model portrays a vivid pictorial of an electrification plan that ensures sufficient distribution of electricity in Chiradzulu district. Hence, Electrification model consisting of geographically referenced data ensures sound decision-making and problem solving in our communities, hence improving socio-economic well-being of people. It is recommendable to implement GIS tools and techniques when carrying out electrification planning and modelling the real world features to generate information that can be usable to solve electricity problems Malawi wide.

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