University of Nairobi

School of Engineering

GIS-BASED POWER TRANSFORMER'S PLANNING AND LOCATION

CASE STUDY: KIRINYAGA WEST SUB-COUNTY

BY

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A Project submitted in partial fulfillment for the Degree of Master of Science in Geographical Information System in the Department of Geospatial and Space Technology of the University of Nairobi

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DECLARATION

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

MARTIN WANJOHI MURIUKI 18/07/2016

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

DR. Ing. S. M. MUSYOKA

…………………

Name of supervisor Date

SAMMY MWANGI MATARA …………………

Name of supervisor Date

DEDICATION

I dedicate this project to all residents of Kirinyaga West Sub County.

ACKNOWLEDGEMENT

This project received support from various organizations and individuals. On this note, I would like first to convey heartfelt gratitude to my supervisors, Dr. - Ing. S.M.Musyoka and Mr. Sammy Mwangi Matara , Department of Geospatial and Space Technology, University of Nairobi, for their guidance, insight and attention that has enabled the success of this project.

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LIST OF ABBREVIATIONS

TX……….. Transformer.

KP……….. Kenya Power

FDB………. Facility Database

DBMS…….Database Management System

GIS……….. Geographical Information Systems.

GPS……….. Global Positioning System.

JPEG………. Joint Photographic Expert Group.

TIFF ………..Tagged Interface File Format.

SS………… Secondary Substation

KVA……… 1,000 Volt Amps

OWA……… Ordered Weighted Averaging

WLC……….Weighted Linear Combination

MCDM……Multi-criteria Decision Making

MV………Medium Voltage

ABSTRACT

This project explores the application of Geographic information system (GIS) as a tool in the energy sector. The objective of the project was to study the distribution of power transformers in Kirinyaga West Sub County and thereafter produce a map showing potential locations for installing new transformers to provide enough spatial coverage with planned energy allocations and minimized distribution losses. To achieve this, factors affecting the distribution and installation of transformers were identified, collected, prepared, standardized, analyzed and overlayed to produce a suitability map indicating potential sites for new transformers. The study showed that approximately 55% of the area of study is efficiently spatially covered by the existing transformers leaving out 45% of the area uncovered. It was also realized that if the current medium voltage network in the area of study is maximized, 29% more of the area would be covered. This leaves approximately 20% requiring extension of the medium voltage network. These percentages are exclusive of the forest cover which is approximately 7% of the study area.

CHAPTER 1: INTRODUCTION

1.1 Background

Energy is one of the key indicators of development in any country, the government of Kenya through Vision 2030 goals has already put in place the facilitating policy framework, regulatory mechanisms for investing in power generation, transmission and distribution. This power should be made available at the points of demand consistently and effectively. Currently in Kenya, this is made possible through Kenya Power and Lighting Company was rebranded Kenya Power in June 2011.

From KPLC official Website, the company is of limited liability whose key responsibility is to plan for sufficient electricity transmission and distribution capacity to meet demand, building and maintaining the power distribution network and retailing of electricity to its customers. Kenya Power is listed on the Nairobi Securities Exchange, The government holding fifty point one percent and private sector holding forty nine point nine percent of the company's shares. During the last few decades the company has been involved in the development of primary and secondary substations, transmission lines of high and low voltage so as to meet the high demand of power. Over time, the appropriate routes for new substations and transmission lines have been restricted, as a result of the development of rural areas and the growing concern over environmental issues.

According to the company's strategic action plans, which can be accessed through the company's website, the company is targeting two million new customers by 2030 in addition to the approximate 3 million already existing customers. This is in line with the country's vision 2030 goals. The company will be able to achieve this target by addition of numerous poles, circuits, power lines and transformers. In addition to the 2 million target, the company needs to reduce system losses, increase grid coverage and improve quality power supply by 2030.

Moreover, the company needs to perform load study analysis and load forecasting which will then influence the growth of network and positioning of new primary and secondary substations rather than following consumer demand.

1.2 Problem statement

The current distribution of transformers has been based on demand by the customers. This has led to irregular pattern of network growth hence unpredictable spatial coverage meaning that willing customers away from existing transformers cannot get connected. If the government is to achieve its target of connecting all Kenyans to electricity, then transformers need to be distributed and installed such that they give total spatial coverage of the country making it possible to connect any Kenyan at the same time minimizing power losses during power distribution. Therefore, there is need to plan ahead of demand by having sites in mind where transformers shall be installed.

1.3 Objectives

1.3.1 General objective

- To develop a map showing potential locations for the placement of new transformers, providing higher spatial coverage with planned energy allocation and minimized transmission loss.

1.3.2 Specific objective

- To identify and map every transformer and high voltage lines in the area of study.
- To identify factors influencing transformer positioning in the electrical network.
- To identify preferences for weighting the factors above.
- To integrate and analyze GIS data by overlay tools.
- To generate a suitability map indicating potential sites for new transformers.

1.4 Justification for the Study

The main reasons why this particular study is valid are:

- There is need for fulfillment of goals in Vision 2030 which demands that every Kenyan should be connected to electricity.

- There is inadequate investment on distribution transformers causing overloading of the distribution system without commensurate strengthening and augmentation.

- Haphazard growth of distribution systems with short sighted supply goals, meaning that potential customers cannot be connected to electricity due to distances of their location from the network.

1.5 Scope of Work

The study uses GIS so as to find the appropriate positions of additional transformers within Kirinyaga west Sub County.

1.6 Organization of the Report

This report is comprised of five chapters. It starts with chapter one which introduces the project while the related literature is reviewed in chapter two. Chapter three describes the materials and methodology used during the project followed by chapter four which describe the results achieved and analysis of these results. Finally, chapter five states the recommendations and conclusions drawn from the project.

CHAPTER 2: LITERATURE REVIEW

2.1 GIS in Electricity Distribution

2.1.1 Geographic Information System GIS:

GIS is a system for capturing, storing, querying, analyzing, display and output of spatial data for problem solving. GIS involves creation of databases for storing data and information which is an important asset of any organization (Mokarram 2003). According to Eastman (1993) these databases can be grouped into: spatial database which describes the location and the shape of geographic features and spatial relationship of map features and attribute database which give the descriptive information of the map features.

It was established by Dominguez and Pinedo-Pascua (2009) during their research work on electricity connectivity in Latin American countries that the GIS system combines different layers of information about a place or phenomenon for better understanding and depending on the purpose, different layers can be put together for better analysis. With GIS one can select the specific information required depending upon the intended application at a particular stage.

2.1.2 Geographic Information System GIS in the Power Sector

According to Nagaraja (2008) Geographical Information System technology plays an important role in mapping the consumers and electrical network assets on a geographical base map to help define the consumer's electrical connectivity. Using GIS, the entire electrical network can be overlaid on a satellite image or a vector base map, with the facility for zooming, resizing and scrolling.

In summary of the above, it can be noted that a successful GIS integrates the spatial data with various utility applications - Customer Information System, Assets Management, Outage Management and Utility Billing System and provides interfaces for cross-application data portability.

Rashidat et al. (2006) describe the process of digitizing of electrical network assets, consumer indexing and network mapping involves:

- Survey of electrical consumers and network assets using handheld GPS devises through the Identification of all consumers and their service connections, followed by the preparation of GIS base map.
- Digitizing electrical network assets such as Substations, Feeders, Transformers and Poles.
- Differential GPS is preferred to establish geo-coordinates with acceptable accuracy from which the electrical connectivity with reference to the Pole, Transformer, Feeder and Substation is plotted on the base map.
- Mapping, indexing and coding of electrical consumers and network assets with defined electrical relationships: This requires collection and updating of data of consumers along with their electrical connection attributes.

GIS provides a wide range of solutions in power distribution sector, the interfaces between GIS and other utility software applications should be well-defined. It is useful in the electrical power system through its software and hardware being used as tools for storing, analyzing, interpreting, updating, displaying information, and maintaining the system. It has been proven to be a workable system to connect database information such as billing, material account, distribution analysis and outage reporting in power utility. (Jayant Sinha 2009)

According to Rezaee et al (2009) GIS also helps power companies to discover things about their investments and risks allowing the simultaneous assessment of technical, financial, and environmental factors. It plays an important role in decision making and problem solving through mapping the consumers and electrical network assets on a base map which then define the consumer's electrical connectivity. In addition to this, it helps with network routing and power component positioning which determines maximum coverage and the optimal path that has the shortest and the fastest distance and minimum cost.

Studies have been conducted to show the advantages of applying geo-spatial techniques in power distribution planning and network constructions. For example Barnard (2008) used various factors to identify "the best path for an extension or new network", the important factors he used were: roads, land cover, household positions and slope, which he combined to obtain a suitability map. He concluded that the implementation of GIS was highly valuable in finding areas which were supply deficit, showed overloaded demand, sparse capacity pockets and ideal spaces for new substations.

In addition Kaijuka (2006) used numerous factors to come up with a network development plan for intensifying electrification along the existing routes. The factors used were: population distribution and population density, location of demand centers i.e. schools and village trading centers, road network, health centers, and finally the projection of high demand centers or regions as an assimilation of the above variables.

Power distribution issues cannot be handled by studying a particular attribute, rather power distribution can be modelled as a multifactorial task connected to a large number of variables which the decision makers need to choose the appropriate options. This is through considering both the techno-economic competitiveness and also socio-cultural dynamics and environmental consequences, making the task intricate (Rahman et al. 2013).

Multi-criteria analysis is one such common technique followed by researchers for holistically studying the parameters that contribute in the distribution of electricity in any given region.

2.2 Kenya Power and Lighting Company Limited

According to Kenya Power’s website, it owns and operates most of the electricity transmission and distribution system in the country and sells electricity to over 2.6 million customers (as at April 2014). It is engaged in the transmission, distribution and retail of electricity purchased in bulk from Kenya Electricity Generating Company (KenGen), Independent Power Producers (IPPs), Uganda Electricity Transmission Company Limited (UETCL) and Tanzania Electric Supply Company Limited (TANESCO).

From the company’s power distribution Master Plan, its network of transmission and distribution lines covers about 47,035 kilometers. The national grid is operated as an integral network linked by a 220 kilovolts and 132 kilovolts transmission network. In additional to this, there is a new 400 kilovolts transmission line. The company is listed on the Nairobi Securities Exchange

The key responsibilities of the company include: planning for sufficient electricity generation and transmission capacity to meet demand; building and maintaining the power distribution and transmission network and retailing of electricity to its customers.

From the company's financial year report 2006/7 Kenya Power had more than 980,000 customers who consuming over 5,000 Gigawatt hours of electricity. There was effective generation capacity of 1041 Megawatts during this year. The demand was projected to grow to 1153 MW in the financial year 2007/2008 against an effective generation capacity of 1185 MW, leaving a reserve capacity of three percent. Generation capacity was boosted when the ongoing committed generation projects with a combined capacity of 556 MW were commissioned between 2008 and 2010. Some of the projects include the 60MW Sondu Miriu plant, and additional 52.2 MW from Iber Africa Power and 25 MW from Mumias Sugar Company Ltd.

According to the company's website, electricity is transmitted at high voltages. In Kenya, electrical power is generated at between 11 and 15kV. The electricity is then stepped up to 220kV or 132kV for transmission to substations. It is then stepped down to 132kV, 66kV, 33kV and 11kV at various feeder points for distribution to consumers. Large industrial and commercial customers are supplied at these high voltages. The electricity is stepped down to 415v/240v for other consumers. Transmission and distribution of power can be categorized into four major lines;

132 -4000 KV ………Ultra-high voltages

52-132 KV …………High voltage

1-52 KV…………...Medium voltage

0 - 1 KV ……………Low voltage

2.2.1 Gis in Kenya Power & Lighting Company Limited

GIS plays a very important role in modern management of electric utility companies. GIS is an important tool in developing accurate database, improving internal efficiency levels pertaining to power supply monitoring, commercial and customer services. It is useful for important functions such as network analysis, facility management, energy audit, trouble call management, load management, theft detection etc.

In the customer's chapter under the company's website, it is described that in the last few decades, the company has been developing power substations, transmission high and low voltage lines to keep up with the rapid growth of the power demand. Moreover, the suitable routes for new substations and transmission lines has been getting restricted, as a result of development of rural areas and the growing concern over environmental issues. One of the target of Vision 2030 is to have two million new customers in addition to the existing three million customers and also to reduce system losses, increase grid coverage and improve quality power supply.

Through emphasized use of GIS, the company can be able to keep track of its assets e.g. Electricity poles, circuits, power lines, transformers and customers and have ways of performing load study analysis and manage power outages. The use of GIS has come in handy in organizing the information of location voltage and distribution of electricity on a computer system linking the database to map and also integrating GIS with other company systems. Since in GIS information is easily updatable and accurate it thus caters for the needs of maintaining the enormous power infrastructure.

GIS manages information on the distribution of electricity to customers and information describing the attributes of each customer such as location, contacts and electricity use. Kenya Power uses it for management of the customers and planned or unplanned outage management. It is a valuable tool not only for mapping facilities but also in improved decision making and better managing infrastructure GIS in Kenya power is used for the study and analysis for electrical distribution system, analysis and design, suitability analysis. It can also be integrated with the transport management system which reduces complains response time remarkably. GIS and GPS can be integrated for mobile mapping and analysis of electric distribution circuits.

Using GIS function analysis tools, one can be able to retrieve any information. An example using the maps created, is when an engineer in the company needs to know the date of installation of a given transformer, he or she clicks the transformer symbol. The attributes of this transformer will appear. If same engineer wants to know more complex information, say he only wants to see on the map, transformers which are the 100 KVA transformers in a given area that were installed prior to a given date; The query tools of FDB will quickly process this , and show on the map only those transformers. At another instance if he wants to assess the requirement of a cable to be laid along a certain road, FDB will return the results of processing considering even all the bends and turns the road may have. The cable length shown by the GIS will be precise and will help in procuring the exact required quantity of the cable.

GIS plays a major role in maintenance and monitoring of electric system. Using GIS, the entire electrical network is be overlaid on a satellite image or a vector base map, with the facility for zooming, resizing and scrolling. Using its applications, customers are also mapped to the corresponding electricity network. This helps the user to see and analyze all customers connected to a given transformer and consequently the whole hierarchy to the substation. The purpose of such application is to index all the consumers and categorize the whole consumer database with respect to their electrical address. This GIs should integrate the spatial data with utility applications like Customer Information System, Assets Management, Outage Management and Utility Billing System and provide interfaces for cross-application data portability as well for it to be successful (Smith 2005).

Generally it has been observed that, GIS provides a wide range of solution to the entire business value chain in the power distribution sector from setting up distribution network and load management to customer information, assets management, billing and customer services. Digital system provides timely, accurate and easier way of acquiring information, which is very vital in taking prompt and accurate decisions.

2.3 Multi-Criteria Evaluation.

Rural energy issues cannot be handled by studying a particular attribute, rather rural electrification can be modeled as a multifactorial task connected to a large number of variables: decision makers need to choose the appropriate options by considering both the techno-economic competitiveness and socio-cultural dynamics and environmental consequences, making the task intricate (Rahman et al. 2013).

Multi-criteria analysis is one such common technique followed by researchers when studying the parameters that contribute in the variation of electricity in a given region. Nerini (2012) in his work highlighted the importance of performing a multi-criteria analysis for choosing the right parameters to create a new aggregate index for identifying the appropriate electrification technology. It has also been shown by Munda and Russi (2005) that in the case of rural renewable energy policies, multi-criteria analyses aid decision makers to assess the contribution of different parameters and makes planning more effective.

The entire study has been performed on the GIS platform enabling data interoperability and the effect of one variable over the other. The dynamism and robustness of GIS in managing numerous data sets and several available means to compare different parameters for studying energy alternatives for rural communities has been established by Dominguez and Pinedo-Pascua (2009) in their research work on Latin American countries.

Spatial multi-criteria decision making is the application of multi-criteria analysis in spatial context where alternatives, criteria and other elements of the problem have explicit spatial dimensions. Multi-criteria analysis has been coupled with geographical information systems (GIS) to enhance spatial multi-criteria decision making since the late1980s.

The integration of multi-criteria decision making (MCDM) techniques with GIS has considerably advanced the conventional map overlay approaches to the land-use suitability analysis (Carver, 1991; Banai, 1993; Eastman, 1997; Malczewski, 1999; Thill, 1999). GIS-based MCDM can be thought of as a process that combines and transforms spatial and a spatial data (input) into a resultant decision (output).

The MCDM procedures define a relationship between the input maps and the output map. The procedures involve the utilization of geographical data, the decision maker's preferences and the manipulation of the data and preferences according to specified decision rules. Accordingly, two considerations are of critical importance for spatial MCDA:

(i) The GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and
(ii) The MCDM capabilities for combining the geographical data and the decision maker's preferences into uni-dimensional values of alternative decisions.

A number of multi-criteria decision rules have been implemented in the GIS environment for tackling land-use suitability problems. The decision rules can be classified into multi-objective and multi-attribute decision making methods (Malczewski, 1999).

The multi-objective approaches are mathematical programming model oriented methods, while multi-attribute decision making methods are data-oriented. Multi-attribute techniques are also referred to as discrete methods because they assume the number of alternatives is given explicitly, while in the multi-objective methods the alternatives must be generated.

2.4 Weighted Linear Combination Methods.

The WLC and Boolean overlay operations, such as intersection (AND) and union (OR), are considered the most straightforward and the most often employed. WLC (or simple additive weighting) is based on the concept of a weighted average. The decision maker directly assigns the weights of ‘relative importance’ to each attribute map layer (Yager, 1988).

The overlay techniques allow the evaluation criterion map layers (input maps) to be combined in order to determine the composite map layer (output map). The methods can be implemented in both raster and vector GIS environments. Some GIS systems have built-in routines for the WLC method. There are, however, some fundamental limitations associated with the use of these procedures in a decision making process. Jiang and Eastman (2000) give a comprehensive discussion of those limitations and suggest that the Ordered Weighted Averaging (OWA) approach provides an extension to and generalization of the conventional map combination methods in GIS.

Ordered weighted averaging is a class of multi-criteria operators (Yager, 1988). It involves two sets of weights: criterion importance weights and order weights. An importance weight is assigned to a given criterion (attribute) for all locations in a study area to indicate its relative importance (according to the decision-maker’s preferences) in the set of criteria under consideration. The order weights are associated with the criterion values on a location-by-location (object-by-object) basis. They are assigned to a location’s attribute values in decreasing order without considering which attribute the value comes from.

The OWA operations make it possible to develop a variety of land use strategies ranging from an extremity pessimistic (the minimum-type strategy based of the logical AND combination) through all intermediate the neutral-towards-risk strategy (corresponding to the conventional WLC) to an extremely pessimistic strategy (the maximum-type strategy based on the logical OR combination). Thus, OWA can be considered as an extension and a generalization of the conventional combination procedures in GIS (Jiang and Eastman, 2000).

2.5 Role of Geographic Information System in Multi-criteria Evaluation.

2.5.1 Role of GIS

GIS is capable of performing an integrated analysis of spatial and attributes data. GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multisource datasets such as data on land use, population, topography, hydrology, climate, vegetation, transportation network, public infrastructure, etc. The data are manipulated and analyzed to obtain information useful for a particular application such as suitability analysis. The aim of a GIS analysis is to help a user to answer questions concerned with geographical patterns and processes (Prakash, 2003)

2.5.2 Spatial Decision Making Process.

Decision alternatives can be defined as alternative courses of action among which the decision maker must choose. A spatial decision alternative consists of at least two elements:

- action (what to do?) and
- Location (where to do it?).

The spatial component of a decision alternative can be specified explicitly or implicitly.

2.5.3. Evaluation Criteria.

In the spatial context, evaluation criteria are associated with geographical entities and relationships between entities, and can be represented in the form of maps. A criterion map models the preferences of the decision maker concerning a particular concept, while a simple map layer is a representation of some spatial real data. A criterion map represents subjective preferential information. Two different persons may assign different values to the same mapping unit in a criterion map (Miller1998).

2.5.4 Constraints.

A constraint is a natural or artificial restrictions on the potential alternatives. Constraints are often used in the pre-analysis steps to divide alternatives into two categories: acceptable" or unacceptable. In other words, they non-considerable options during an evaluation process.

2.5.6 Standardization.

The evaluation of alternatives may be expressed according to different scales (ordinal, interval, and ratio). However, a large number of multi-criteria methods require that all of their criteria are expressed in a similar scale. Standardizing the criteria permits the rescaling of all the evaluation dimensions between zero and one. This allows between and within criteria comparisons.

2.5.7 Criteria Weights.

In multi-criteria problems the decision maker often considers one criterion to be more important than the other. This relative importance is expressed in terms of numbers which are often referred to as weights, and are assigned to different criteria. These weights deeply influence the final choice and may lead to a non-applicable decision when the interpretations of such weights are misunderstood by the decision maker. When a simple arrangement technique is used, the decision maker sets the criteria in an order of preference (Eastman, 1997).

- The cardinal simple arrangement technique involves each criterion being evaluated according to a pre-established scale.
- Some other indirect methods are also available such as the interactive estimation method.
- There are also a relatively complex weight assignment techniques such as the indifference trade-offs technique and the analytic hierarchy process (AHP).

2.6 Factors Affecting Distribution Transformer Location

Firstly, the size of the resident population determines the amount of housing in the municipality and thus the resulting electricity consumption. Secondly, economic and social activities require office buildings, industrial zones, business parks, shopping areas and various infrastructures, all of which considerably increase a municipality's electricity needs. According to the latest Brussels energy balance (2012), the tertiary sector represents almost two thirds of the total electricity consumption, while the housing sector accounts for twenty five percent, industry six percent and the transport sector five percent.

There are several factors that affect distribution of transformers. For the purpose of this project, the factors were selected from interviews with design engineers and further research. For example, a study by Kaijuka (2006) used a multitude of factors to formulate a network development plan for intensifying electrification along the existing routes and the variables considered included population distribution and population density, location of demand centers i.e. schools and village trading centers, road network, health centers, slope and finally the projection of high demand centers or regions as an assimilation of the above variables.

