ADAMA SCIENCE & TECHNOLOGY UNIVERSITY

School of Graduate Studies
Department of Geomatics Engineering

Thesis on:

Wind farm Site Selection **using Multi criteria GIS** ***Modelling*****:**

A case of Debre Brehan Zuria Wereda, Semen shewa zone, Amhara Region, Ethiopia

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A Thesis Submitted to the department of Geomatics Engineering, Adama science and Technology University, in Partial Fulfillment of the Requirements for the Award of a Master's Degree in Geodesy and Geomatics Engineering

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Adama, Ethiopia

Declarations

I, Dereje Amakelew Tsega, Registration Number/I.D. Number GSR/5553/06, do hereby declare that this Thesis is my original work and that it has not been submitted partially; or in full, by any other person for an award of a degree in any other universities or academic institution.

Name of Participant Dereje Amakelew Signature……………………. Date…………….

This Thesis has been submitted for examination with my approval as College supervisor.

Name of Advisor Essayas Deribe (PhD) Signature……………………. Date……………

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Approval sheet

The undersigned certify that they have read and hereby recommend to Adama Science and Technology University to accept the Thesis submitted by Dereje Amakelew Tesga, and entitled "*Wind farm Site Selection* using Multi criteria GIS *Modelling*"; a case of Debre Brihan Zuria Wereda, Semen Shewa Zone, Amhara Region", in partial fulfillment of the requirements for the award of a Master's Degree in Geodesy and Geomatics Engineering.

Name of chairperson ……………….………………Signature………………….Date……………

Name of Advisor……………………………………Signature…………………Date……………

Name of Internal Examiner …………………………...Signature………………. Date……………

Name of External Examiner …………………………..Signature…………. ……. Date…………

Abstract

One of the most significant obstacles to develop wind power is land use restrictions. Development of wind power plants requires land with sufficient wind resources, proximity to the power grid, and compatibility with environmental and regulatory requirements. This study focus on GIS based multi criteria wind farm site selection. Geographic Information Systems (GIS) have been widely used to identify the suitable wind farm locations. In this study, a GIS-based multi-criteria approach was developed to identify the areas that are best suited to wind farm site in Debre Brihan Zuria Wereda, Semen Shewa Zone, Amhara region. 10 criteria's were adopted in this method, including distance to roads, distance to transmission lines, engineering geology, wind potential, land use, Settlement, slope, elevation, forest and hydrology. The suitability of wind farm site selection was modeled by a weighted overlay and Boolean overlay of geospatial layers corresponding to these criteria using Arc GIS model builder. The final wind farm site suitability map reveals that the study area was divided into five different suitability categories. The area under extremely very good, good, moderate, poor, and restricted lands stand at 29.2%, 35.7%, 9%, 21.5% and 4.6%, respectively. The results indicates that the method is capable of identifying locations highly suited for wind farm site. The methods and the result of the study could help identify suitable wind farm locations in other areas across the country.

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Table of Contents

List of tables

List of figures

List of Appendixes

Acronyms/ Abbreviations

AHP – Analytical Hierarchy Process

CRU climate research unit

DEM Digital Elevation model

DSS decision support systems

EDSS- Environmental decision support systems

EEPCO_ Ethiopian Electric Power Corporation

ESRI_ Environmental Science research institute

GIS – Geographic Information System

GW_ Giga watt

MCA – Multi-Criteria Analysis

MCE – Multi-Criteria Evaluation

MW_ mega watt

NGCC_ National Geomatics center of china

NGO_ Nongovernmental organization

NREL_ National renewable energy laboratory

MCDM_ Multi-Criteria decision making

SDSS_ Spatial decision support system

SWERA- Solar and wind energy resource assessment

USA_ united states of America

USGS_ United states geological survey

WFLC_ wind farm location criteria

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Clean, renewable energy sources are highly required throughout the world, due to concerns associated with fossil fuel availability, fluctuating oil prices, air pollution emissions, and global warming (Kyoto, 1997). Of the available renewable energy sources, wind energy holds great promise as recent technological advances have brought down its cost to the point where it is competitive with conventional fuel sources (Fairley, 2000). Renewable energy systems are environmentally friendly compared to conventional energy systems. These systems do not produce any physical pollution such as greenhouse gases (Babban, S.M.J, & Parry.T, 2001). Further, they do not exhaust any natural resource and the inputs they use are abundant in nature (Tsoustos, Frantheskaki, & Gekas, 2005).

One of the most significant obstacles to developing wind power is land use restrictions. Development of wind power plants requires land with sufficient wind resources, proximity to the power grid, and compatibility with environmental and regulatory requirements (Wind Energy Series, 1997). The identification of environmentally and geographically favorable locations that are also associated to the highest potentials for energy production represent a complex decision-making process that requires evaluation of economic and environmental limitations.

Roughly 95 percent of Ethiopia's electric energy system is dependent on hydropower. However, due to siltation of the reservoirs, some of the hydropower plants are losing storage volume resulting in reduced energy output throughout the year. Another restriction of the hydropower system is caused by the variability of rainfall episodes and amount. In years of low rainfall and drought the amount of water available during the rainy season from July until September does not allow for the reservoirs to be filled up to the required level. These extreme changes in water availability indicate the problems of the Ethiopian electricity supply. On the other hand the energy sector in Ethiopia is expanding rapidly, and there is a need to supplement the power supply from the hydropower plants (including the new ones) by alternative energy sources, such as wind as the fluctuating water availability is a long term problem. Thus, in order to guarantee security of supply, the power generation system has to be diversifies (EEPCO, 2006)

This paper uses Geographic Information System (GIS) to select most suitable sites of wind renewable energy systems. The two main barriers to large-scale implementation of wind power are: the apparent intermittency of winds, and the difficulty in identifying decent wind locations, especially in developing countries. The first barrier can be ameliorated by linking multiple wind farms together. Such an approach can virtually eliminate low wind speed events and thus substantially minimize wind power intermittency (C.Archer, 2005). The benefits are greater for larger wind power installations areas, as the spatial and temporal correlation of wind speeds is substantially reduced. This study focuses on the second issue, which is the optimal siting of wind farms on the Debre Brihan Zuria Wereda. It is thus very essential to identify and define the amount of wind energy that could be technically exploited in the study area. Maps of wind power potential at 80m, which is the hub height of a modern wind turbine and implementation of screening criteria related to socio-economic, Environmental and Geographic constraints. The analysis of wind speed distribution at a different height than the wind speed is available, is another important factor that should be considered when assessing the wind potentials at a proposed site. (Mentis, Wind Energy Assesment in Africs A GIS based approach, 2013).