Four set of factors were settled on for the purpose of this project and they are;

- Existing transformers.
- Existing mv line
- Roads.
- Location of Demand centers i.e., health centers, schools and towns.
- forest
- Population

2.6.1. Population

Population distribution refers to the spread of people across the world, i.e. where do people live while Population density is the number of people living in a particular area – usually 1 square mile or 1 square kilometer and can be written as total population/land area. If the population is high, it demands a corresponding high number of transformers required to serve the population and on the same note, the higher the population density in an area the higher the rating of transformer serving it shall be required.

2.6.2. Location of Demand Centers.

The secondary substations are best positioned along major roads due to accessibility during maintenance. Demand centers including schools, towns and health centers are vital points that require transformers.

2.6.3. Distance from Existing Transformer.

A transformer should serve an approximate geographical area of 600 meters. This is to avoid power losses due to power conduction over longer distances and also to ensure that the protection mechanism (fuses) perform optimum.

2.6.4. Constraints.

These are factors within the area of interest that shall not be considered for establishing new positions for transformers. For the purpose of this project, there were three constraints considered:

- Roads
- Rivers
- Forests
- Primary substations

CHAPTER 3: MATERIALS AND METHODS

3.1 Area of Study.

Kirinyaga West sub-county, shown in figure 3.1 below, is one the four sub counties that make up Kirinyaga county, others being Mwea, Kirinyaga Central and Gichugu sub-counties.

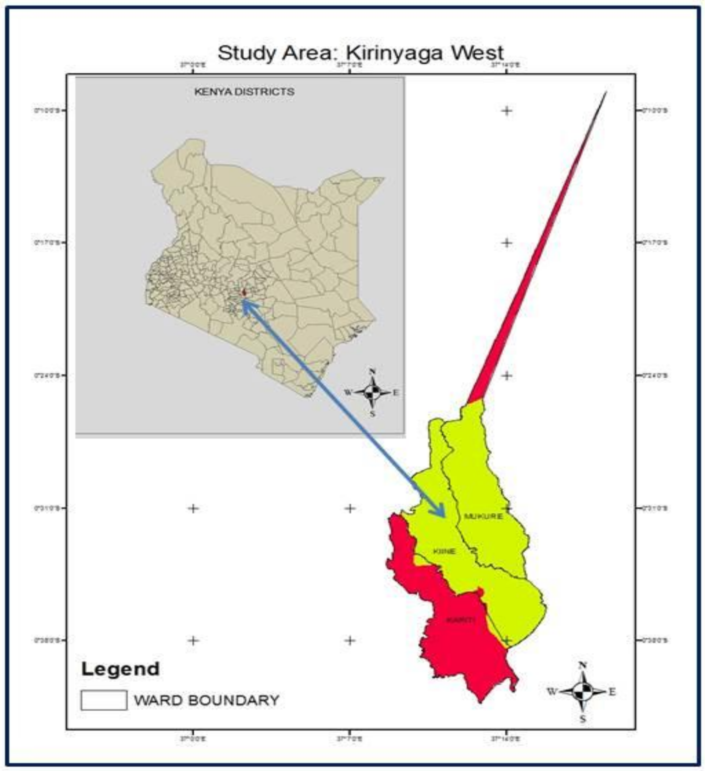

Figure 3.1: Area of study

It has a geographical coverage of about 210 square kilometers and is located between latitude-0° 30´ 20´´ degrees and 0° 45´ 00´´ degrees and longitude 37° 00´ 00´´ and 37° 28´ 00´´ degrees. It has its headquarters at Baricho and lies on the lower slopes of Mt. Kenya and has one industrial town called Sagana and an administrative town, Baricho. The sub county has an average of 99,515 people and these are housed in 29,491 households. It has a population density of 472.15. The sub-county has 187 existing transformers and currently has 7,459 customers consuming 644855.8KWH (kilowatts per hour). The total length of medium voltage line sections in the area is 628 kilometers. The maximum demand registered is 1333.0 KVA around eight past midday.

3.2 Overview of the Methodology

Figure 3.2 below is an illustration of steps followed while carrying out this project. The project's started with collecting the datasets, preparing these datasets, standardizing the datasets, weighting and overlaying these datasets to finally achieving the results and analyzing them.

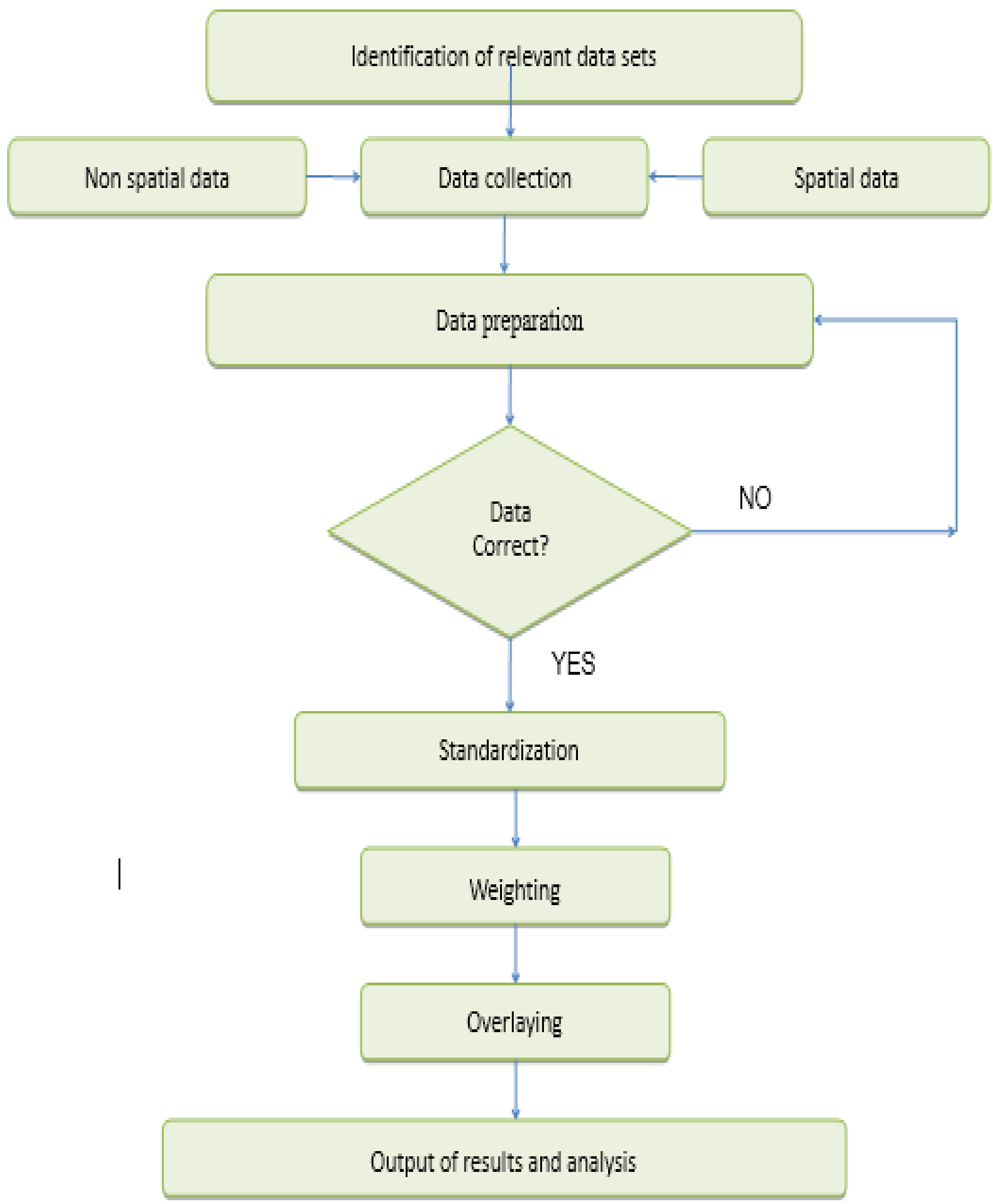

Figure 3.2: Overview of Methodology

3.3 Data Sets and Sources

Table 3.1: Datasets and Sources

To carry out this project, a set of datasets was required. This set of data is listed in Table 3.1

DATA TYPE	DATA SOURCE
Administrative Boundaries	World Resource Institute- Kenya GIS Data
Schools Data	Ministry of Education Website
Electricity Network Map	Kenya Power
Attributes of electricity distribution network components	Kenya Power
Road network	Digitization from Google earth
Health centers data	World Resource Institute- Kenya GIS Data
Towns	ILRI GIS website
Population Data (2009)	ILRI GIS website
Topographical map (1:50,000)	Survey of Kenya. (SOK)

3.3.1 Hardware:

- Computer with specifications of 500 Gb hard disk memory, 5Gbv DDR3 RAM and Intel core i5 Processor
- Flash disk of capacity 8 Gb
- SD card of capacity 8 Gb
- Digital camera
- Printer
- Hand held GPS

3.3.2 Software

- ArcGIS version 10.1
- Global Mapper version 10.1
- FDB
- Microsoft Office 2010 suite

3.4 Data Preparation.

This stage was about harmonizing datasets which involved confirming and ensuring that the datasets were in the same projection and datum and unifying of the mapping scale before further analysis. Most of the data was in UTM projection, Arc 1960 datum and hence it was used for all data and results. Re-projection and transformation was done to any other data in different projection. The definition and re-projection of coordinate system was carried out using Arc Map 10.1 and Global Mapper. Figure 3.3 is a snapshot of that process in Global Mapper version 15.0.

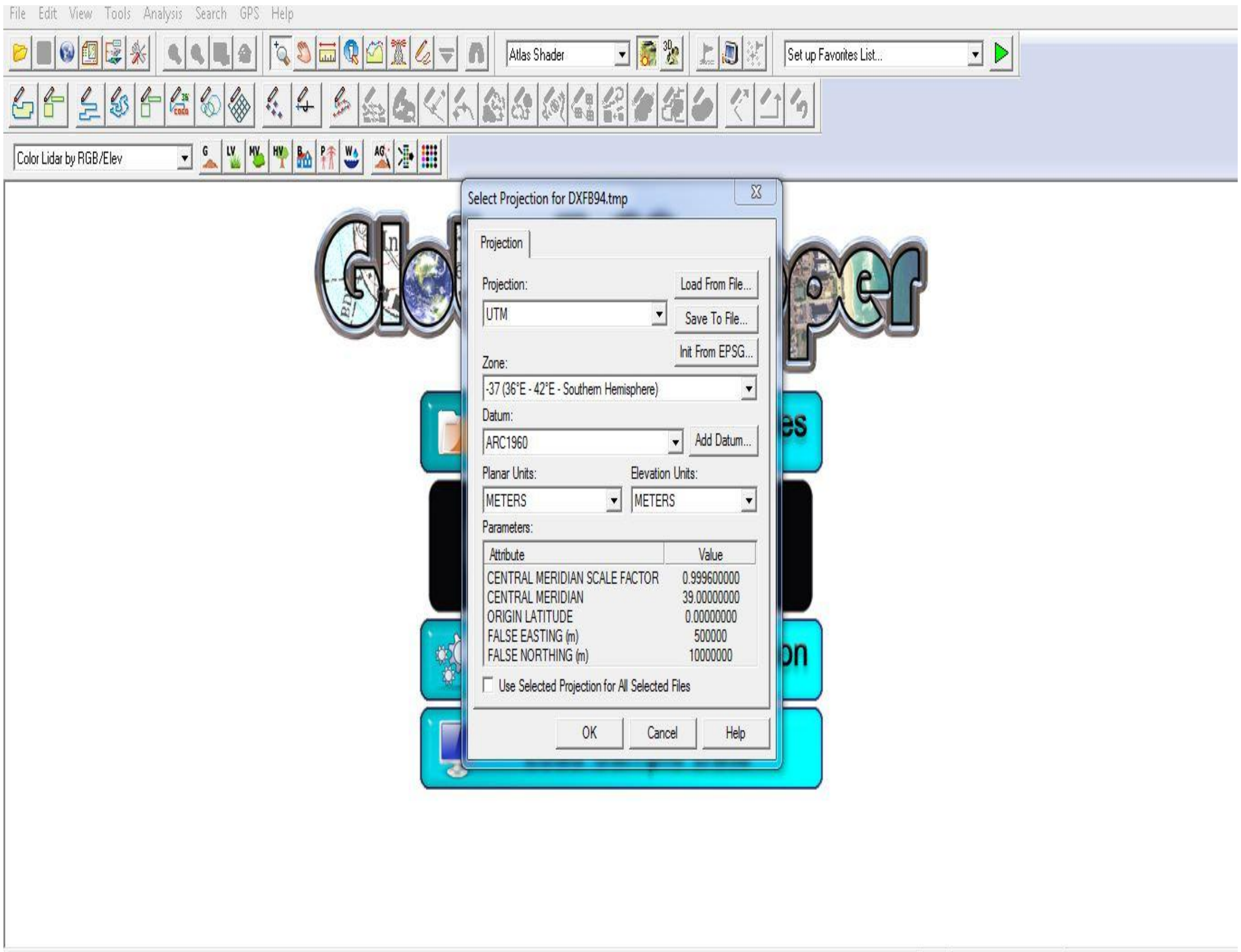

Figure 3.3: Defining Projection in Global Mapper

3.4.1 Constraints Preparation and Processing.

The constraints for the project were two i.e. forests and rivers. This means that the planning and distribution of transformers cannot be considered in these two factors. Figure 3.4 illustrates the workflow for processing these constraints.

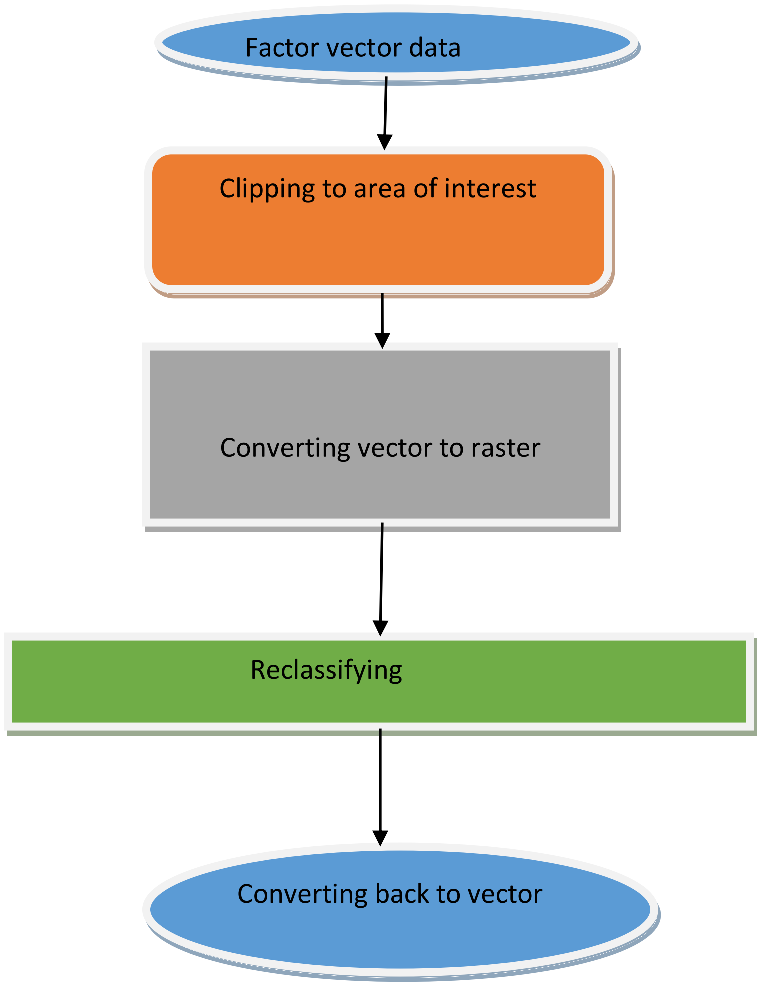

Figure 3.4: Constraints processing flow diagram

Figure 3.5 is the constraints map. The area in green is Mt. Kenya forest and shall not be considered in distribution of transformers.

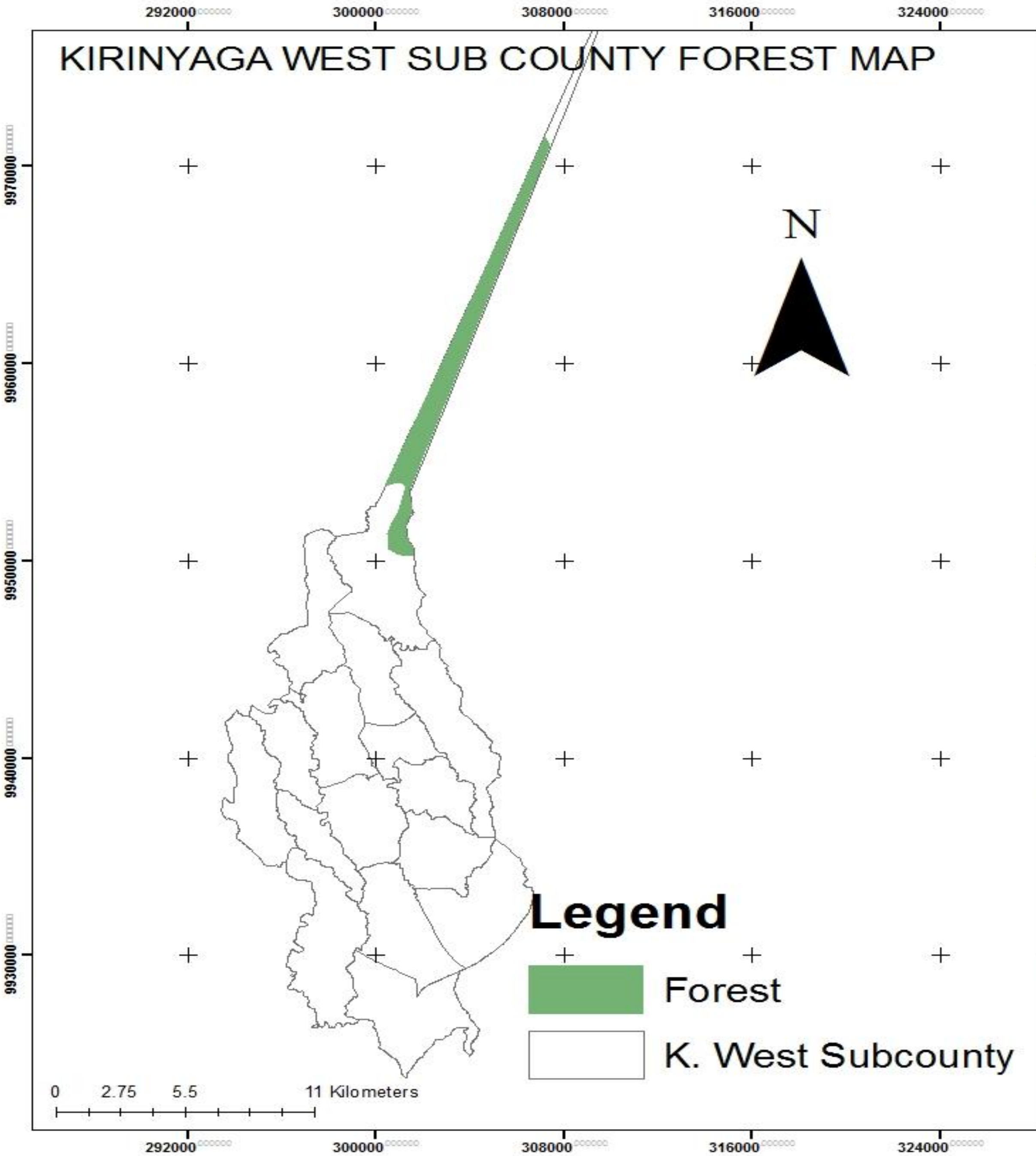

Figure 3.5: Kirinyaga West Sub county Forest Map

3.4.2 Factors Preparation and Processing

The factors considered in this project are roads, existing transformers, and demand centers. Demand centers in this case refer to the institutions or points that require power connection due to the high number of consumers. These include, towns, health centers and schools.

3.4.2.1 Existing Medium Voltage Network

This is the power line conducting power from the primary substation to the transformers. It maybe 11kv, 33kv or 66kv. In the study area, the medium voltage lines are majorly from Kerugoya substation, Sagana substation and others coming all the way from Karatina substation which is outside the area of study. The reason for considering this is that a transformer is only active when connected to MV line. This data was obtained from Kenya power facility database. The line features were extracted using the shape file of area of study. Figure 3.6 is a map of existing Mv network covering the area of study.

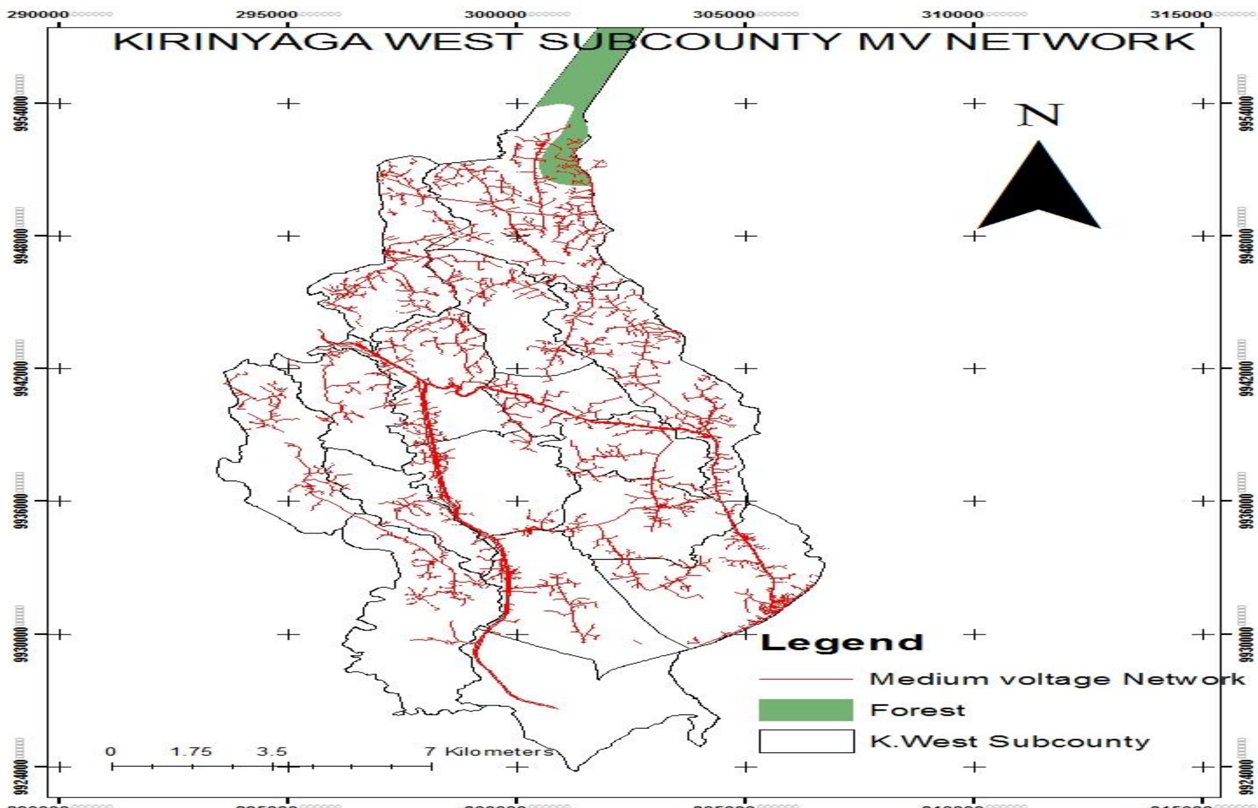

Figure 3.6: Existing Kirinyaga West Sub county Mv network Map.

3.4.2.2 Road Network.

Road network is an important factor in transformer distribution. One would easily notice that almost all the Kenyan medium voltage network lines follow the roads. There are two reasons to this. First is that it takes lesser time in acquiring way leaves. It is easier to seek for way leave along road reserve from the body concerned i.e. Kerra or Kura unlike seeking way leave from each land owner in case the network cuts across farms. However, this is inevitable in areas without clear road network or the costs involved especially in hilly areas where the roads meander around the hills. The second reason and more important of the two is to allow access of the network and the transformers during installation and incase of maintenance or repair. The poles and conductors are heavy and hence the installation is best suited where vehicles purposed to carry them can efficiently travel along. The roads were obtained from Kenya GIS data website and densified through digitization from Google Earth as illustrated in Figure 3.7

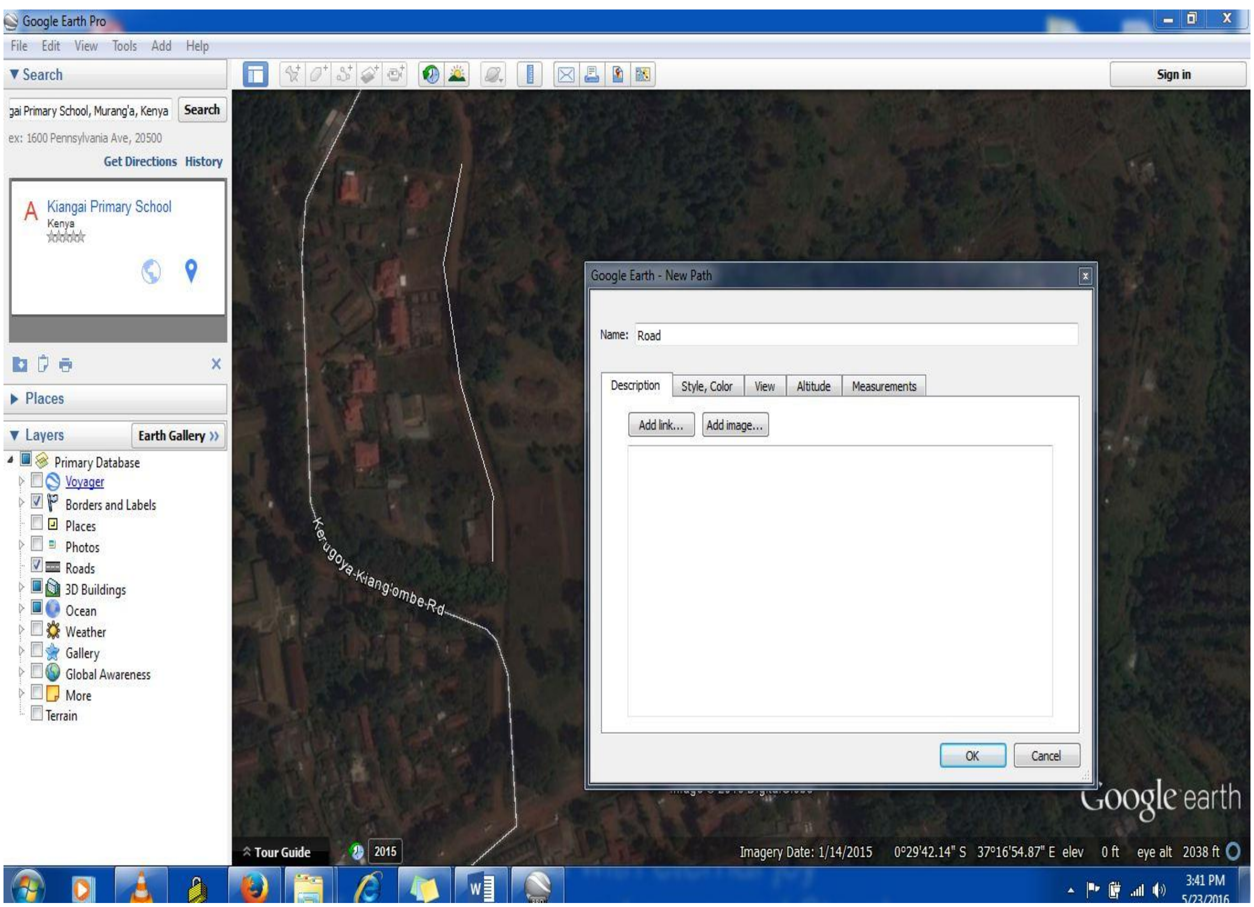

Figure 3.7: Snapshot of Digitization of Roads from Google Earth.

The data above was overlayed with sub county map and forest map to produce a road map for the sub county illustrated in Figure 3.8

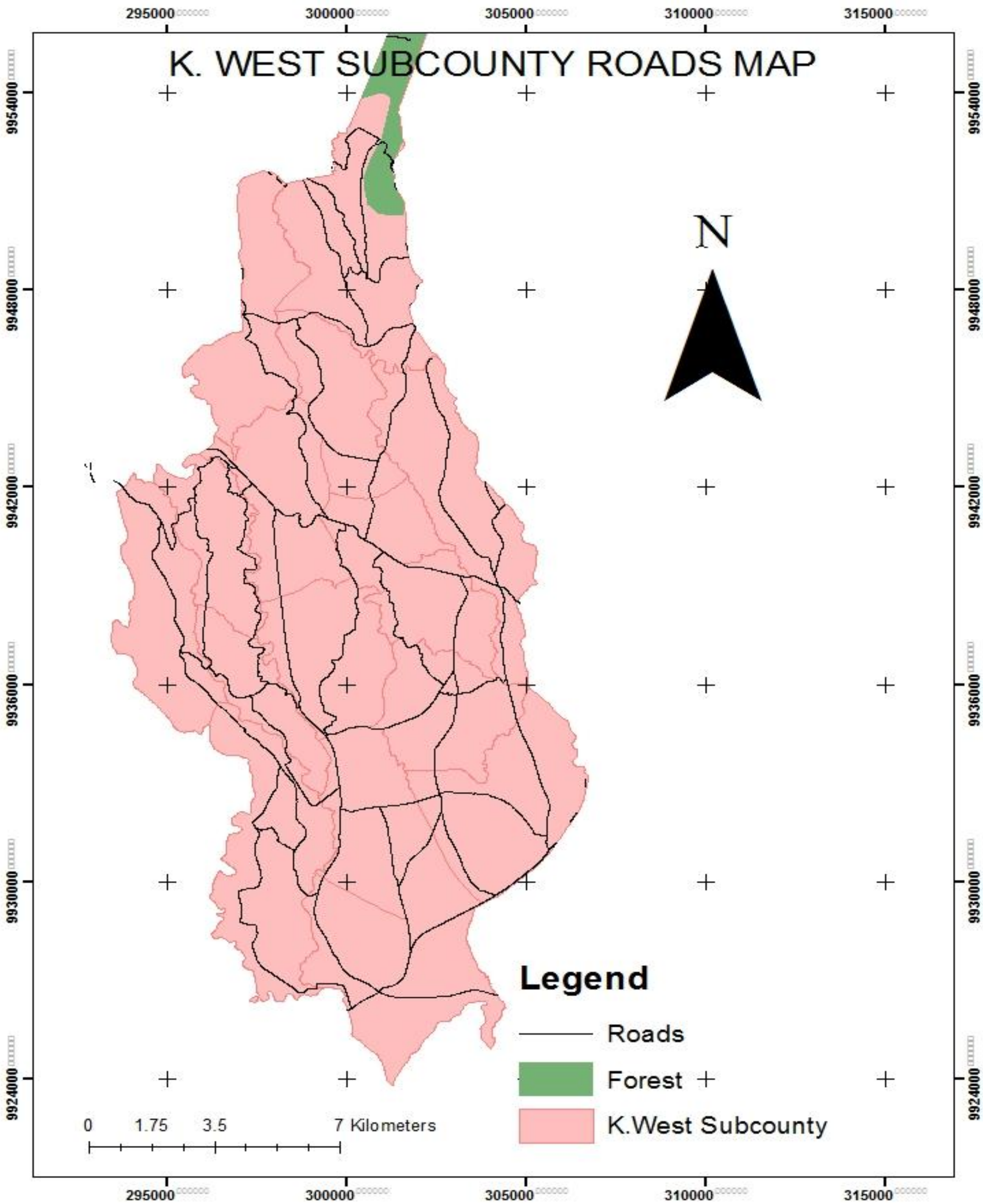

Figure 3.8: Kirinyaga West Sub county Road network.

Following the above, the forest map, sub county map and the road map were overlayed with existing mv map to produce a constraints map of the three factors as illustrated in Figure 3.9

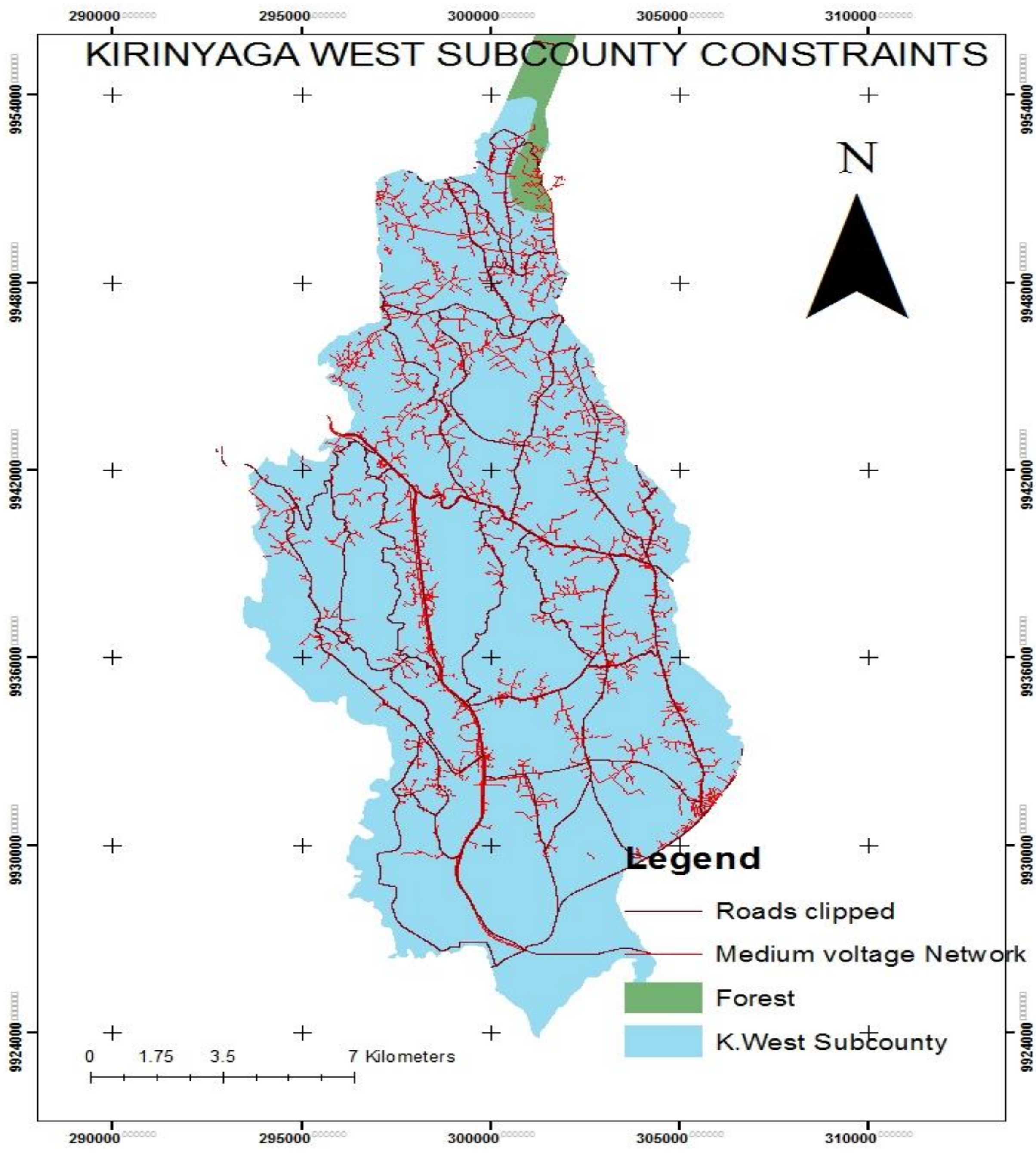

Figure 3.9: Combined Map of the three Factors in the sub county.

3.4.2.3 Health Centers Preparation and Processing.

Health facilities are key demand centers due to the purpose they serve to the society. They require power all through to run various medical equipment installed in the facilities. The other reason that make them suitable for consideration during distribution is the availability of land since public health facilities are located on government land hence easy availability of way leaves. The data for health centers was obtained from Kenya GIS data website and it was densified using Google Earth. The health centers were clipped to the area of study as indicated in Figure 3.10

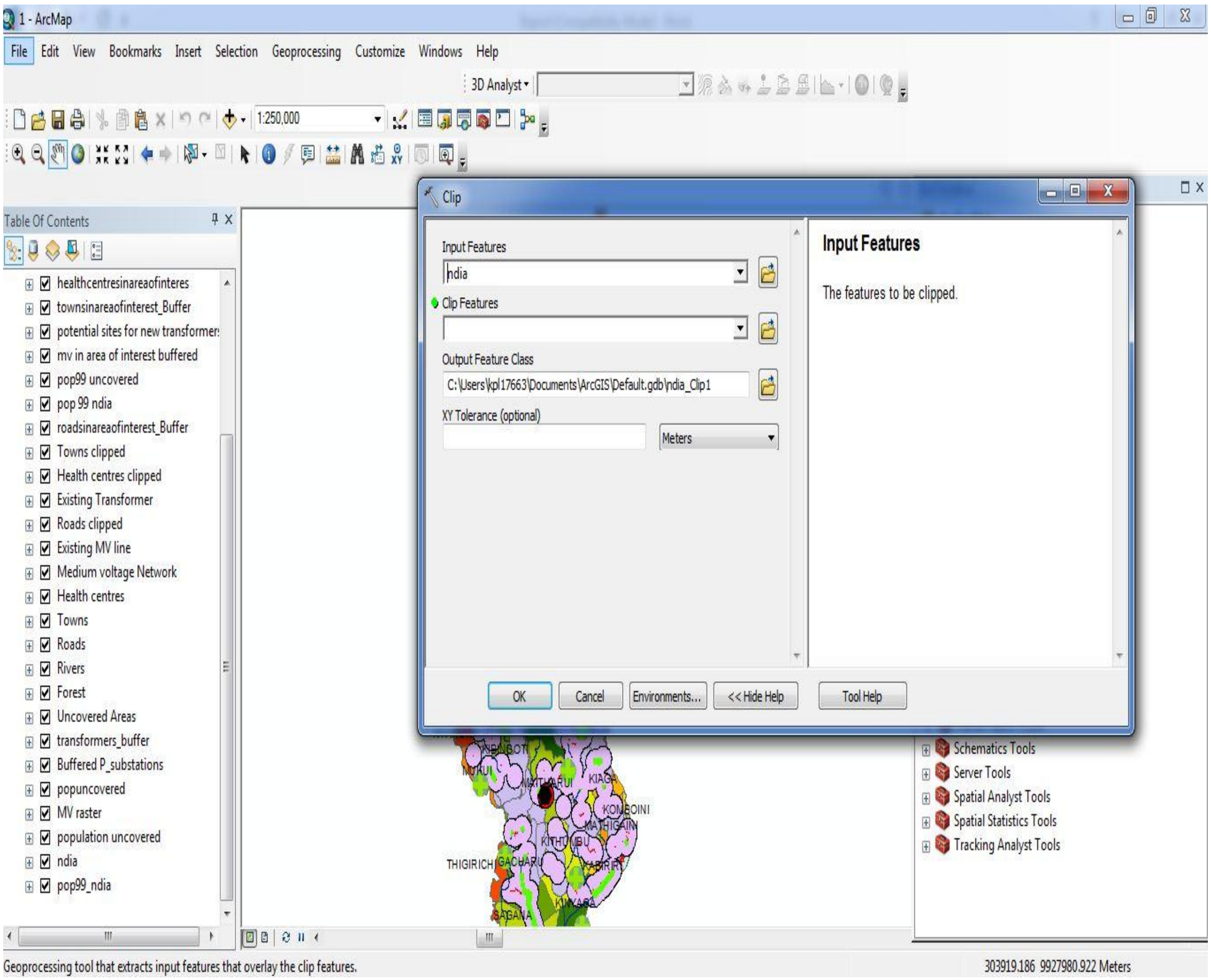

Figure 3.10: A Snapshot of Clipping process in Arc Map 10.1.

Following the clipping process, the health centers data was overlayed in Arc Map with the sub county map to produce the sub county health centers map indicated in Figure 3.11

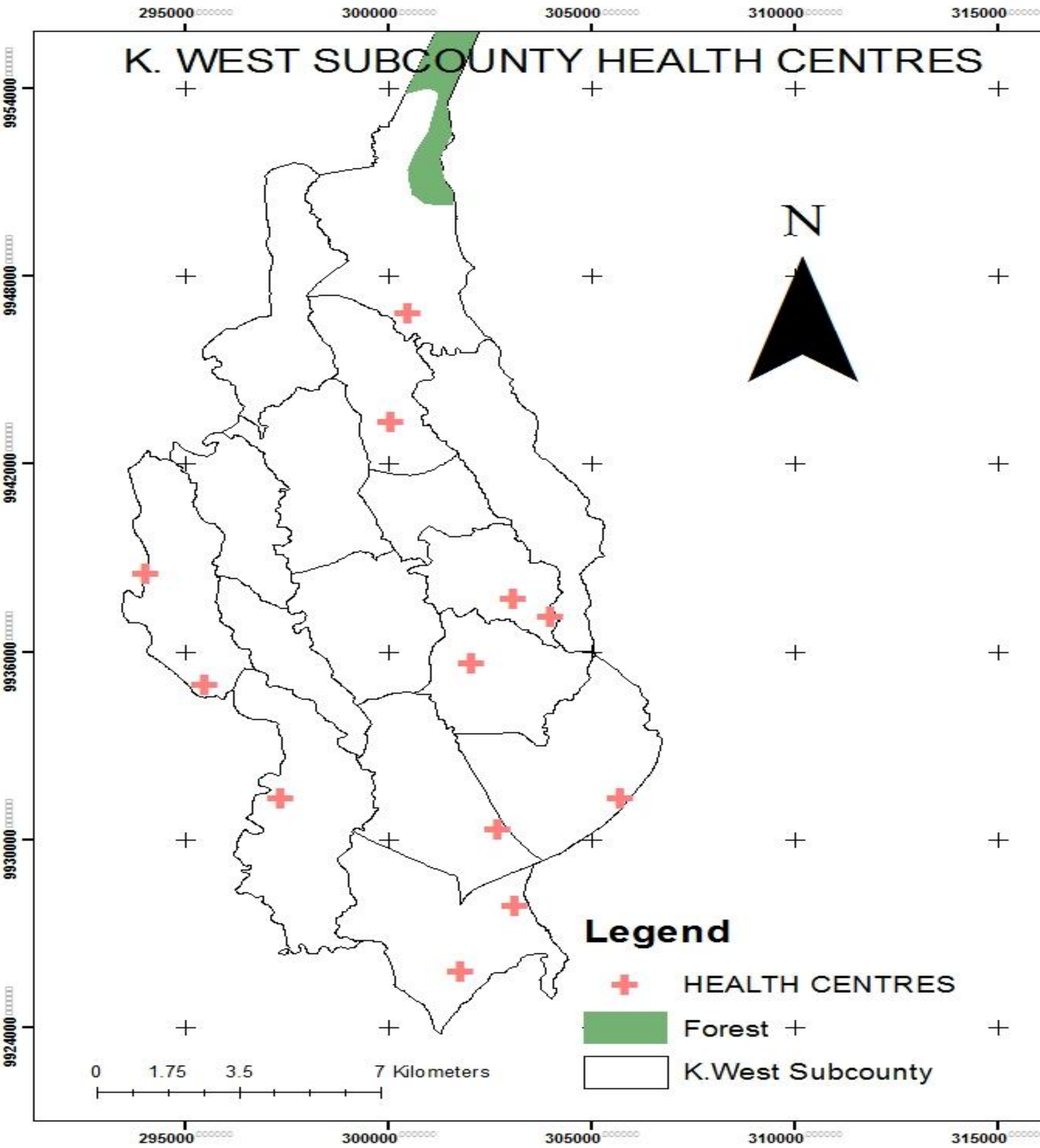

Figure 3.11: Kirinyaga West Sub county Health Centers Map.

3.4.2.4 Towns Preparation and Processing.

Towns are referred to as demand centers in this project due to the various businesses set up in their location. Power is a major infrastructure required for these businesses e.g. shops, hotels, factories, offices etc., hence they have been considered here as a key demand center. The town's data was obtained from ILRI website and clipped to area of study. The process was similar to the one for health centers. Figure 3.12 is the town's map of the area of study.