1.2 Statement of the problem

The world's population will continue to grow for several decades to come. Energy demand is likely to increase even faster, and the proportion of energy supplied by electricity will also grow at the same rate (William P. & Marry A., 2004). The main sources of energy (fossil fuels: coal, petroleum and gas) that we use are believed to be running out. Moreover, these sources of energy can cause harm to our environment if not properly managed.

Most of Ethiopian's Electric energy system is dependent on hydropower. However, due to siltation of the reservoir and variability of rainfall episode and amount, some of the hydropower plants are losing storage volume resulting in reduced energy output throughout the year (EEPCO, 2006). Therefore, there is a need to supplement the power supply from hydro power plant by alternative energy resources along with adaptation strategy against those environmental consequences that cannot be reversed. One of these clean and renewable alternative resources is wind energy.

Therefore, the use of wind energy for use in urban and rural centers is an alternative future direction and a possibility. On the basis of these scenarios there is a need to assess potential areas for use of wind energy. One of the most significant obstacles to develop wind power is land use restrictions. Development of wind power plants requires land with sufficient wind resources, proximity to the power grid, and compatibility with environmental and regulatory requirements. Therefore, the main goal of the proposed study is to select optimum wind energy farm in the study area Using GIS based multi criteria modelling.

1.3 Objectives

1.3.1 General Objective of the Study

The general objective of this research is to identify and map the most suitable wind farm site in Debre Brihan Zuria Wereda, using Multi criteria modelling.

1.3.2 Specific Objectives

The specific objectives of this research are to:

- determine the relative importance of the criteria for wind farm site using the AHP method
- develop GIS based suitability model for wind farm site
- map the most suitable site for wind farm in the study area
- identify the restricted area

1.4 Research Questions

1. What are those factors which affect potential wind farm site selection?
2. Which is the most suitable site for wind farm site?
3. What are those restricted area for wind farm site selection?
4. What are those constraint which affect wind farm site selection?

1.5 Methodology

Wind farm site selection depends upon numerous factors. A group of technical, economic and Environmental factors were incorporated into a GIS tool to define the locations for wind farm sites. The criteria must be identified and include factors and constraints. In this study criteria were selected based on Best Practice through comprehensive literature review. Geographic information systems (GIS) and Multi criteria analysis with overlay analysis techniques were used in solving site selection problems. The analytical hierarchical process (AHP) also used to determine the weight of each criteria. The proposed methodology is built using Arc GIS model builder, which is given in Fig.3.6, for site selection of wind farm is explained in detail in chapter three.

1.6 Significance of the Study

The importance of the study is to provide comprehensive information about suitable wind farm site to Debre Brihan Zuria Wereda. This study will be considered as a reference for any wind energy technology implementation projects that can be uses a possible solution to the energy problems of the country. The results of the study can be used for future energy plan by government, researchers, decision makers, policy maker's entrepreneurs, and NGO's.

1.7 Scope of the Study

The thesis work mainly focus on suitable wind farm siting in Debre Brihan Zuria and keyet Wereda. The study is also done based on economical, technical and environmental factors of the area. The other aspects such as conceptual, Mechanical, Electrical and mathematical model and implementation constraint of wind technology are not the concern of this research because these are not economically, professionally and timely feasible.

1.8 Study area description

1.8.1 Location

Debre Berhan zuria is a city and woreda in central Ethiopia. Located in the Semien Shewa Zone of the Amhara Region, about 130 kilometers north east of Addis Ababa on the paved highway to Dessie, the town has a latitude and longitude of 9°30′ N 39°17′ E ,10°00′ N 39°45′E and an elevation of 2,840 meters. Today, it is the administrative center of the Semien Shewa Zone of the Amhara Region.