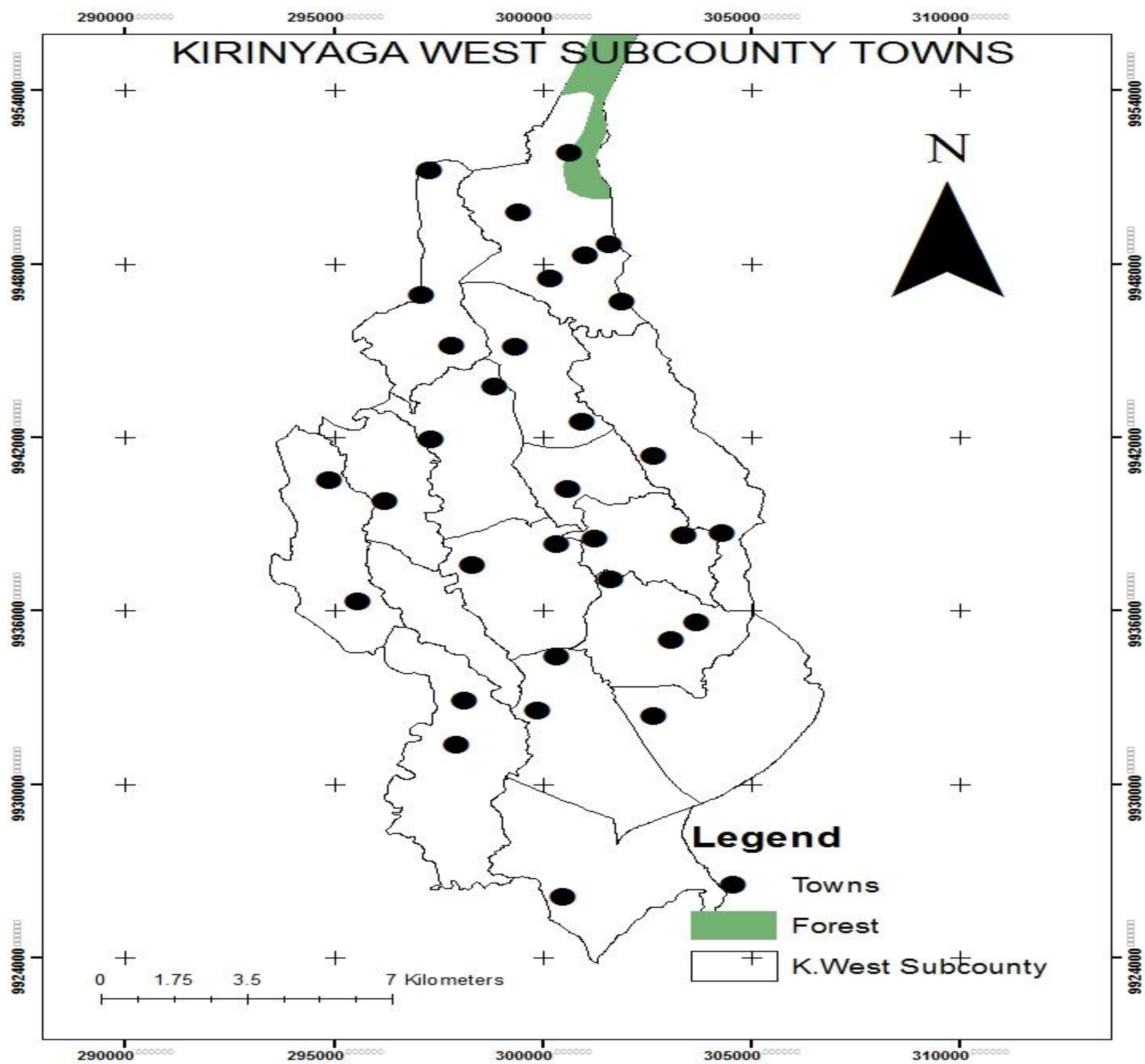

Figure 3.12: Kirinyaga West Sub county Town's Map.

3.4.2.5 Public Primary Schools Preparation and Processing

Schools are also key demand centers. This is so since each area is served by a certain primary school, hence in many cases one will find that transformers are placed near schools as they are more or less central points for villages. The main reason for consideration of this as a key factor is the project currently being rolled out by the government through Rural Electrification Authority of making sure there is a transformer in each public primary school. Data for schools was obtained from the Ministry of Education website. The data was in excel, but was plotted in AutoCAD, exported to arc map and saved in vector format to ensure all data was in harmony. It was also duly re-projected. Figure 3.13 is the school's map in area of study.

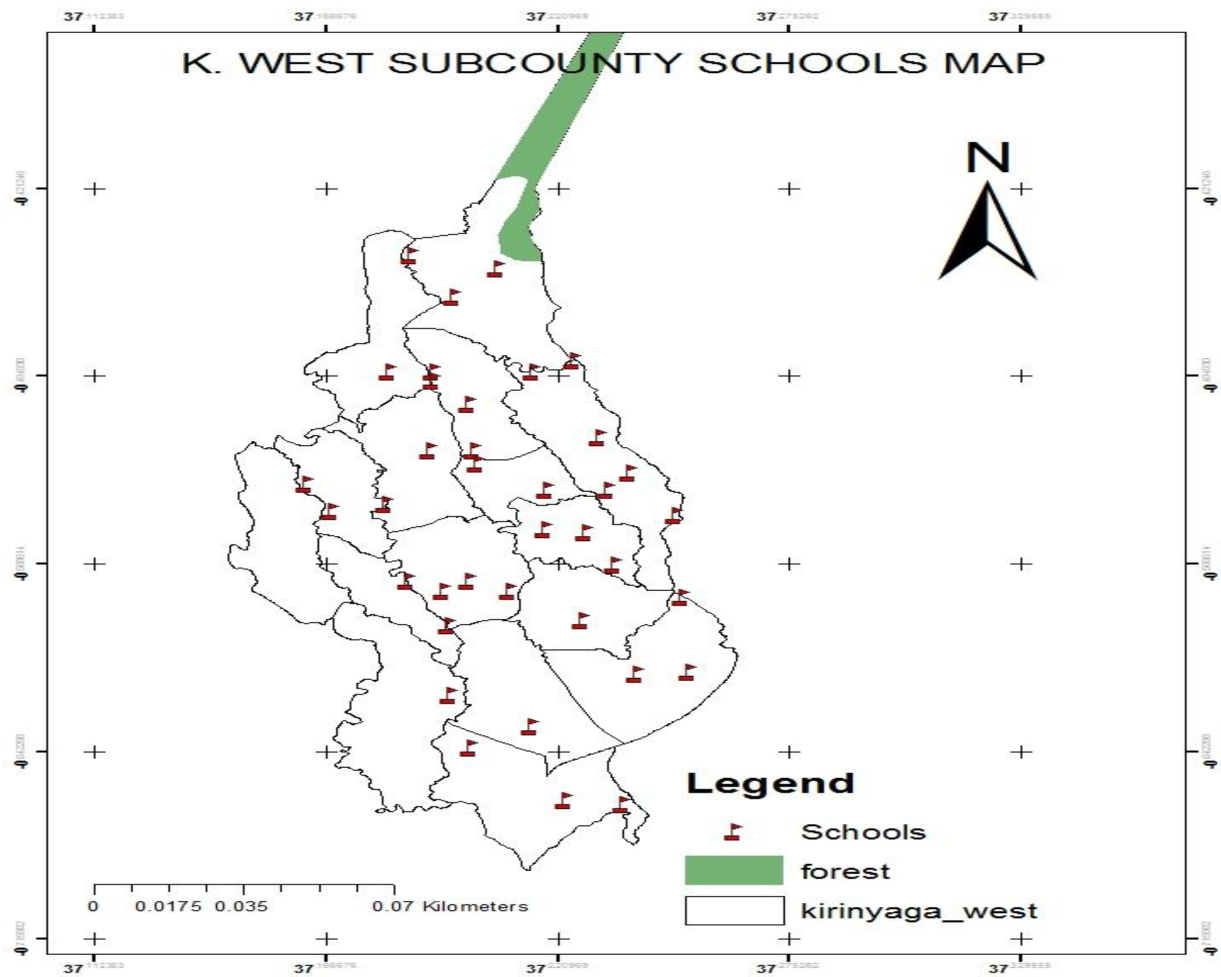

Figure 3.13: Kirinyaga West Sub county Schools Map.

3.4.2.6 Population Preparation and Processing

Population is also a factor especially when considering not only the spatial coverage but the power consumption in an area. In this case, the population class considered is the number of households per square kilometer. The population data was obtained from ILRI website, clipped to area of study and reclassified to have three classes of 0-1000, 1000-1500 and 1500-2500 households per square kilometer. Figure 3.14 is a snapshot of reclassification process in Arc Map 10.1

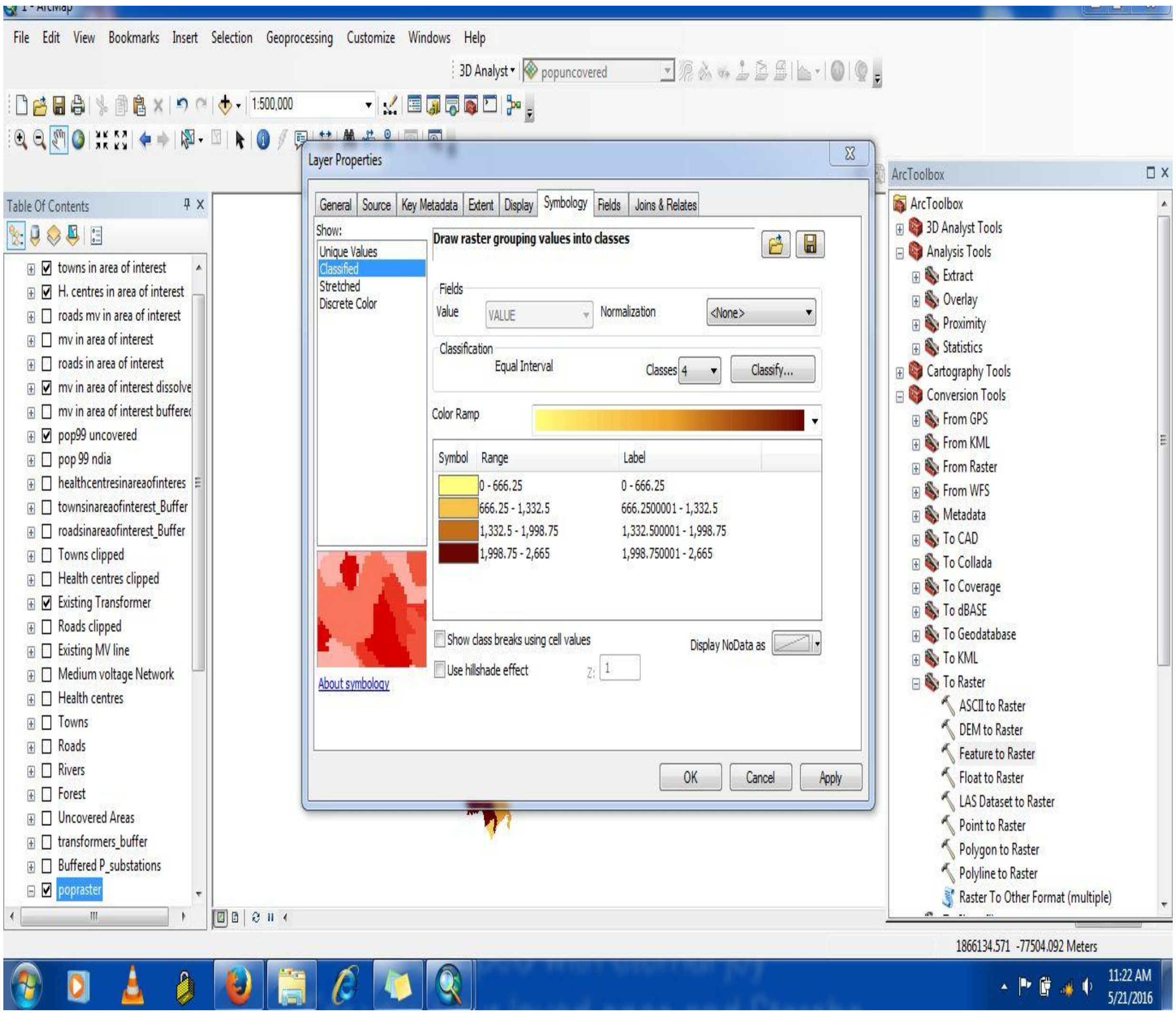

Figure 3.14: A Snapshot of Reclassifying Population process

Following reclassification, a population map was produced and it is illustrated in figure 3.15

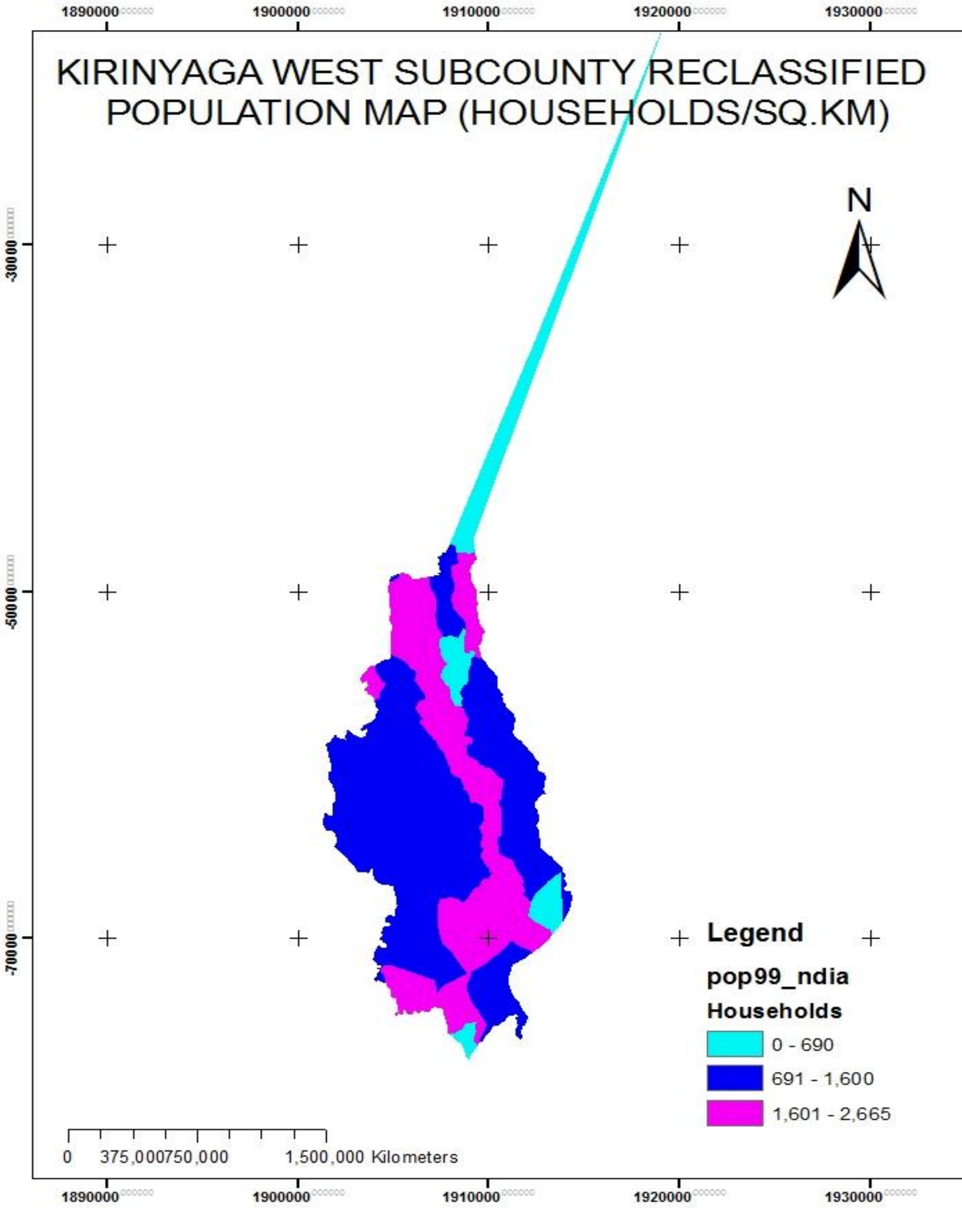

Figure 3.15: Kirinyaga West Sub county Population Map

3.4.2.7 Existing transformers Preparation and Processing.

In the area of study, there are 187 transformers. Majority (91%) are of 100Kva rating while the rest vary according to purpose, either large power factories which may be served by a 250KVa or small operators e.g. water pumps may be served from 50KVa. The transformers data was obtained from the Kenya Power Facility Database. The shape file of area of study was used to clip the transformers and their attributes. The following is the map of transformers in the sub county. Figure 3.16 is the map of these transformers in the area of study.

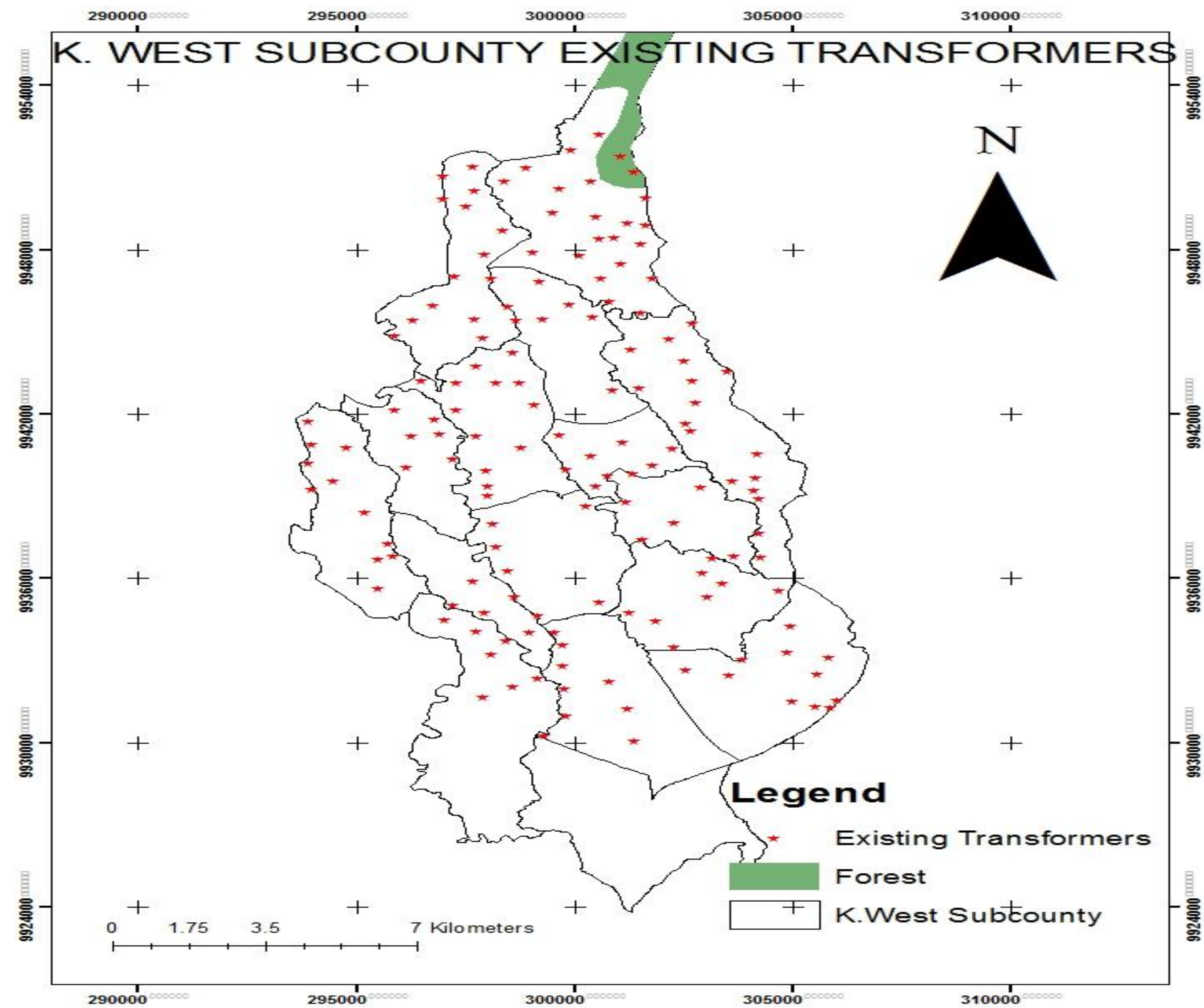

Figure 3.16: Kirinyaga West Sub county Existing Transformers Map.

According to Kenya Power's technical standards, a transformer is supposed to serve a customer farthest at 600 meters from its position. For the purpose of this project, the area each transformer can serve was determined to be a circle 600 meters radius. Hence, each existing transformer was buffered at 600 meters. Figure 3.17 is a snapshot of buffering process in Arc Map 10.1.

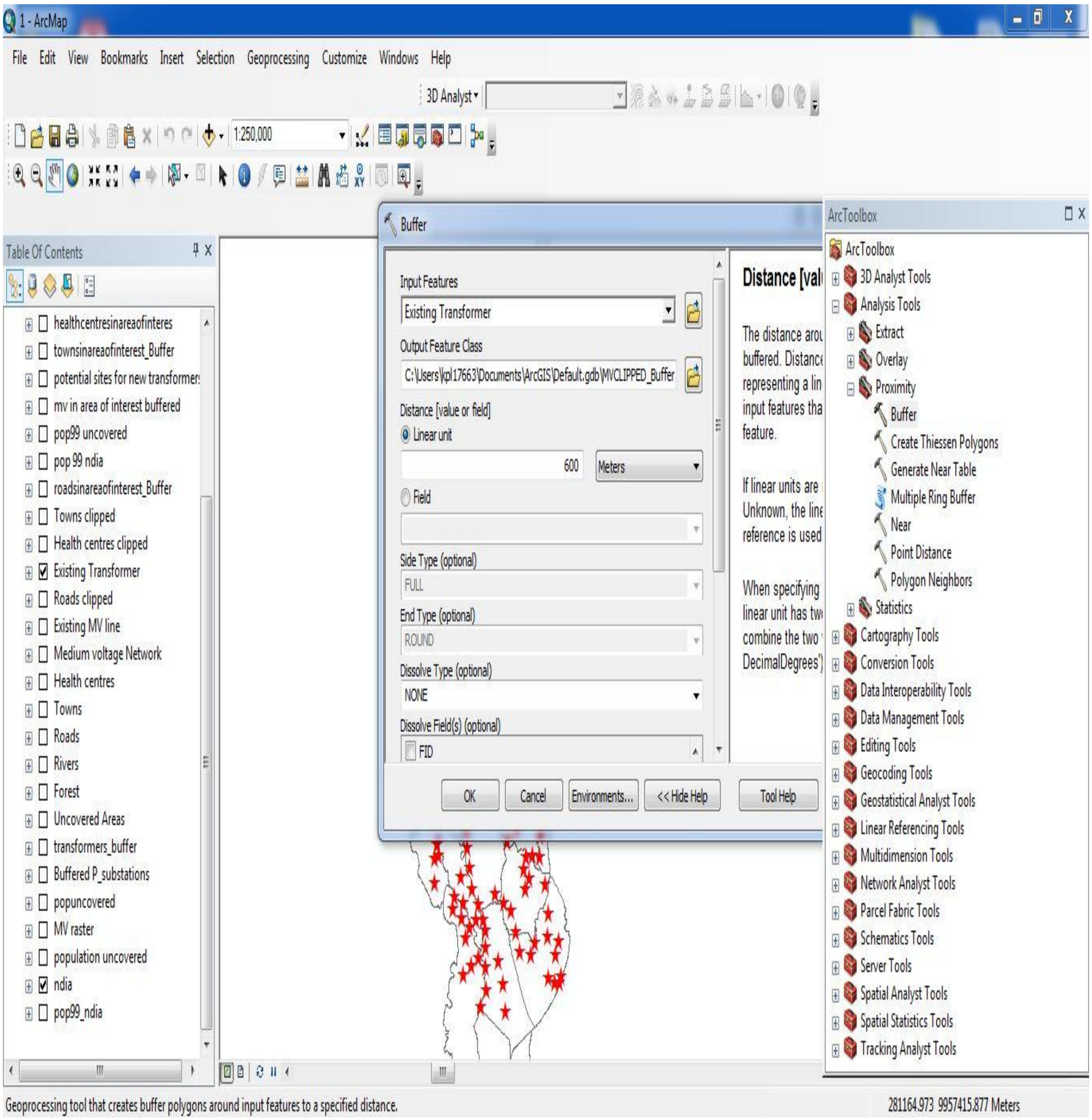

Figure 3.17: A Snapshot of Buffering Process in Arc Map.

Figure 3.18 is the map produced after buffering.

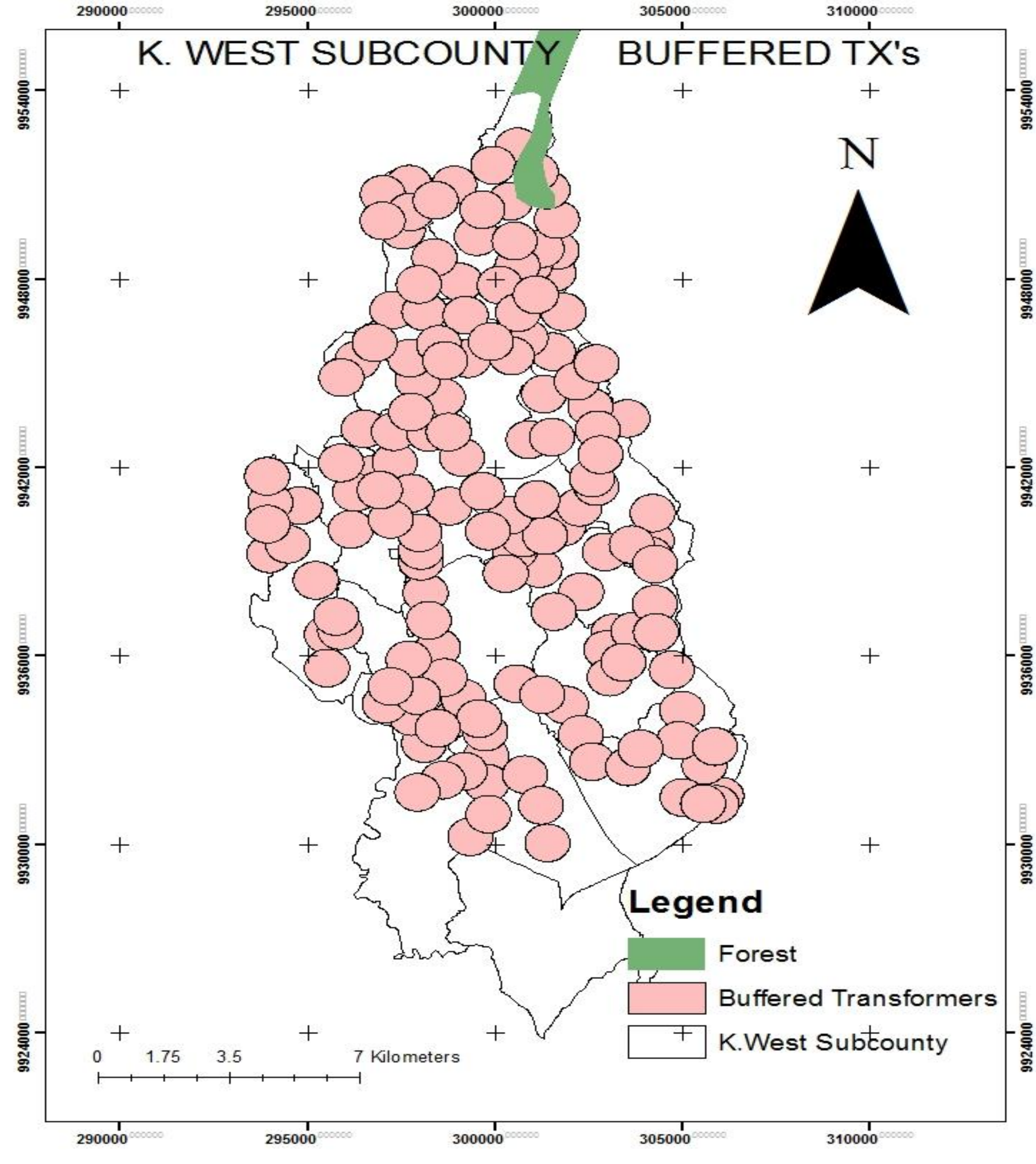

Figure 3.18: Kirinyaga West Sub county Transformers Buffered at 600m.

Following the buffering, the buffer zones were all dissolved to create total area covered by the existing transformers. Figure 3.19 is as snapshot of dissolving in Arc Map 10.1

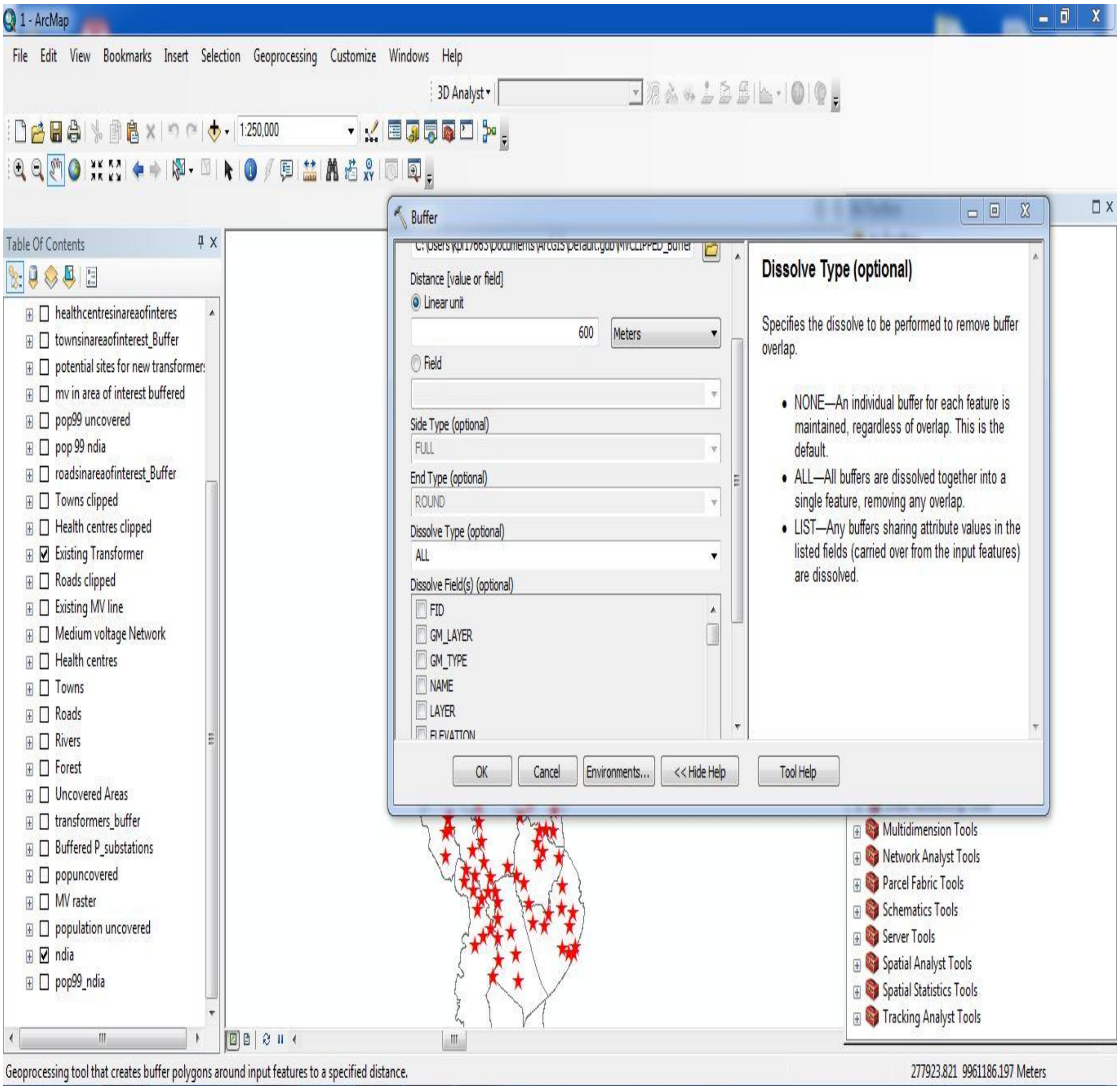

Figure 3.19: A Snapshot of Dissolving Process in Arc Map.

Figure 3.20 illustrates the spatial coverage of existing transformers based on the assumption that each transformer shall serve an area of radius 600 meters.

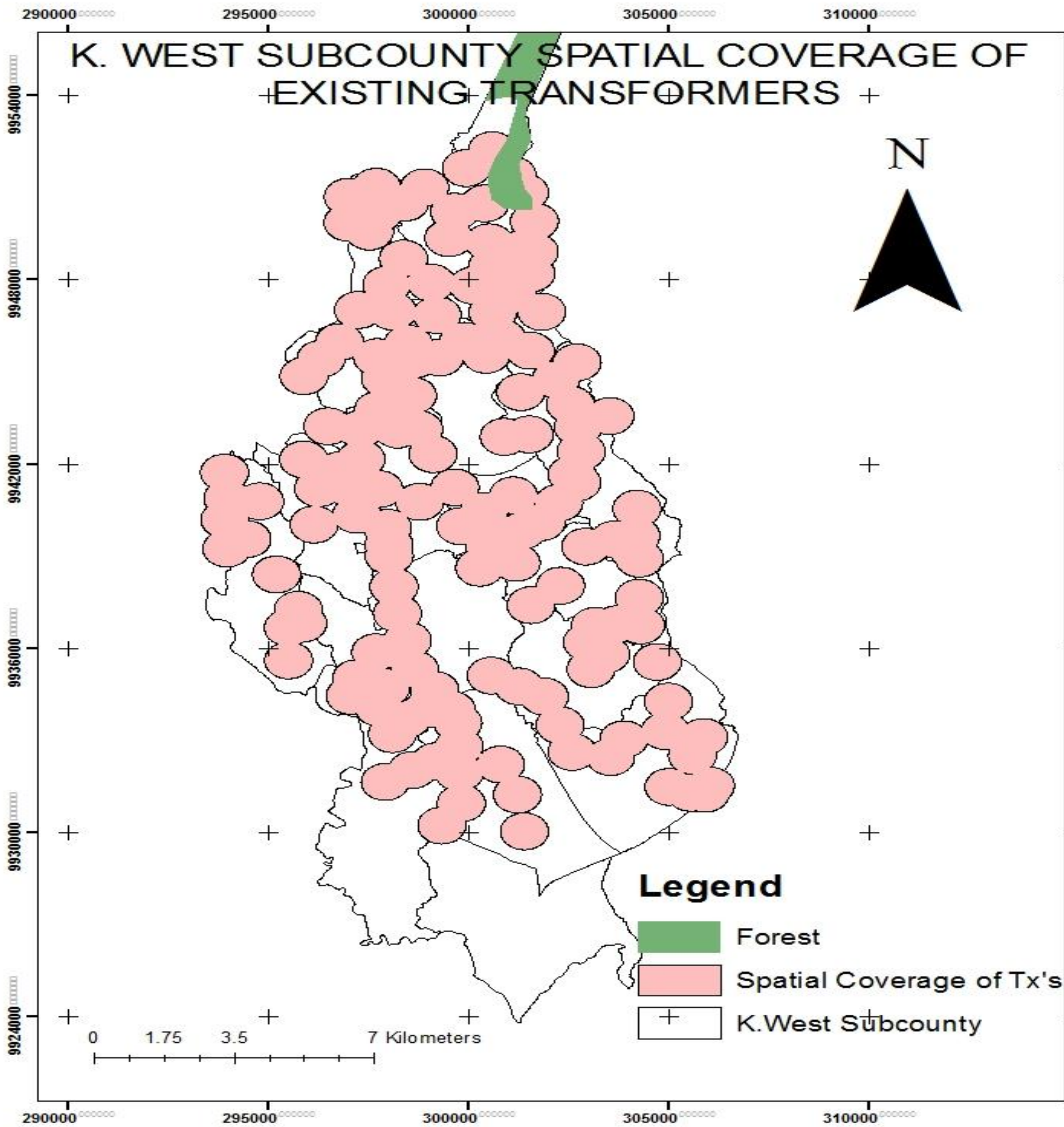

Figure 3.20: Dissolved Buffer Zones of Existing Transformers.

3.5 Area of Interest Preparation and Processing

Having known the spatial coverage of transformers in the area of study, it followed that the area of interest is the one with zero coverage as indicated in the map. To obtain this, the serviced area was clipped from the area of study using the erase tool of Arc Map 10.1. Figure 3.21 is a snapshot of erasing process.

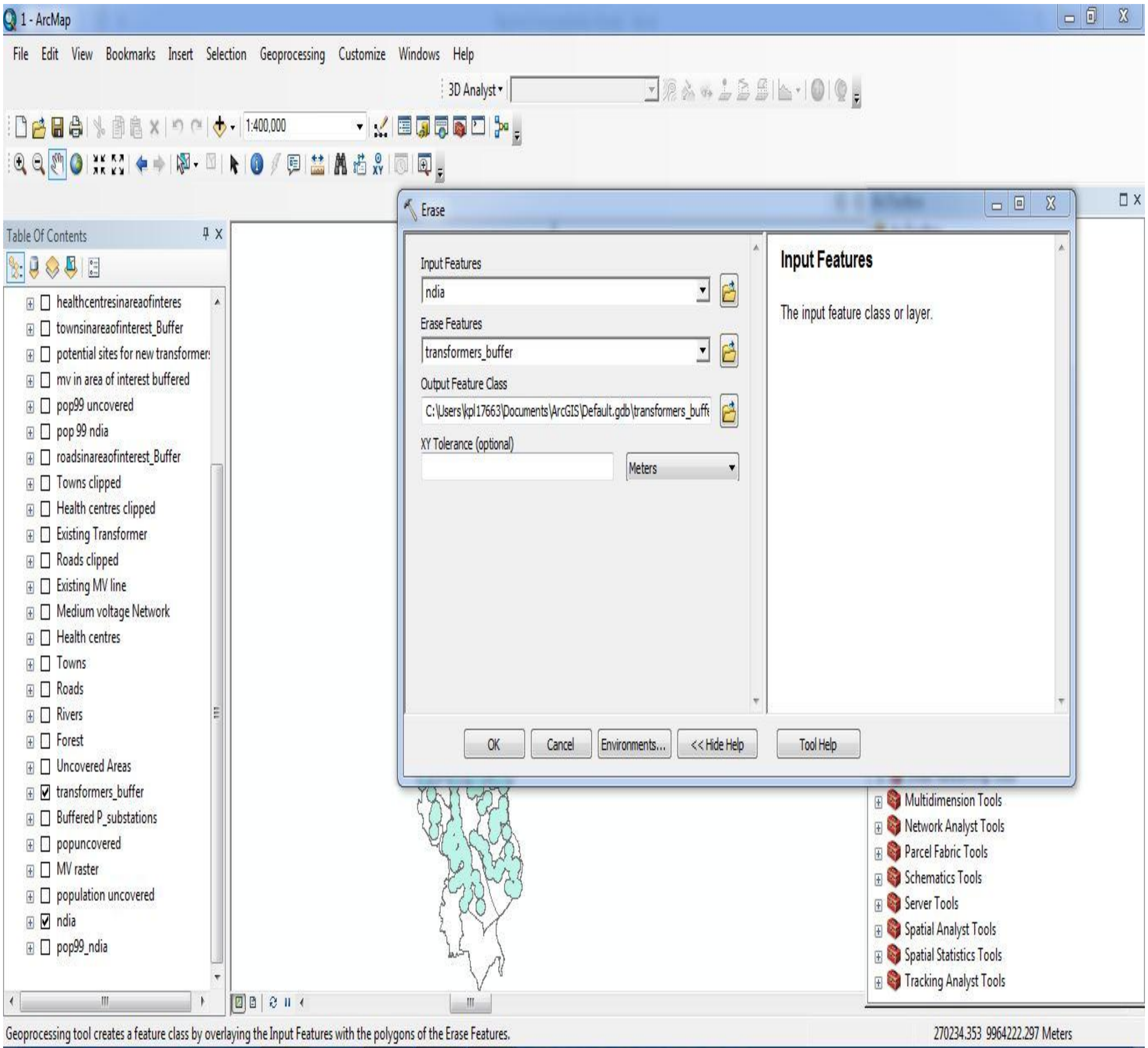

Figure 3.21: A Snapshot of Erasing Covered Areas to Obtain Area of Interest.

The resulting map indicates the areas without transformers that need consideration during planning and distribution of new transformers. Figure 3.22 illustrates this.

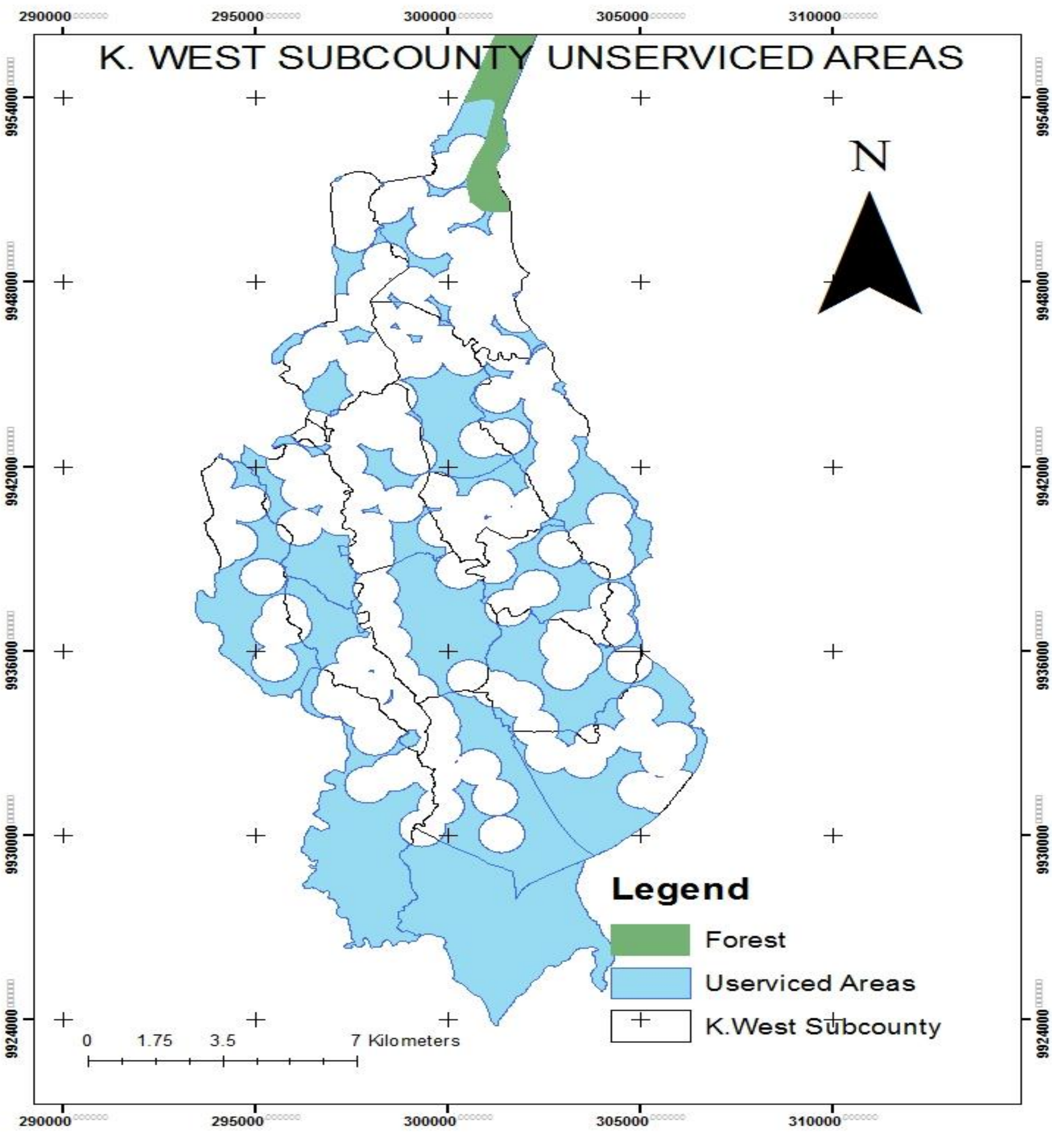

Figure 3.22: Kirinyaga West Sub county Unserviced Areas.