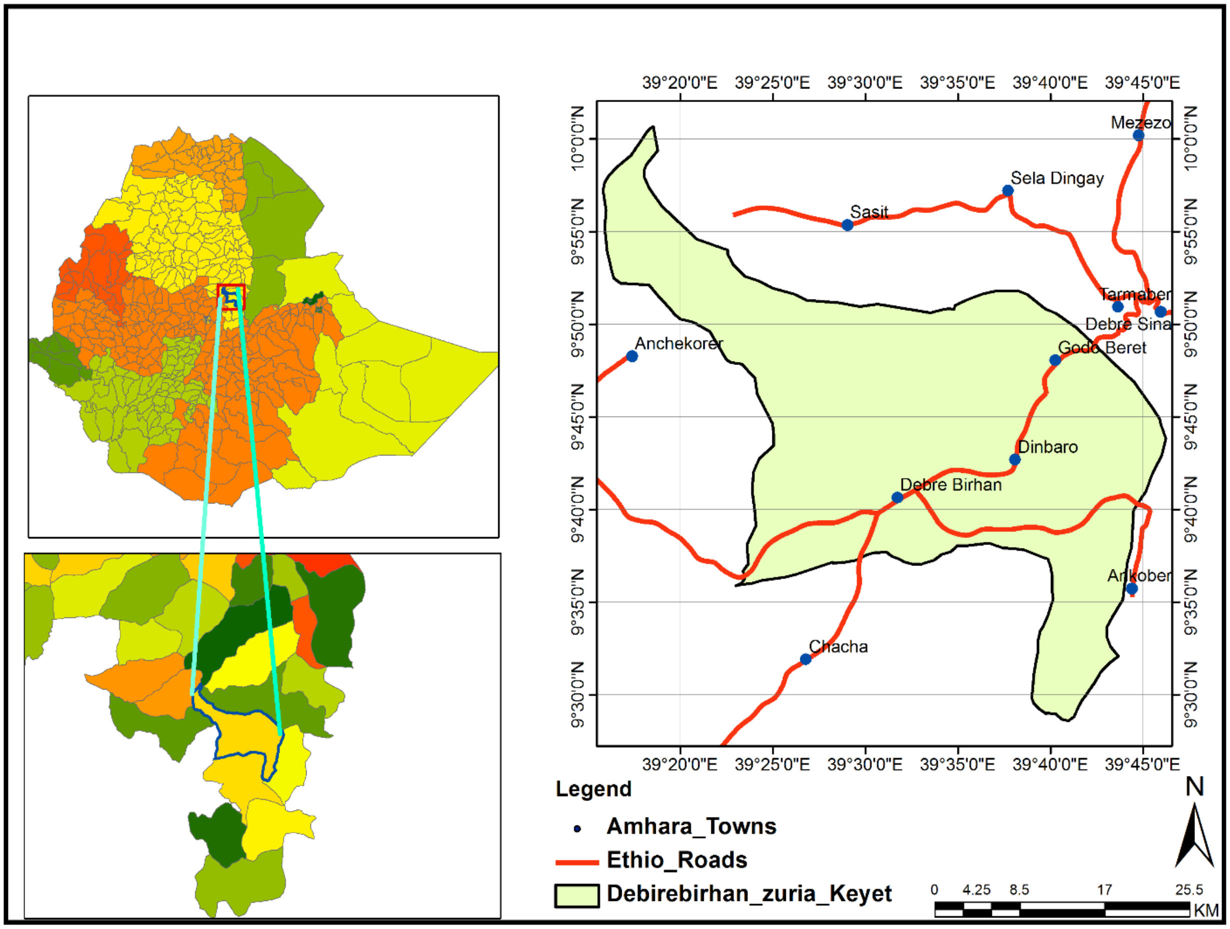


Figure 1.1 Study area map

1.8.2 Vegetation

The dominant vegetation types of the area are represented by eucalyptus trees, junipers, scattered acacia “girar”, thorn bushes, small shrubs and many green plants. Dense eucalyptus trees are found at highly elevated areas in the north western and central parts of the study area.

1.8.3 Climate

The mean annual temperature and rain fall of the plateau area range from 20°c to 25°c and 500 to1600 mm. Generally the climate of the area ranges from humid (high land, “Dega to Weina Dega”) climatic zones. Based on the 10 years metrological and installed wind mast data, over all annual average wind speed in the region is gentle moderate, with an average wind speed and power density of 7.78 m/s and 500W/m^2 respectively at 78 m hub height. (solomon Feleke et al, 2014)

1.8.4 Topography

The study area is part of the central Ethiopia plateau and western most part of the rift margin and floor of the Main Ethiopian rift (MER). On the basis of morphology and drainage type, the area is divided into: plateau and escarpment. The maximum and the minimum elevation of the study area are 3704 m and 1559 m above mean sea level.

1.8.5 Accessibility

The study area can be accessed through one major asphalt road, Addis Ababa – Debre Birhan – Dessie. Two gravel roads that split 70 km to the northwest and 62 km to the east from Debre Birhan town takes to Inewari and Ankober town, respectively. In addition, all weather gravel roads and other motor able but dry weather roads and several foot trails are also available throughout the area.

1.8.6 Engineering Geology

The study area engineering geology generally classified as rocks and soils. the following engineering geological units are identified in the study area; Engineering Geological Rock Units: Rocks with extremely high mass strength (Rehi) , Rocks with very high mass strength (Rvhi) , Rocks with high mass strength (Rhi) and Engineering Geological Soil Unit: as Alluvial soil and Eluvial soil. The study area classified for engineering geological mapping as presented below;

- **Rock with extremely high mass strength (Rehi)**

Rocks that were classified as Rehi are dominantly the lithologies: dofan basalt, fentale ignimbrite, fentale trachyte and trachyte units. These units are exposed in the eastern part of the project area. The point load Strength is higher than 10 Mpa. This implies that the unit belongs to the class of rock with extremely high mass strength (Rehi).

- **Rock with very high mass strength (Rvhi)**

The tarmaber basalt is classified as Rvhi. It is exposed in central and western part of the project area. The unit is also characterized by light to dark grey colour, fine to medium grained and porphyritic texture. The point load strength ranges from 3 to 10 Mpa.

- **Rock with high mass strength (Rhi)**

The rock units that are classified as Rhi includes: kesem basalt, mudstone, sandstone and sela dengay ignimbrite. This group of rock is exposed in the north and central part. The point load strength is approximately between 1 and 3 Mpa which indicates the rock has high mass strength.

- **Eluvial Soil**

Eluvial Soils in the study area are found in the western part of the project area. From soil exposure these soils have silty clay composition and they are brown to reddish brown in colour. In general, they show medium degree of plasticity, fine to coarse grained and rough texture. (Geological Survey of Ethiopia, 2010)

1.8.7 Land use/ land cover

The total land size of the study area is 1199.0198 KM^2. The land use types found in the study area can be classified into six classes. These are Forest, bare land, built-up, Vegetation, cultivated land and water bodies.

1.9 Organization of the Paper

This thesis includes five chapters. The first chapter presents the introductory part, which describes the background of the study and the study area, statement of the problem, the objectives of this research, Meteorological approach, research question, significance of the study, scope of the study, description of the study area, limitation of the study and organization of the paper. The Second Chapter discus the available literature related to the study, reviewed of related papers to find the scientific support and the theories behind the methodology. The third chapter is explains the data collection, software, the approaches of the data process. The fourth chapter focuses on the results and discussion, building the GIS- based MCA is the most important part of the whole study. In this chapter, the result is introduced and the determination of criteria and factor weight computation are key parts of the study.

Chapter 5 concludes by summarizing the findings, contributions and limitations of this research. This chapter also provides recommendations to improve the wind farm site selection in the future siting decisions.