To check the accuracy of the map, an overlay of the existing transformers and the unserviced areas was created. Figure 3.23 is the resulting map and it is clear that no transformer exists in the uncovered areas.

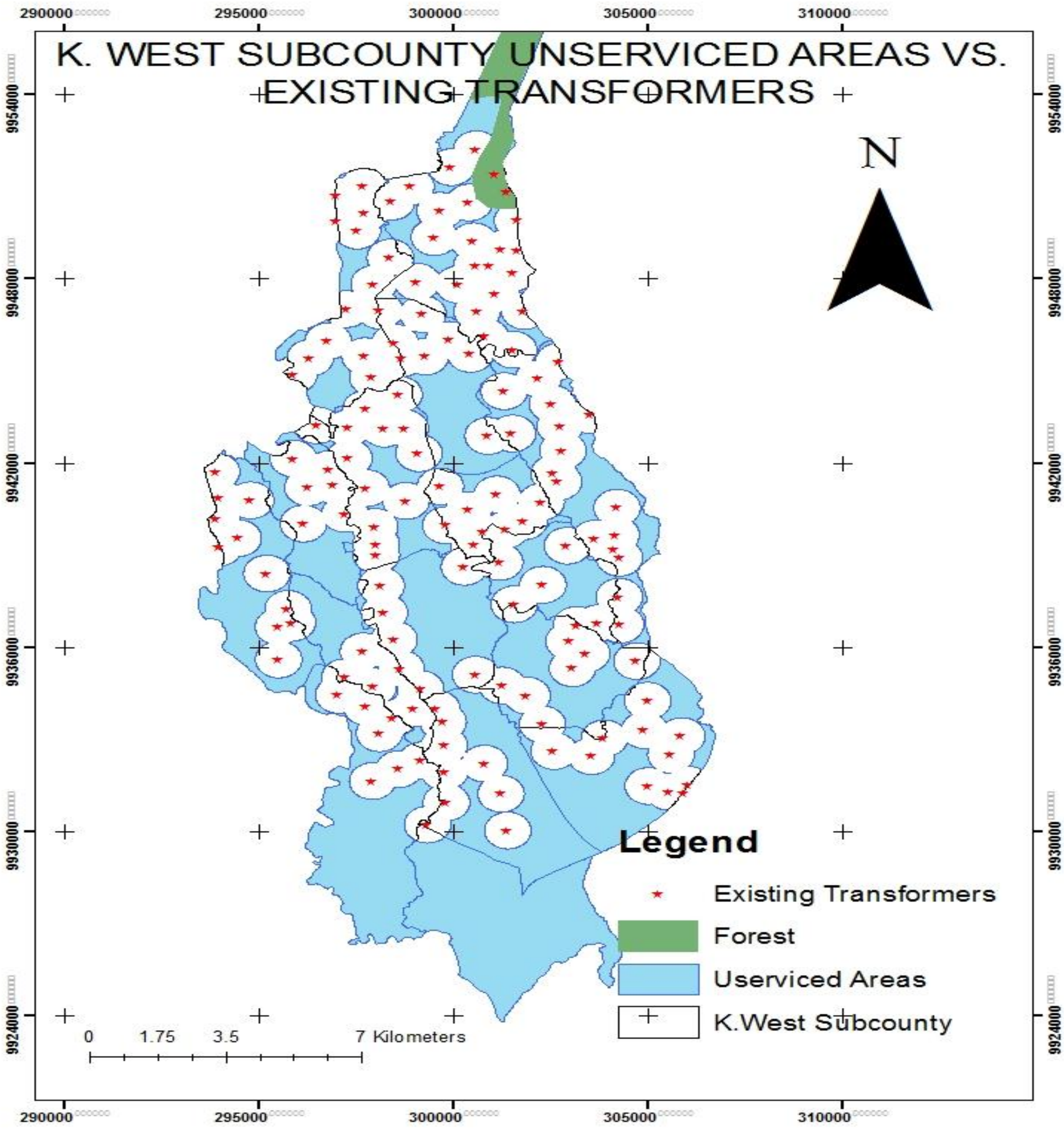

Figure 3.23: Kirinyaga West Sub county Unserviced Areas vs. Existing Transformers.

3.6 Clipping Factors to the Area of Interest.

From the above procedure, the datasets had been prepared to yield both the factors and unserviced areas. What remained was to clip the factors to the uncovered areas which then would be overlayed for analysis in planning and distributing transformers in this area. All factors were clipped using same procedure as illustrated in Figure 3.24.

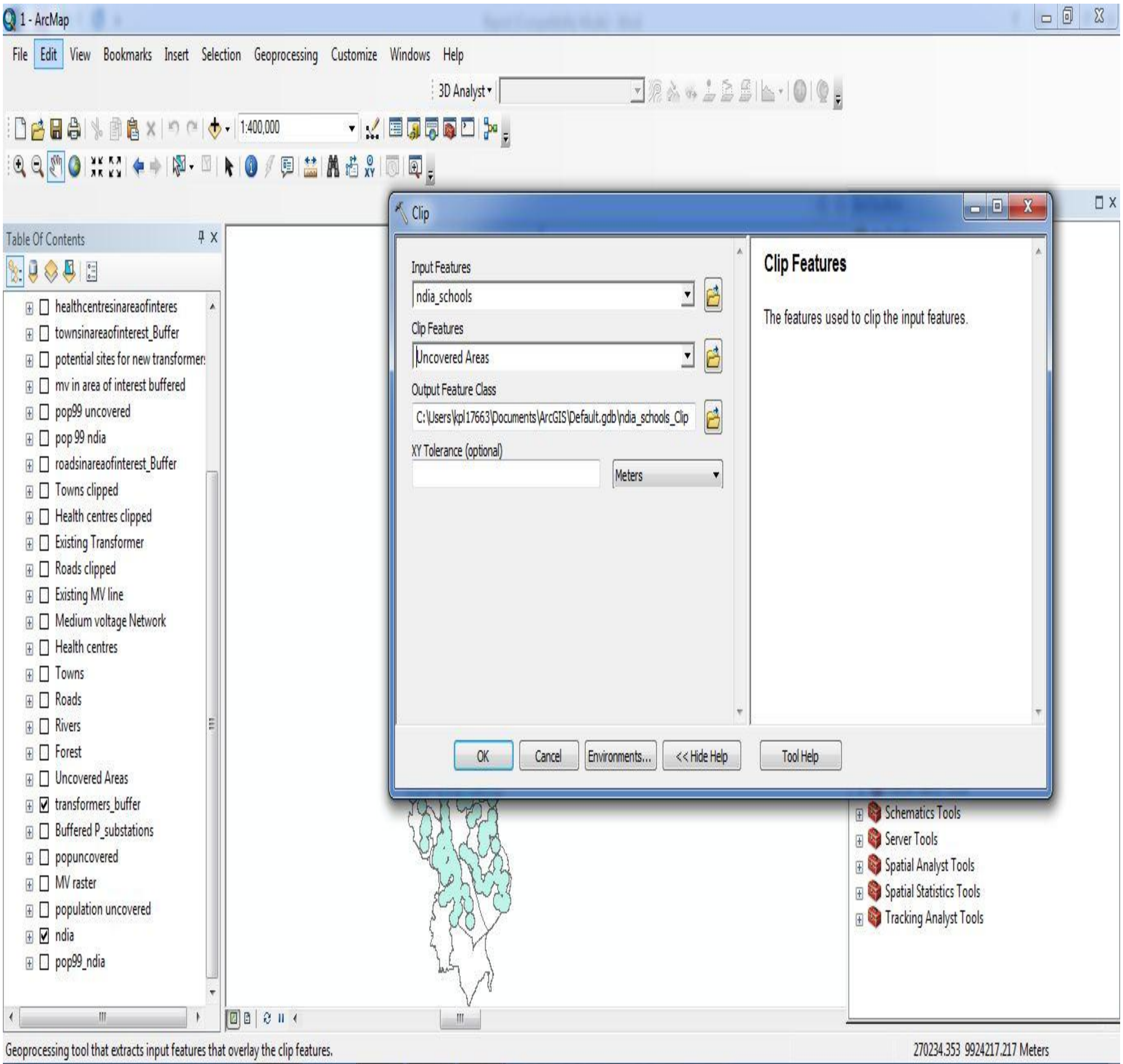

Figure 3.24: A snap shot of Clipping Schools to Uncovered Areas.

Following the clipping process, factor maps of the unserviced areas were produced. An example is Figure 3.26 illustrating the schools in area of interest.

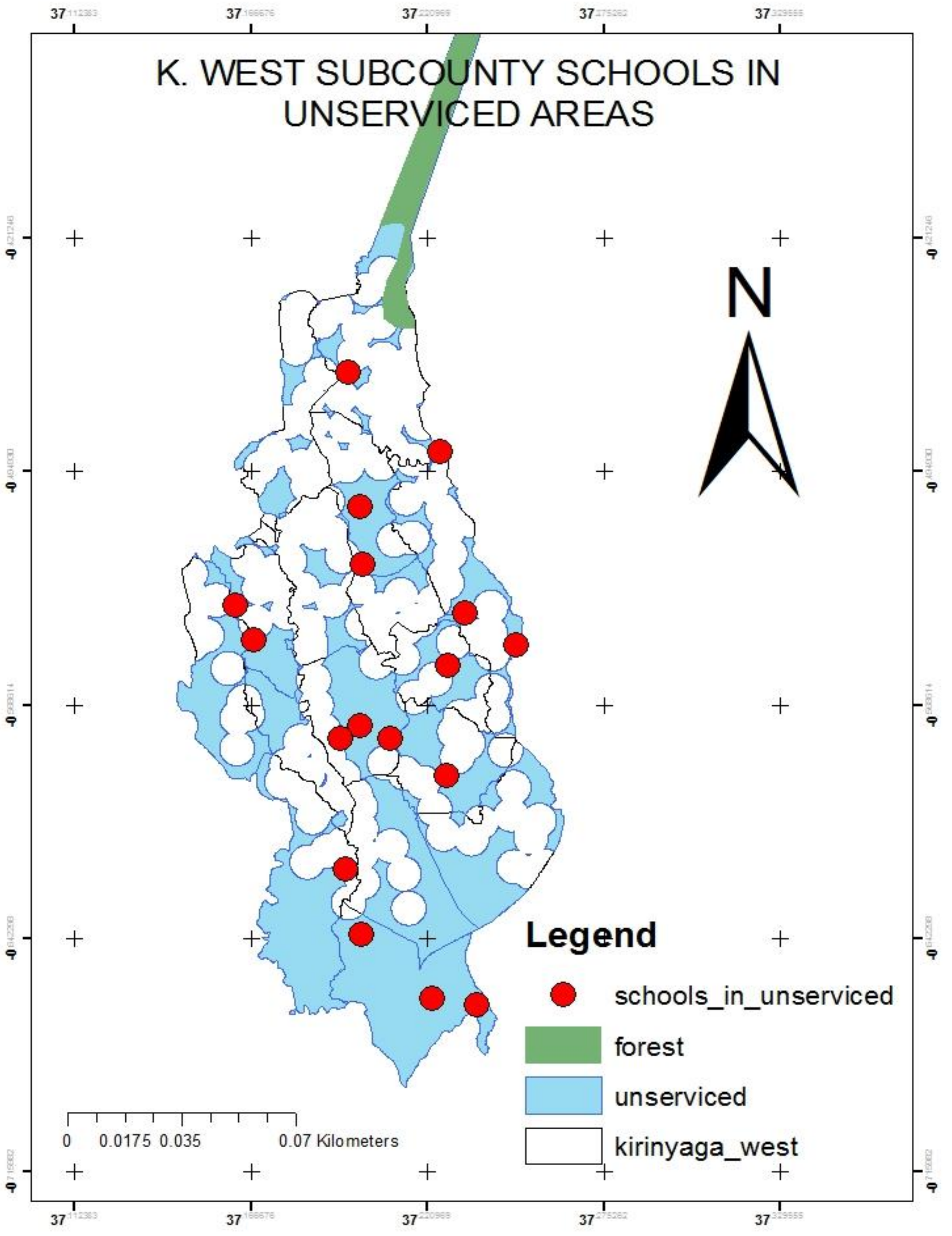

Figure 3.25: Map illustrating Schools in Unserviced Areas.

After producing the map of schools in unserviced areas, maps of the other factors were produced in similar process. Figure 3.26 is the map of towns in the unserviced areas.

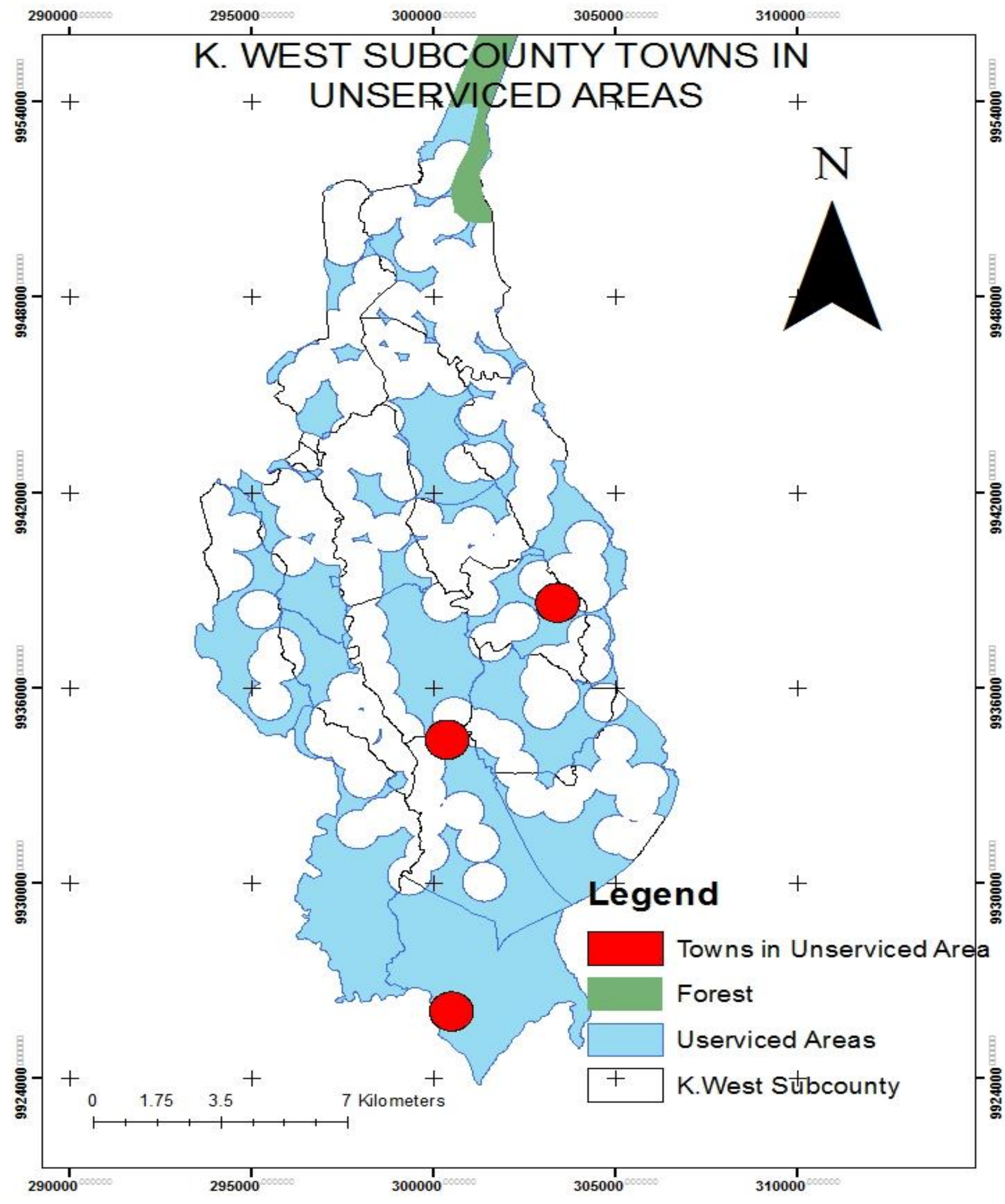

Figure 3.26: Towns in Unserviced Areas.

Figure 3.27 illustrates the medium voltage network in the unserviced areas.

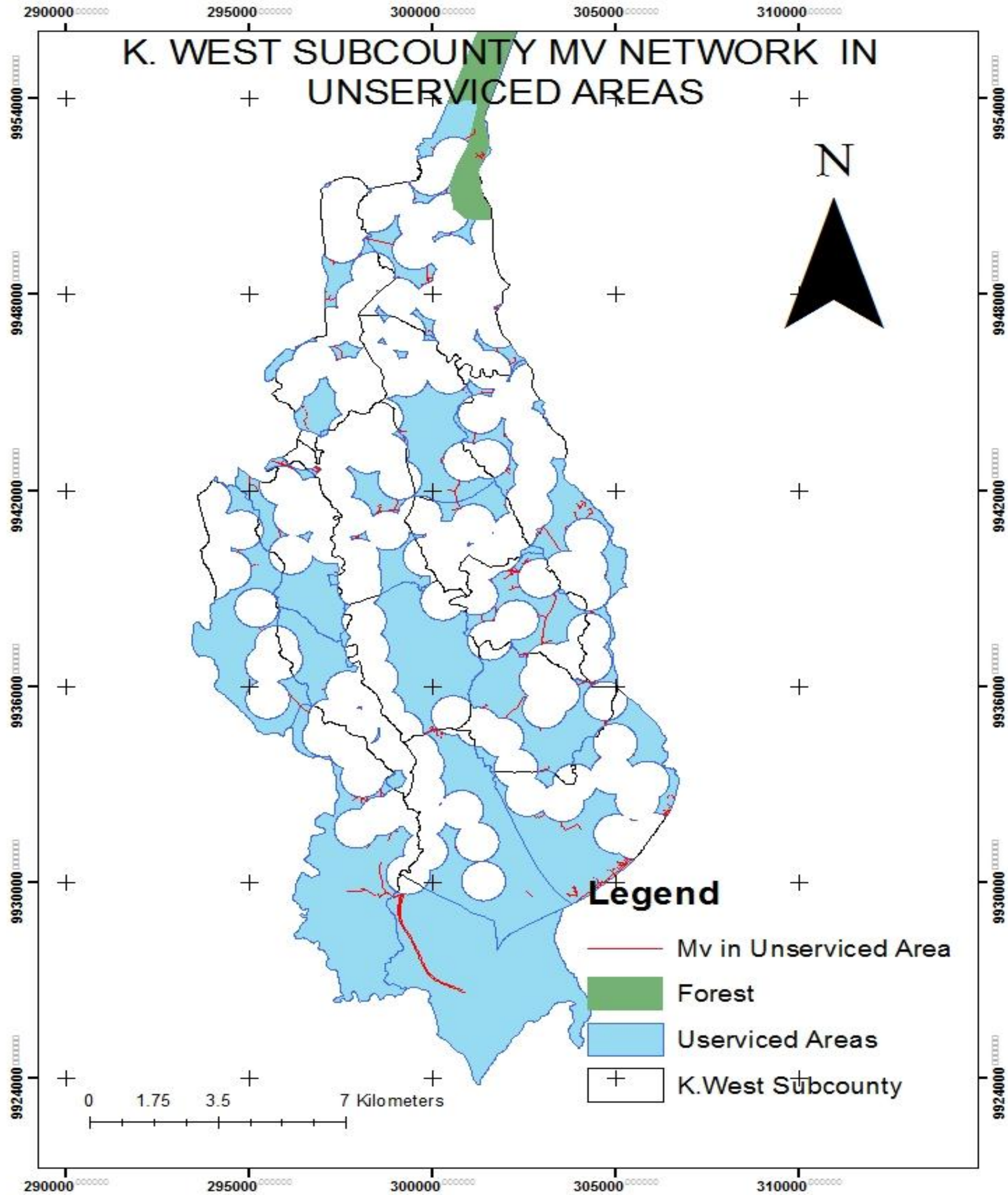

Figure 3.27: The Mv Network in Unserviced Areas.