1.10 Limitations of the study

The study had some limitations, including lack of appropriate financial support, the very critical and principal was problem of acquiring relevant data such as; wind speed and wind power density map of the study area at the standard hub height, due to its unavailability and lack of willingness by few officers to provide relevant data was major limitation.

However, formally and informally the author tried to collect the necessary primary and secondary data and other needed documents so as to complete the study and come up with the desired result.

CHAPTER TWO: LITERATURE REVIEW

2.1 Empirical Review

According to the Global Wind Energy Council developing countries and emerging economies some of whom were barely on the global wind map only a few years ago - have now surged to the forefront in terms of new installed wind capacity. Also in Africa, the potential of wind energy has started to be recognized and in Egypt, Morocco, Tunisia and South Africa several wind farms have already been installed. Currently, by far the largest share in wind energy production in Africa is held by Egypt and Morocco where most wind power installations are located with total capacities of 550 MW and 1300 MW respectively by the end of 2012 (Global Wind Energy Council, 2011).

There are several studies performed recently about optimum wind farm siting and potential assessment using the application of GIS and remote sensing across the world. Some of them are reviewed as the following: Dimitrios Mentis, conducted research on wind energy potential assessment across Africa using GIS application. He has used some data set such as: wind speed(1 year data) land use /land cover, topographic data, environmentally restricted area as potential factor for wind power potential assessment of the study area by "aiming to provide estimates of the theoretical, geographical and technical wind power potential in each African country, to indicate possible and sufficient sites to locate wind farms by demonstrating the results in GIS maps and to promote the increase of wind power penetration into the African energy system." According to his study the wind energy potential on the continent is significant. In most regions, the technical potential exceeds the electricity consumption. The countries with the least wind power potential are Equatorial Guinea, Gabon, Central African Republic, Burundi, Liberia, Benin and Togo while Sudan, South Africa and Algeria are the foremost countries in terms of technical wind power potential. The main weaknesses of the study reviewed the omission of certain relevant criteria such as: road accessibility and geological characteristics, the unsupported categorization of all the criterion as constraint and inappropriate and unclear utilization of Geographic information system approach. (Mentis, Wind Energy Assessment in Africa,A GIS-based approach, 2013)

Adam Miller and Ruopu Li, carried out a study entitled in "A Geospatial Approach for Prioritizing Wind Farm Development in Northeast Nebraska, USA". The study used a GIS-based multi-criteria approach to identify the areas that are best suited to wind energy development in study area. Seven criteria were adopted in this method, including distance to roads, closeness to transmission lines, population density, wind potential, land use, distance to cities, slope and exclusionary areas. The suitability of wind farm development was modeled by a weighted overlay of geospatial layers corresponding to these criteria. The results indicate that the model is capable of identifying locations highly suited for wind farm development. Finally, they have recommended that the approach that they have used could help to identify suitable wind farm locations in other areas with a similar geographic background. (Adam & Ruopu , 2014)

Serwan M.J. Baban and Tim Parry conducted a research entitled “Developing and applying a GIS-assisted approach to locating wind farms in the UK”. The objectives of the study were to gain an understanding of the factors necessary to determine site suitability for wind farms in the UK, to develop simplified GIS-assisted wind farm locating criteria in the UK, and to use these criteria and evaluate their performance. To achieve the above mentioned objective the authors have been used the wind farm location criteria (WFLC) consists of a number of constraint factors including: topography, wind speed and direction, land use/cover, population, access, hydrology, ecology and resources. Geographic information system used for factor map preparation, classification, buffering, weight allocation and finally for overlaying to get the most suitable wind farm site in the study area. Finally, the authors found out that the GIS is potentially well suited for locating wind farms for the following reasons:

1. It has capabilities to manage and analyze the volumes of diverse multidisciplinary data needed in the application;

2. It has the functionality to perform “what if” scenarios which can be used either to evaluate the effects of different planning polices and to select those most suitable or to find the optimum wind farm site among a number of potential sites;

3. It has the ability to be used for “modelling impacts” of proposed and operational sites and suggest modifications to minimize them.

All the above, in association with clear indications that the demand for wind farms is on the increase in the UK and the EU, demonstrates clearly that the GIS has great potential in this field. (Baban & Tim , 2000)

Manuchehr Farajzadeh, Ali Taghilo and Mehran Safa also conducted a study entitled “The Wind Energy Potential Zoning Using GIS and Fuzzy Mcdm Based Approach; Study Area: Zanjan

Province, Iran”. The main aim of the paper was introduce of new wind energy sites in Zanjan province based on multicriteria analysis using powerful GIS tools. By incorporating the following datasets; wind speed data of five station at elevation of 50M above the ground, Environmental data, proximity to access roads, vegetation type, soil conditions, DEM, distance from urban and rural centers, land use, distance from rivers and water bodies. Using AHP and fuzzy TOPSIS technique in conjunction with GIS, as methodology wind turbine potentials of the study area are evaluated. They have used pairwise comparison so as to derive weights allocation for each identified criteria and after fuzzification of both criteria weights and criteria map layers using triangular fuzzy numbers, fuzzy TOPSIS technique is utilized to integrate and rank more suitable alternatives for wind turbine installation. The results of their study shows that the ability of multi criteria methods to evaluate of suitable sites in geographic areas in one side and good potentials sites of Zanjan province to establish new energy plans in other side. (Manuchehr, Ali, & Mehran, 2013)

D.G. Vagiona and N.M. Karanikolas have also conducted a research entitled” a multi criteria approach to evaluate offshore wind farms siting in Greece”. The general objective of their paper was to provide an integrated implementation of multi criteria analysis methods and GIS tools applications in order to select the most appropriate installation of offshore wind farms in Greece. The following data was used as potential factor; Average wind velocity, Distance to protected areas, Distance to ship routes, Distance from the shore, Connection to the electricity network. AHP method was used on the pair-wise comparison method in order to determine the weights for every unique criteria.

In the national basis there are few studies performed about wind resource assessment. According to Adams (Adams, 1985), "the Rift Valley and the Eastern lowlands have a moderate wind regime well suited for medium machines, the Western province (all around the Sudanese border) are generally poor in wind energy. The rest of the country (mainly the Central highlands) is suitable for low or medium running machines, especially if careful site selection is used."

(Wolde-Ghiorgis, 1974) has made a wind energy survey using wind data collected by the National Meteorological Services Agency (NAMSA) and showed that mean winds speeds greater than 2.8 M/s is found extensively in Ethiopia.

Furthermore, a considerable approach regarding the Wind farm land suitability using remote sensing and GIS is introduced by Eyaya Belay. Several criteria as well as corresponding weighting factors are introduced in his study using a GIS working environment for a case study in Adama wereda, Ethiopia. (Belay, 2007)

In this study, criteria identification and selection addressed by considering the criteria used in the studies reviewed. An overview of the most important criteria for the suitability assessment of wind farm sites is provided in Table 3.1. While some relevant criteria can be more or less applied similarly worldwide (e.g. average wind speed), others vary substantially due to national regulations and legislations (e.g. distance from urban areas). Issue related to Multi criteria decision making and weight computation of factors tackled through a transparent and sound application of the AHP methodology based on the procedure proposed by. (Saaty T. , 1990) Finally, the aforementioned sources as well as other useful literatures are used to develop a solid methodology on how to fulfill the objectives of this study, which are stated in the first Chapter.

2.2 Conceptual Review

2.2.1 Basics of Renewable Energy

Renewable energy is a well-established technology, and a domestic resource that has the potential to supply power to the whole world. It is becoming increasingly evident that renewable energy technologies have a strategic role to play in the achievement of the goals of sustained economic development and environmental protection. When focusing on the availability of renewable energy sources, it is important to define the type of potential that is considered. In the literature, various types of potentials are defined. There is no one single definition for the various types of potentials. We distinguish and define five types of potentials

• Theoretical potential: The highest level of potential is the theoretical potential. This potential only takes into account restrictions with respect to natural and climatic parameters.

• Geographical potential: Most renewable energy sources have geographical restrictions, e.g. land use land cover that reduce the theoretical potential. The geographical potential is the theoretical potential limited by the resources at geographical locations that are suitable.

• Technical potential: The geographical potential is further reduced due to technical limitations as conversion efficiencies, resulting in the technical potential.

• Economic potential: The economic potential is the technical potential at cost levels considered competitive.

• Market potential: The market potential is the total amount of renewable energy that can be implemented in the market taking into account the demand for energy, the competing technologies, the costs and subsidies of renewable energy sources, and the barriers. As also opportunities are included, the market potential may in theory be larger than the economic potential, but usually the market potential is lower because of all kind of barriers.

2.2.2 Global Wind Energy Potential

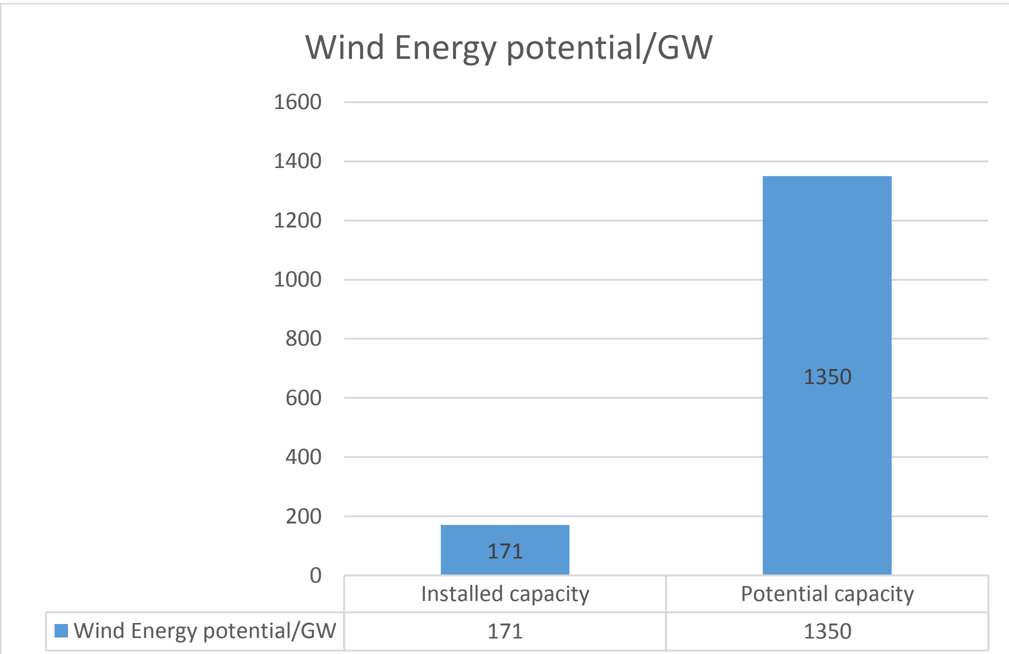
The use of wind power is increasing rapidly over time. Currently, there is about 74 GW installed capacity over the world and a further increase is expected. The technical potential of wind onshore depends on wind resources, land available for the installation of wind turbines and the amount and rated power of wind turbines installed per unit of land area (horizontal power density). A typical wind turbine for onshore production is at present around 2 MW of size and has a hub height of around 80 m. With increasing turbine sizes, the hub heights increase and apart from cost reduction, this also gives access to higher wind speeds. On a global scale there are various studies that have assessed the technical potential of wind energy onshore, (UNDP/WEC, 2010) although all use a similar approach, there are some minor differences between the approaches. The results obtained by (Hoogwijk M., 2004) are used here because it is the only study covering the globe, and the results and estimates can be easily converted using more recent numbers. The wind speed is converted to output in terms of full-load hours using a linear relation. The land available depends on land use change. A suitability factor was applied for each land use type, e.g. Assuming tropical forest to be excluded, high availability for agricultural and grassland area and limited availability for regular forest areas. In addition, urban areas and natural reserves have been excluded. At these suitable areas, a power density of 4 MW/ km was assumed. The output of a wind turbine was calculated assuming a wind turbine with a size of 1 MW. Here we assume that in 2050 the wind turbines have on average a higher capacity and therefore a higher hub height (100 m). This results in higher wind speeds and therefore an increased output when assuming a roughness length of 0.1 m of 10%. The basis of the estimate by (Hoogwijk M., 2004) is the Climate Research Unit (CRU) meteorological data. This database is not specifically constructed for wind energy analyses. The CRU data, however, is currently the only set of globally available data. The CRU wind data are obtained from measurements at 10 m height and extrapolated to hub height. In general higher resolution assessment with correction for terrain, obstacles and roughness will give higher wind energy resource potentials. (Monique Hoogwijk & Wina Graus, 2008)