Figure 3.28 illustrates the health centres in the unserviced areas

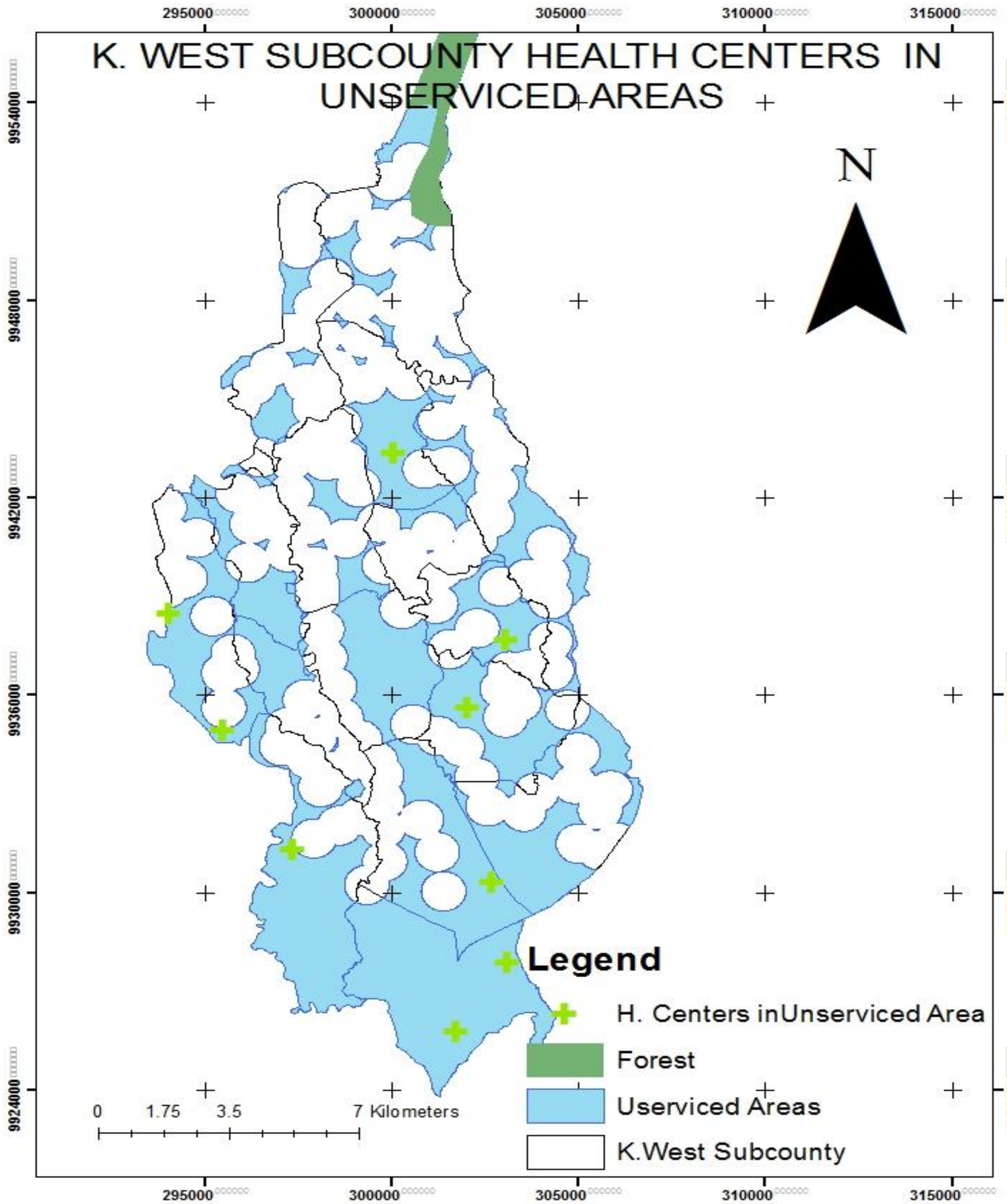

Figure 3.28: Health Centers in Unserviced Areas.

Figure 3.29 illustrates the road network in the unserviced areas.

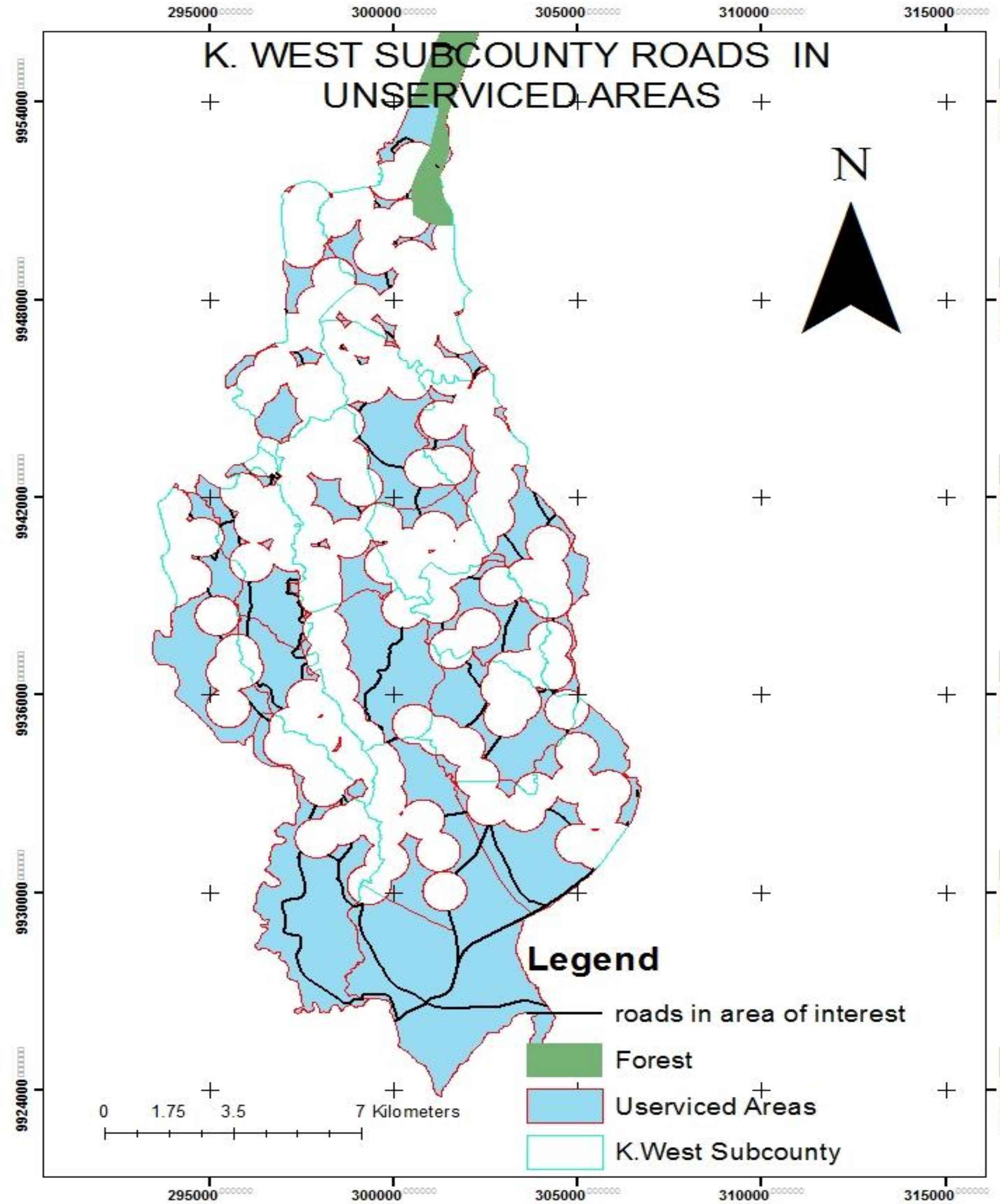

Figure 3.29: Roads in Unserviced Areas.

The above process led to the production of the individual maps of factors in the unserviced areas. Following this, these individual factors were overlayed in Arc Map 10.1 to produce a combined map as illustrated in Figure 3.30

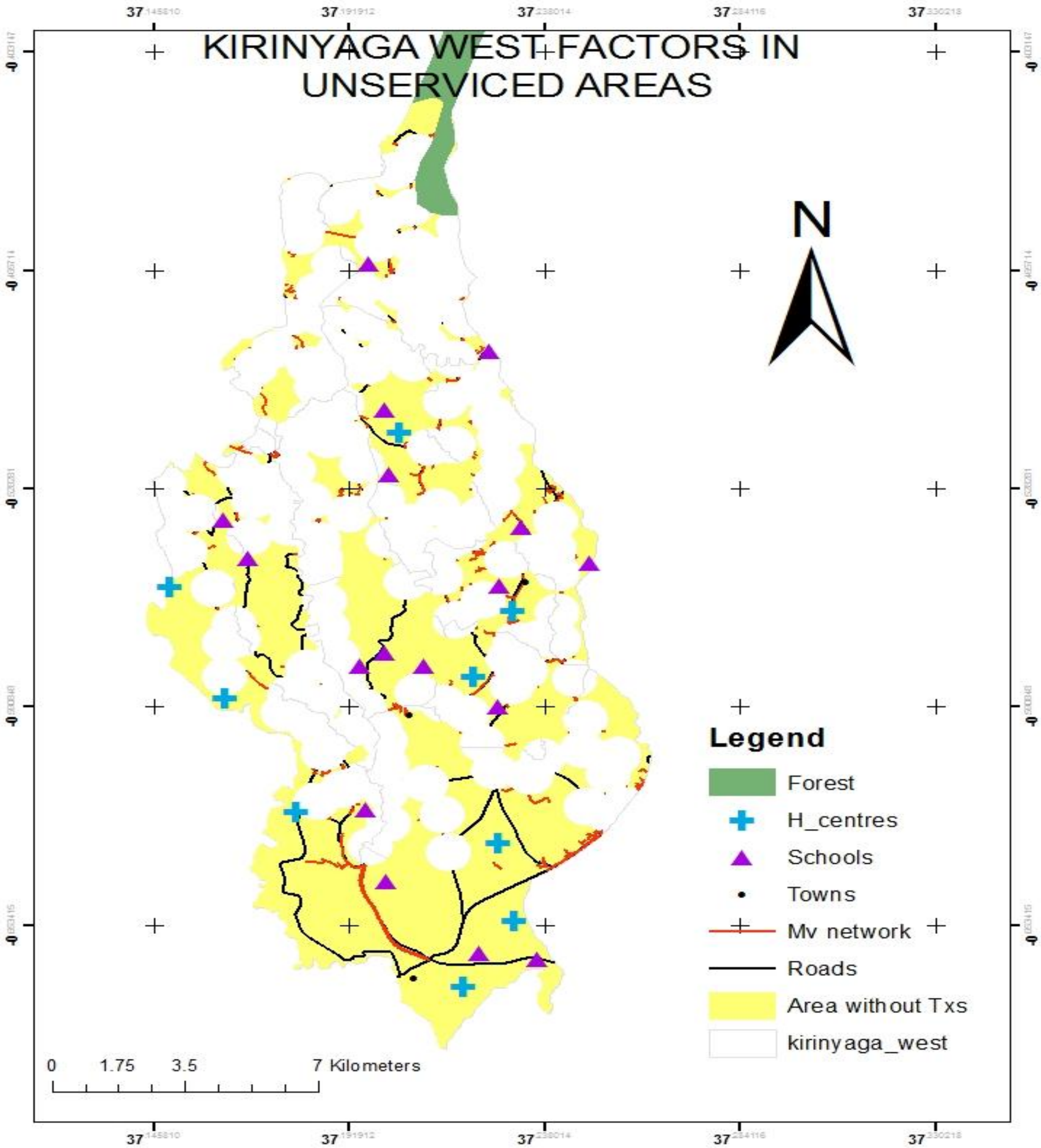

Figure 3.30: Combined Factors In Unserviced Areas.

3.7 Analysis of Factors to Produce with Potential Sites for New Transformers.

Having prepared the datasets, it was time to overlay the factors to produce a map of potential sites for the transformers. To start with, it is important to note that in the first overlay, only the sections with both Mv network and roads was considered. This involved intersecting the zones where there is mv and road network, in the uncovered areas. Figure 3.31 is a snapshot of the intersection process.

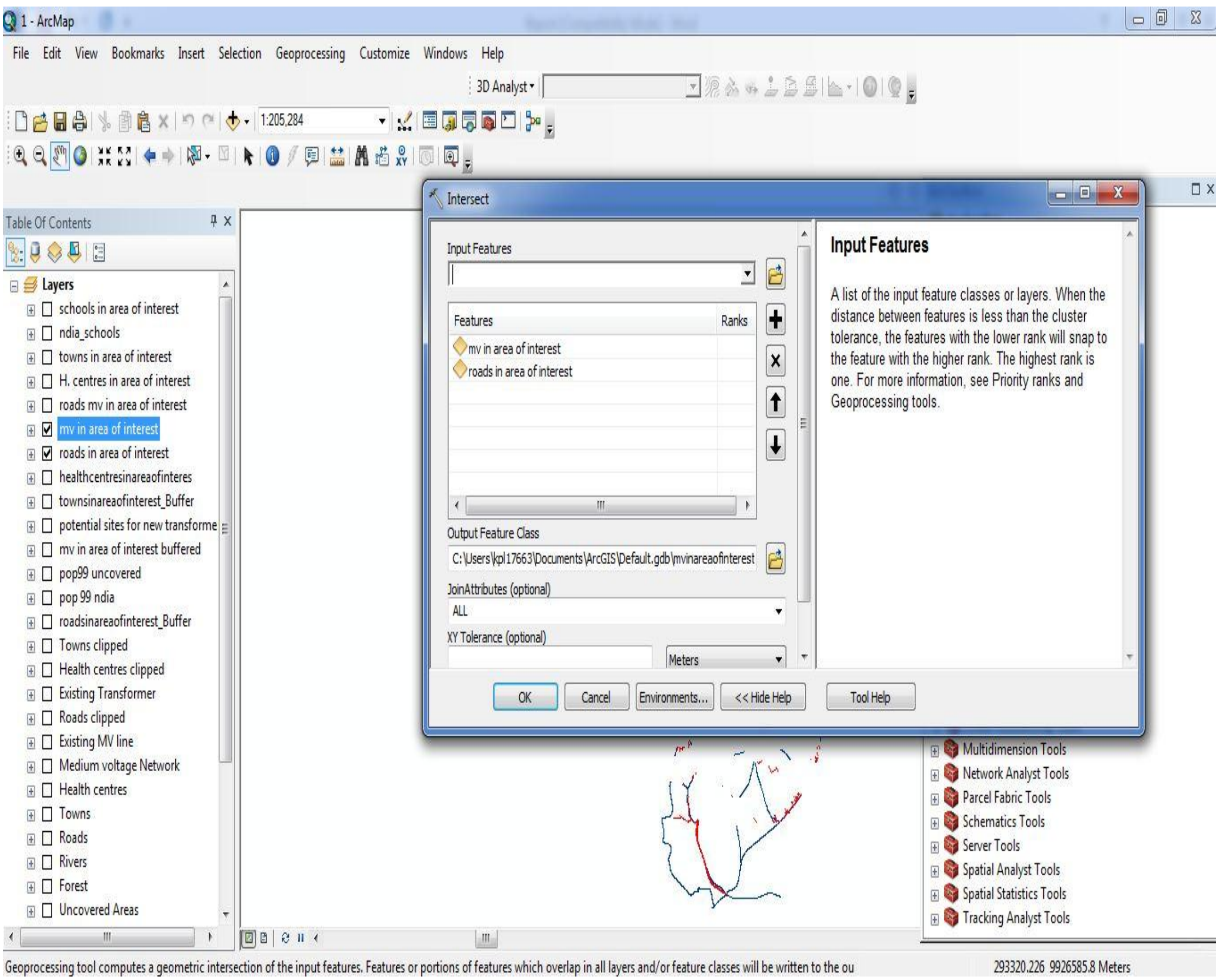

Figure 3.31: A Snap shot of Intersecting Roads and Mv in Uncovered Areas in Arc Map.

Figure 3.32 illustrates the results of the intersection process described above. These intersections indicate potential sites based on existence of these two factors in the area of study.

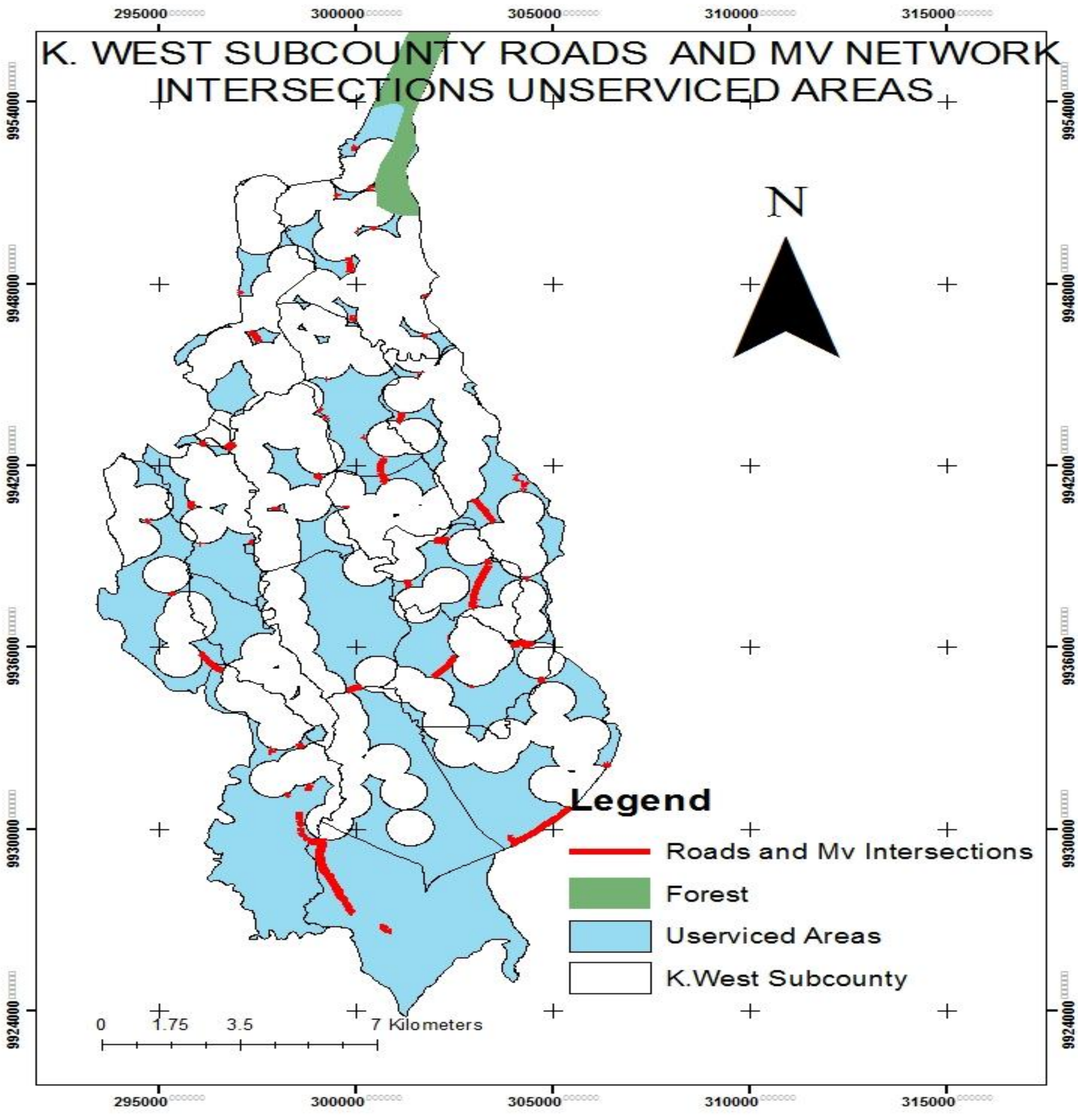

Figure 3.32: Kirinyaga West Sub County Potential Sites Map based on Intersection.

Since transformers are not always located along these two factors, it required further analysis. This involved considering situations of security of the transformer in which case it is installed inside an institutions compound, or in someone's compound. However, this distance too does not exceed 600 metres from main medium voltage lines. Hence, the medium voltage lines in area of interest was buffered at 600 metres and the roads buffered at 60 metres. These buffer zones were merged and dissolved to form a continuous area feature on which transformers would be installed following further technical, environmental and financial analysis.

CHAPTER 4: RESULTS AND ANALYSIS

To get the spatial aspect of potential sites, the intersections were buffered as described in the previous chapter. Figure 4.1 is the map of potential sites for new transformers.

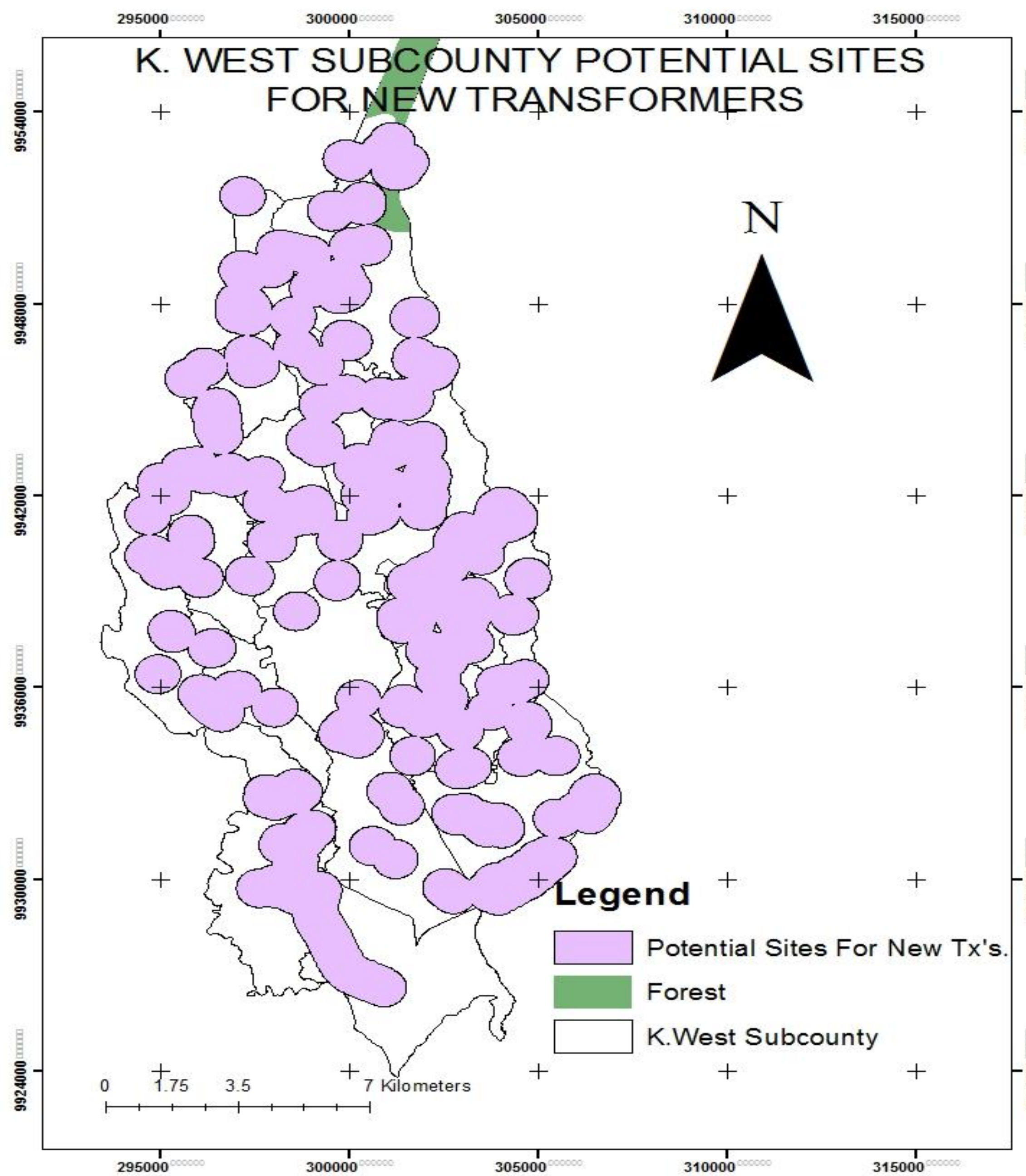

Figure 4.1: Kirinyaga West Sub county Transformers Potential Sites Map.