2.2.3 Energy Sector in Ethiopia

Water energy resources are rich in Ethiopia. There are 9 rivers that can be used for developing hydropower in the whole country, ranking second in the total water energy resources in Africa. According to the statistics, the total hydropower resource reserves in the whole Ethiopia are about 45,000M W. At present, the development level is relatively low, about 4% of the total amounts. Meanwhile, there are abundant geothermal resources in Ethiopia, with total 16 confirmed geothermal resource rich areas currently. However, the petroleum and natural gas resources are relatively short in Ethiopia. Until 2003, the total crude oil reserves in the whole country were about 428,000 barrels and the natural gas reserves were about 2.5×10^{10}m3, which cannot satisfy the domestic demand. Currently, hydropower is the main power supply in Ethiopia. EEPCo is the only electric utility enterprise in Ethiopia. The power system in Ethiopia is divided into two systems, namely ICS (Interconnected System) and SCS (Self Contained System). ICS is the most important power system in Ethiopia, which is a system dominated in hydropower. SCS is relatively independent, comprising small hydropower and diesel generators. Until the end of 2010, the total installed capacity of power system in Ethiopia was 2,059.69MW, with total ICS installed capacity of 2,022.2MW and total SCS installed capacity of 37.49MW. Now, there are 141 substations in EEPCo, including 138 ICS substations, 10 hydropower substations, 3 diesel substations and 3 small SCS hydropower substations. The existing transmission line system is 10,397.42km in EEPCo at present. In which, ICS possesses 400kV line of 620.72km single circuit power transmission and 65.98km double circuit power transmission, 230kV line of 2842.53km single circuit power transmission and 443.77km double circuit power transmission, 132kV line of 4,202.81km single circuit power transmission and 113.34km double circuit power transmission, 66kV line of 1835.11km, and 45kV line of 264.16km single circuit power transmission and 9km double circuit power transmission. The remaining transmission line is possessed by SCS. According to the data provided by EEPCo, the total ICS installed capacity in 2010 was 2022.2MW. In which, there were 11 hydropower stations, with a total installed capacity of 1,842.6MW, accounting for 91.1% of the whole ICS; with 172.3MW in diesel generator, accounting for 8.5% of the whole ICS. (Hydro china corporation, 2012)

2.2.4 Wind Energy in Ethiopia

The government of Ethiopia with the collaboration of Chinese government prepared solar and wind master plan for the whole country, which can be very useful to identify the gross amount and distribution condition of wind and solar energy resources, construction conditions, cost and other limiting factors of wind and solar power generation projects. Based on the analysis of this master plan: Ethiopia has a capacity of 1,350 GW of energy from wind. The Ashegoda Wind Farm, about 700 kms North of Addis Ababa has started generating 120 MW of electricity per year. It helps to start diversifying electricity generation, which would otherwise remain entirely from hydropower and thus susceptible to extreme weather events. Its construction was funded from both domestic and international sources. The Adama Wind Farm, which is also now operational, is about 80kms South of Addis Ababa. It produces 51MW of electricity per year. (Ministry of Water and Energy, 2013)



2.2.5 Wind Energy and Extrapolation Method

Wind shear is described as the variation of wind speed with elevation. Wind speed is slower at lower elevations due to friction of the natural environment or artificial obstacles on the ground. The two most common methods of estimating vertical wind speed gradient are the logarithmic law and the Hellman power law. Each of these two approaches emphasizes the influence of surface roughness. The log law can be described as the equation:

$$\frac{V(z)}{V(zr)} = \frac{\ln\left(\frac{z}{zo}\right)}{ln\left(\frac{zr}{zo}\right)} \text{-----------------} \textbf{Equation 1}$$

Where v(z) is the wind speed at height z, V(zr) is the wind speed at reference height zr and 0z is the surface roughness length. The surface roughness length is a parameter used to characterize wind shear in the condition of the surface roughness elements with various heights. The typical values for different types of terrain have been estimated as the following:

Table 2-1 Typical Surface Roughness Lengths **(T. Burton, 2001)**

Type of terrain Roughness length Z	**Type of terrain Roughness length Z**
Cities, forests	0.7
Suburbs, wooded countryside	0.3
Villages, countryside with trees and buildings	0.1
Open farmland, few trees and buildings	0.03
Flat grassy plains	0.01
Flat desert, rough sea	0.001

Following a similar concept, the empirically developed Hellman power law correlates wind speed at diverse heights and is expressed by:

$$\frac{V(z)}{V(zr)} = \left(\frac{z}{zr}\right)a$$ **---Equation 2**

Where a is the Hellman exponent, 0.2 is given for the continental area, or approximately 1/7 with stable atmosphere (D. L. Sisterson, 1983), (F. Bañuelos-Ruedas, 2010). Several studies have previously indicated that the Hellman exponent does not accurately predict wind profile with the 1/7 power law. Instead, a significant variation results from terrain as well as location characteristics. Typical power law exponent values for different types of terrains have been observed using the roughness elements on the ground (Table 2-2).

Table 2-2 typical power law exponents for varying terrain

Terrain Description	Power law exponent,
Urban areas with tall building	0.4
Wooded country – small towns and suburbs	0.28 – 0.30
Many trees and occasional building	0.22 – 0.24
Tall row crops, hedges, a few trees	0.20
Level country with foot-high grass, occasional tree	0.16
Short grass on untilled ground	0.14
Smooth, hard ground, lake or ocean	0.10

2.2.7 Application of GIS for wind energy siting

A Geographic Information System (GIS) is the combination of hardware, software, data, and expertise used to create, modify, evaluate and analyze spatial or geographically referenced information in digital format. GIS are comprised of two components, spatial features and attributes. The spatial features are essentially those elements that could be shown on a map. This would include roads, population centers, meteorological stations, and the wind resource distribution. The attributes are the associated information such as land ownership, temperature, wind speed and solar radiation values. The combination of both a computerized map and a database within the same system allows for improved planning and decision making processes.

GIS is the key framework for organizing the resource databases and atlases resulting from the wind assessment activities. The advanced spatial analytic capability offered by a GIS provides distinct advantages in the evaluation and planning of renewable energy deployments. This permits determination of preferred sites for renewable energy systems, including solar or solar-wind hybrid systems. The sophisticated nature of the software requires that the GIS component of the project must be carefully factored into the capacity building plans for developing countries in order for it to be used effectively. (United Nation Enviroment program, 2012)According to The National Renewable Energy laboratory, the essential components of a GIS can be divided into five broad categories: data acquisition; pre-processing; data management; manipulation and analysis; and product generation. Data Acquisition NREL gathers data from many sources including the U.S. Geological Survey, the National Climatic Data Center, foreign countries, and commercial sources. The reliability of a new data source must be assessed before it can be confidently used. If necessary data is not available in digital format, information contained in paper format can be brought into a digital format with manual data entry or map digitizing. Datasets used by NREL include a global 1-square-kilometer (km) resolution digital elevation model, detailed hydrography layers, federal land ownership, federal facility locations, and political features. Preprocessing Data from outside sources must be preprocessed to ensure it will match other data formats at NREL. In particular, the units of measurement and the coordinate system must be consistent to ensure all data can be used together appropriately. Data Management: The databases are defined with specific, common fields in consistent formats. The data is generally organized by geographic extent, original source, and planned use. Manipulation and Analysis: The data can be manipulated using spatial overlays, extractions, or complex combinations of spatial functions that allow exploration of the spatial relationships in the data. Output Generation: The outputs of a GIS can include statistical reports, tables, charts, on-screen displays, and high-quality maps. The outputs are produced in digital formats that can be quickly and easily distributed to the wind energy industry. (D.M. Heimiller & S.R. Haymes, 2001)

2.2.8 Multi criteria analysis

Finding suitable sites for wind farms is a complex decision-making problem, involving several, sometimes conflicting, criteria and multiple objectives.

The Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales. It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgments that represents how much more one element dominates another with respect to a given attribute. The judgments may be inconsistent, and how to measure inconsistency and improve the judgments, when possible to obtain better consistency is a concern of the AHP (Saaty, 1980). The derived priority scales are synthesized by multiplying them by the priority of their parent nodes and adding for all such nodes. The Analytic Hierarchy Process (AHP) was introduced by (Saaty T. , 1977) and is a very popular means to calculate the needed weighting factors by help of a preference matrix where all identified relevant criteria are compared against each other with reproducible preference factors.

2.2.8.1 AHP process description

All criteria/factors which are considered relevant for a decision are compared against each other in a pair-wise comparison matrix which is a measure to express the relative preference among the factors. Therefore numerical values expressing a judgment of the relative importance (or preference) of one factor against another have to be assigned to each factor. Since it is known from psychological studies that an individual cannot simultaneously compare more than 7 ±2 elements, (Saaty T. , 1997) and (Saaty & Vargas, 1991) suggested a scale for comparison consisting of values ranging from 1to 9 which describe the intensity of importance (preference/dominance). A value of 1 expresses “equal importance” and a value of 9 is given for those factors having an “extreme importance” over another factor.

Table 2.3: Example scale for comparisons (Saaty & Vargas, 1991)

Intensity of importance	Description
1	Equal importance
3	Strong or essential importance
5	Moderate importance of one factor over another
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values Reciprocals Values for inverse comparison

2.2.9 Overlay Analysis

Overlay analysis is a group of methodologies applied in optimal site selection or suitability modeling. It is a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis.

Suitability models identify the best or most preferred locations for a specific phenomenon. Types of problems addressed by suitability analysis include:

- Where to site a new housing development
- Which sites are better for deer habitat
- Where economic growth is most likely to occur
- Where the locations are that are most susceptible to mud slides

Overlay analysis often requires the analysis of many different factors. For instance, choosing the site for a new housing development means assessing such things as land cost, proximity to existing services, slope, and flood frequency. This information exists in different raster's with different value scales: dollars, distances, degrees, and so on. You cannot add a raster of land cost (dollars) to a raster of distance to utilities (meters) and obtain a meaningful result. Additionally, the factors in your analysis may not be equally important. It may be that the cost of land is more important in choosing a site than the distance to utility lines. How much more important is for you to decide. Even within a single raster, you must prioritize values. Some values in a particular raster may be ideal for your purposes (for example, slopes of 0 to 5 degrees), while others may be good, others bad, and still others unacceptable. The following lists the general steps to perform overlay analysis:

1. Define the problem.
2. Break the problem into sub models.
3. Determine significant layers.
4. Reclassify or transform the data within a layer.
5. Weight the input layers.
6. Add or combine the layers.
7. Analyze.

The three main overlay approaches available are Weighted Overlay, Weighted Sum, and Fuzzy Overlay. Each approach has different basic premises and assumptions. The most appropriate approach is dependent on the overlay problem being solved ((ESRI), 2015).