Having identified the potential sites, it was necessary to overlay these sites with the factors that had been considered during this project, especially the demand centres. This stage serves to compare how efficient these new sites are to meeting the need of connecting these demand centres. Figure 4.2 illustrates an overlay which compares the potential sites and the initial unserviced areas. It is evident that not all unserviced areas have the potential of installing additional transformers. This is because the areas lack either medium voltage lines or roads or both.

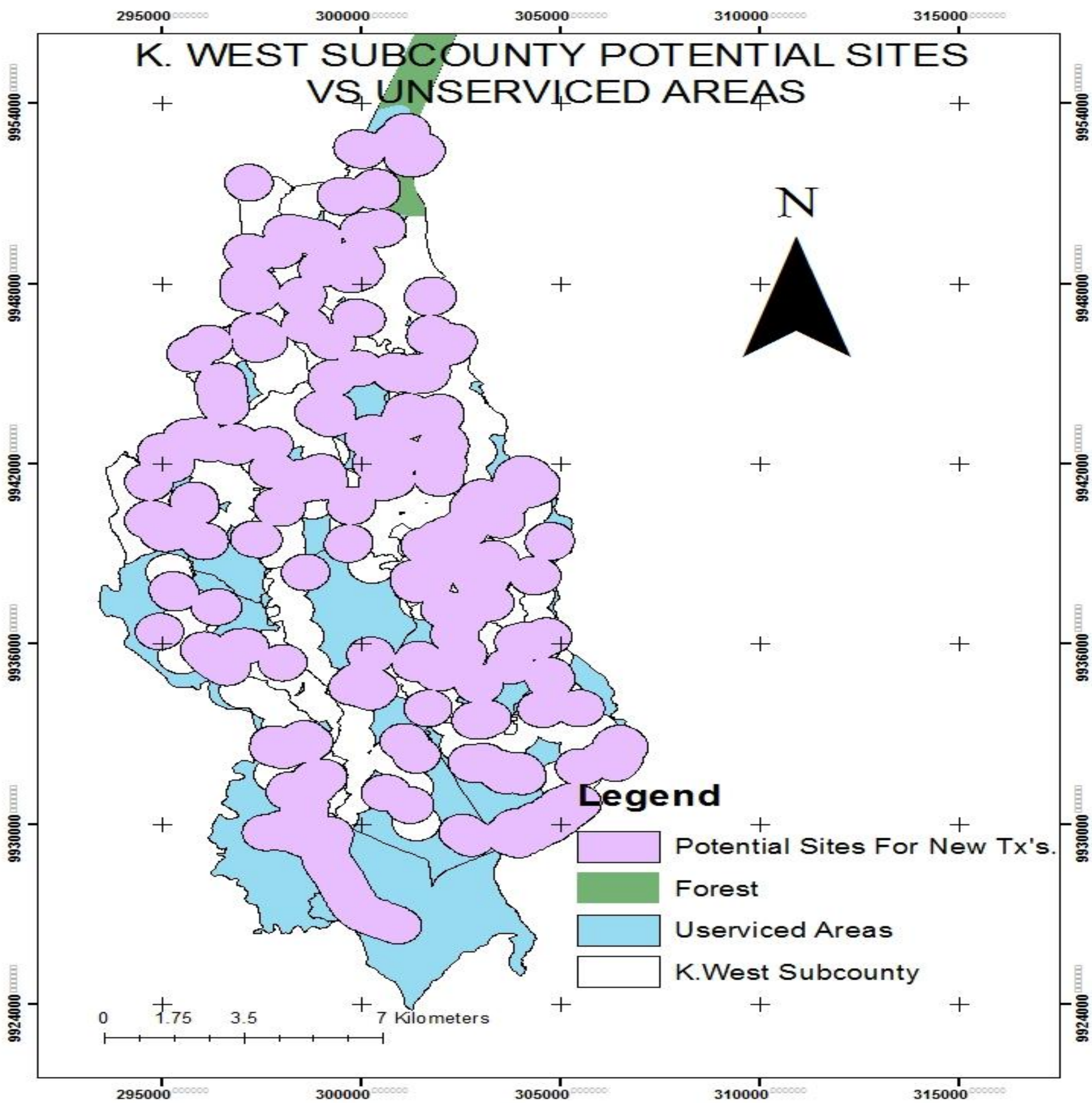

Figure 4.2: Kirinyaga West Sub county Potential vs. Unserviced Areas.

To have a general of distribution of existing and the potential sites, an overlay of these two factors was carried out and Figure 4.3 is the illustration of this comparison.

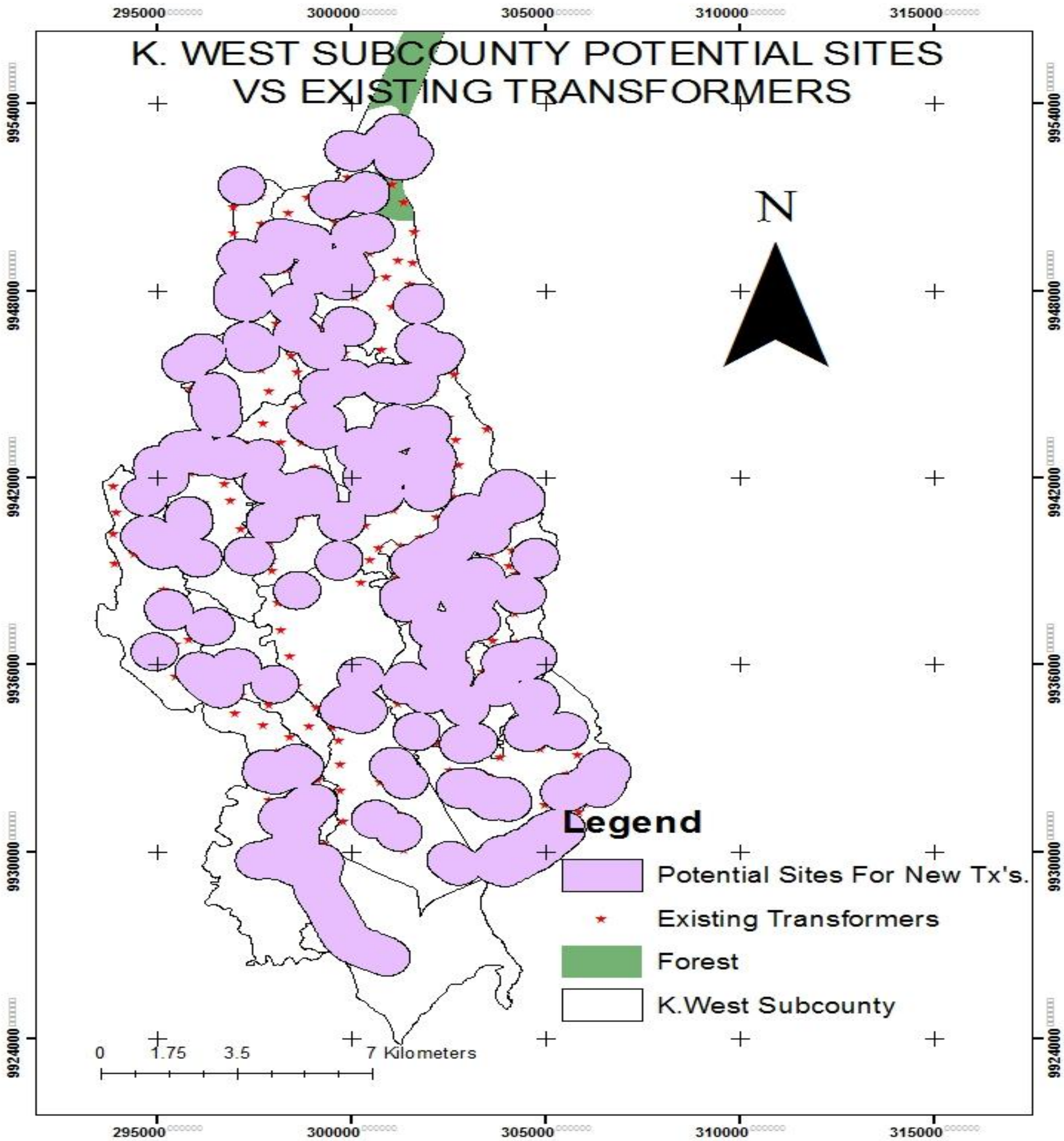

Figure 4.3: Kirinyaga West Sub county Potential Sites vs. Existing Transformers.

In chapter three, key factors referred to as demand centers were described as centers requiring electricity connection. Figure 4.4 illustrates an overlay of these centers with potential sites for additional transformers. It is evident from the map that one town, five health centers and four schools do not lie in the potential sites. The reason to this the lack of medium voltage line around them. A solution for this is given later in this report.

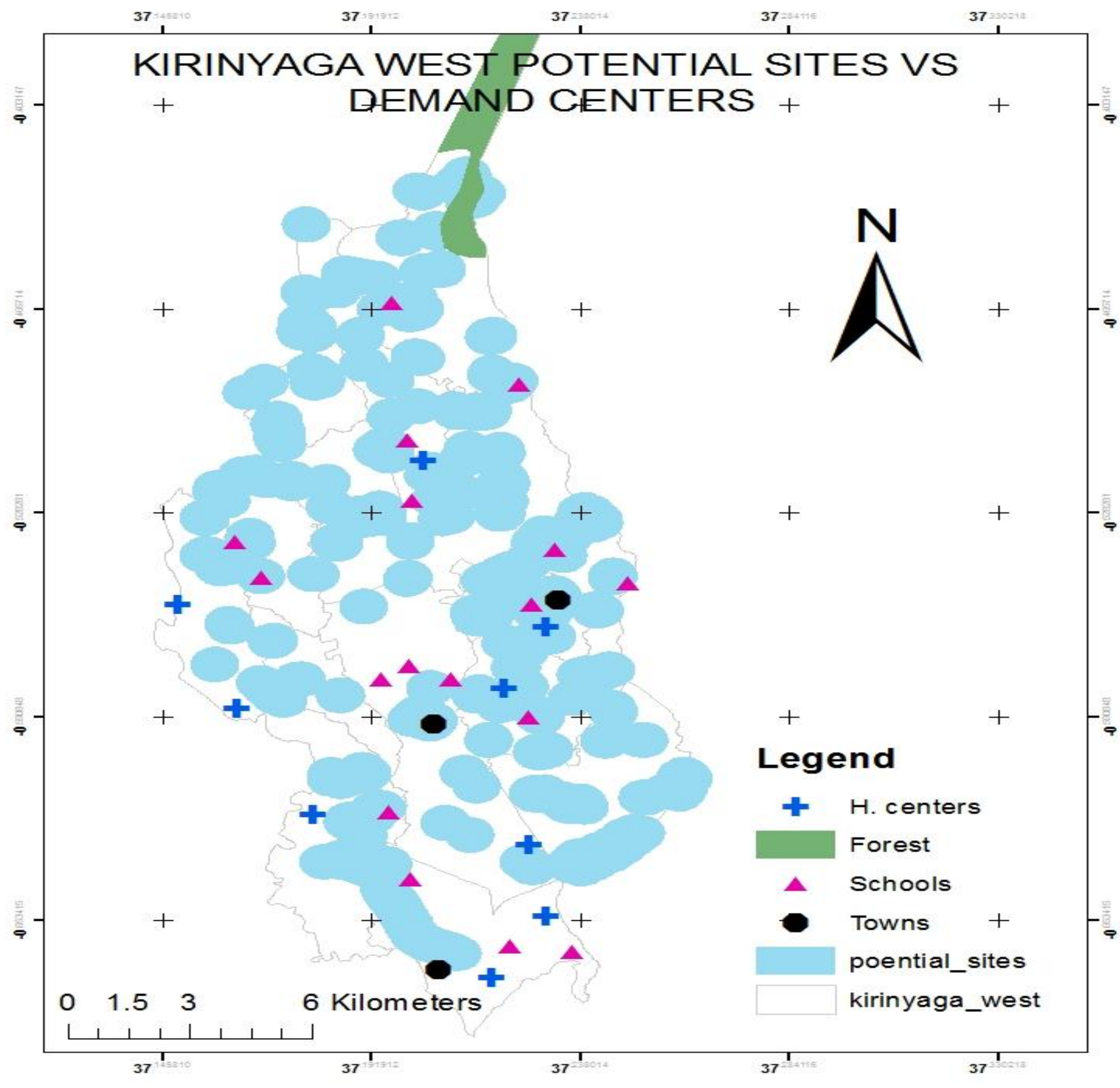

Figure 4.4: Kirinyaga West Sub county Potential Sites vs. Demand Centers.

Population was discussed earlier in this report as a factor affecting the location of a transformer while population density affects the rating of a transformer. To give an impression of this, an overlay of potential sites map and reclassified population map was done. Figure 4.5 illustrates this. The following map would be useful in determining the rating of transformer to install at a particular location. An example is if a transformer is to be installed in any of the pink areas (households 1601-2665) then it is to be of highest rating as the potential customers per square kilometer are more than other areas.

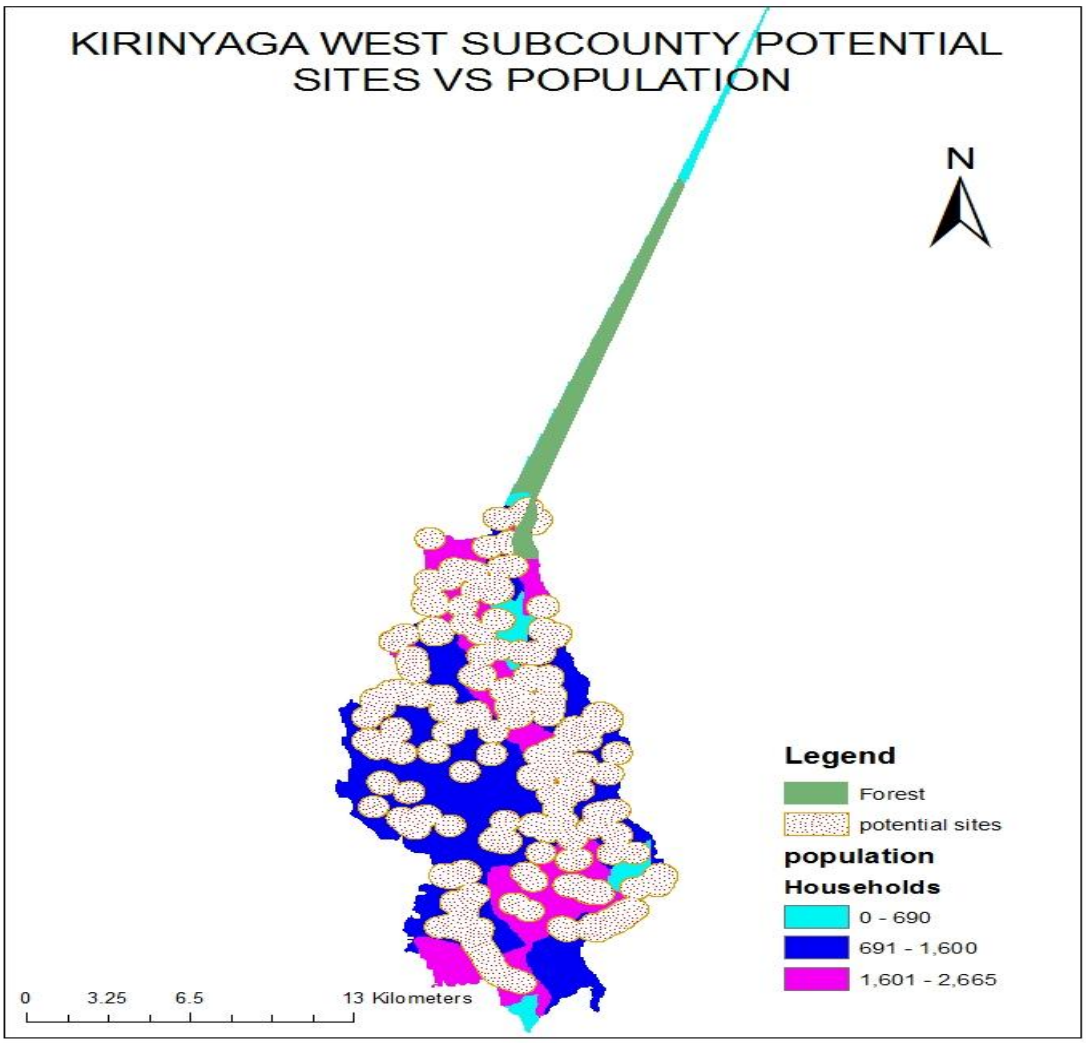

Figure 4.5: Kirinyaga West Sub county Potential Sites vs. Population

In chapter three, it was noted that four schools, one town and five health centres did not fall under potential sites. This was because medium voltage do not exist around these demand centres and hence it dictates that for them to be connected to electricity, it shall require extension of medium voltage lines. To achieve the areas requiring medium voltage lines extension, the potential areas were “subtracted” from unserviced areas through erase tool in Arc Map and the resulting map is illustrated in Figure 4.6.

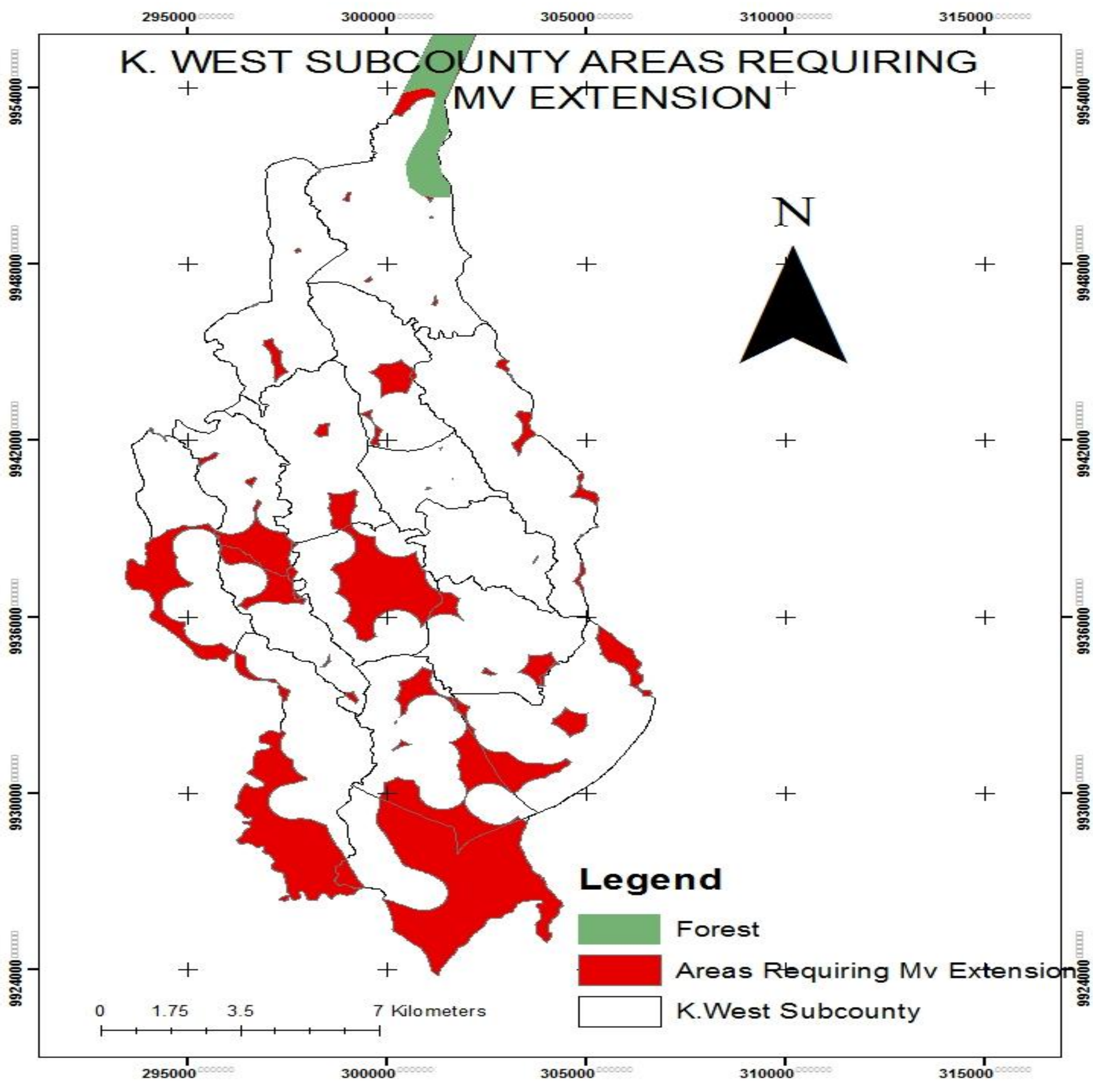

Figure 4.6: Kirinyaga West Sub county Map of Areas Requiring Mv Extension.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Following this research the following conclusions were drawn.

- Approximately 55% of the area of study is efficiently spatially covered by transformers leaving 45% uncovered by transformers.
- If the current medium voltage network in the area of study is maximized, 29% more of the area would be covered by the existing transformers.
- This leaves approximately 20% of the area requiring extension of the medium voltage network.
- These percentages are exclusive of the forest cover which is approximately 7% of the study area.

Hence, the following is recommended;

- There should be immediate consideration of maximizing the current medium voltage network to attain the 29% extra coverage
- There be extension of medium voltage network targeting the remaining approximately 20% of unserviced areas.
- Detailed Energy studies should be carried out in the area to determine specific ratings for each new transformer and also the existing ones.
- That financial studies should be carried out for budgeting and planning for this implementation

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