2.2.9.1 Weighted Overlay Analysis

In Weighted Overlay analysis, a series of tools can complement the Weighted Overlay tool to follow the general overlay analysis steps described above. The Weighted Overlay tool scales the input data on a defined scale (the default being 1 to 9), weights the input rasters, and adds them together. The more favorable locations for each input criterion will be re classed to the higher values such as 9. In the Weighted Overlay tool, the weights assigned to the input rasters must equal 100 percent. The layers are multiplied by the appropriate multiplier, and for each cell, the resulting values are added together. Weighted Overlay assumes that more favorable factors result in the higher values in the output raster, therefore identifying these locations as being the best. Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis. Weighted overlay only accepts integer raster as input, such as a raster of land use or soil types. Continuous (floating point) raster must be reclassified to integer before they can be used. Generally, the values of continuous raster are grouped into ranges, such as for slope, or Euclidean distance outputs. Each range must be assigned a single value before it can be used in the weighted overlay tool. One can either not worry about the value assigned to each range (but note the range of values the new value corresponds to), and assign weights to the cell values in the weighted overlay dialog box later, or we can assign weights at the time of reclassifying, then with the correct evaluation scale chosen, simply add the raster to the weighted overlay dialog box. The cells in the raster will already be set according to suitability (or preference, or risk, or some similarly unifying scale). The output raster can be weighed by importance and added to produce an output raster.

2.2.9.2 Boolean overlay

Boolean logic was introduced by the English mathematician and logician, George Boole. Boolean logic generally applies a binary condition to the inputs and evaluates to a binary condition for the output. The binary condition can be expressed in several ways: "1" and "0", "True" and "False", "yes" and "no", "on" and "off", and so forth. In the Logical Math tools, the false condition is represented with a value of 0, and the True condition as any value other than 0. The Boolean tools evaluate the inputs only as True or False conditions and return the result of the particular tool as a

1 or 0 (True or False) Boolean value. The Combinatorial tools identify unique combinations of input values based on the logic of the particular tool and return a different value for each unique combination. The Relational tools compare the values of one input relative to another and return the result of the particular tool as 1 or 0 Boolean value. ((ESRI), 2015) The Logical tools have different ways to apply Boolean logic, such as identifying only the input cells that are No Data, or using a logical expression that you define to determine which cells are evaluated as true.The Boolean method takes no account of measurement errors or uncertainties; because it is inflexible for estimating real ambiguity. It takes no consideration of partial membership of an object in a set (Malczewski, 2004).

2.2.10 lesson learnt

Countries around the globe have developed policies to include renewable energy as part of national energy strategies. Identifying areas suitable for wind farm site is a component of sustainable energy planning, as it will determine the extent to which wind energy might be connected and developed as part of a renewable energy strategy, taking into account various environmental and technical limitations.

GIS can be integrated with multi-criteria analysis techniques which involves choosing the relevant assessment criteria or impacts and alternatives, scoring how each alternative affects each criterion; weighting the impact and aggregating the score and weight of each alternative. With GIS, map layers corresponding to each constraint criterion are created followed by the allocation of weights to each layer and different scores to each attribute within the layers using reclassification and buffer generation methods.

Reviewed literatures show that models are often made up of a combination approaches such as the Boolean Overlay and the Weighted overlay Combination. case studies of GIS based models for wind energy facility site selection used in the USA, England, Germany, Greece and Egypt illustrates how GIS has been applied by planners and decision-makers in different geographic locations and contexts. A description of each GIS based model is given, taking into account the different assessment criteria used and approach taken to determining site suitability. These GIS based models were assessed on their strengths and weaknesses in locating suitable sites for wind energy development and to show the overall support GIS provides for decision making.

Generally, the GIS based models in the case studies showed that diverse multidisciplinary data were included, alternative scenarios to evaluate the effects of input criteria were created. The GIS based models were developed according to their purpose, context and available data.

CHAPTER THREE: Data, software used and Methods

3.1 Data, Data sources and method of Data collection

The data collection is initial step to all kind of geospatial based research. A set of 10 criteria were chosen for modeling the suitability of wind farm locations, including wind speed potential, land use, geology, Hydrology, proximity to major roads, slope, Elevation, proximity to transmission lines, settlement and forest area. The criteria selection started with a comprehensive literature review and was narrowed down to those criteria believed as relevant and critical to the suitability of a wind farm in the study area.

Table 3.1 list of data sets and data source

Dataset	Format	Source	Resolution	year
Wind speed and wind density	Raster	NREL/https://maps.nrel.gov/swera/	5 KM	2012
Road dataset	jpeg	Ethiopian Road authority		2014
Transmission line	Shape file	Ethiopian Electric Power		2012
Hydrology	Shape file	MOEWR		
Administrative boundary	Shape file	Central statistics agency(CSA)		2008
Elevation	Raster	USGS/Earth explorer	30M	2015
Slope	Raster	USGS/Earth explorer	30M	2015
Land use/land cover	Raster	Nation Geomatics center of China(NGCC)	30M	2010
Engineering Geology	Shape file	Ethiopian Geological Survey	1:250000	2012
Urban area	Shape file	Extracted from land use/cover map		2010
Forest area location	Shape file	Extracted from land use/cover map		2010

3.3 Software used

ArcGIS desktop is well known in the world and the most widely used category of GIS software. It has been developed by Environmental System Research Institute Inc. (ESRI), Redlands, USA. In this study the components of ArcGIS desktop like Arc Map, Arc Catalog, and Arc Toolbox have been used to create the geo database, editing, data management and storage, geo referencing data from different sources, performing spatial multi criteria analysis, generating criteria maps and assigning weightage for each criterion, overlaying, analysis and visualization of output data, and etc.

IDRISI is a comprehensive geographic analysis and image processing system that has been developed by Clark Labs for Cartographic Technology and Geographic Analysis at Clark University, South Carolina, USA. The software has been used to perform multi criteria decision analysis using the built-in decision support module.

3.4 Method of Data Analysis

The data analysis process of wind farm siting involves numerous factors with complicated correlations. Therefore, GIS based multi criteria spatial analysis techniques and AHP approach has been used to address the proposed study. The assessment procedure for wind farm siting is presented as the following in figure 3.1. Multi Criteria Evaluation analyze suitability based on constraints, standardized factors and weighted overlay. Constraints are based on the Boolean criteria (true/false), which limit the analyses to specific regions. Factors define areas or alternatives according to a continuous measure of suitability. Factor weights was determined by the Analytical Hierarchy Process.

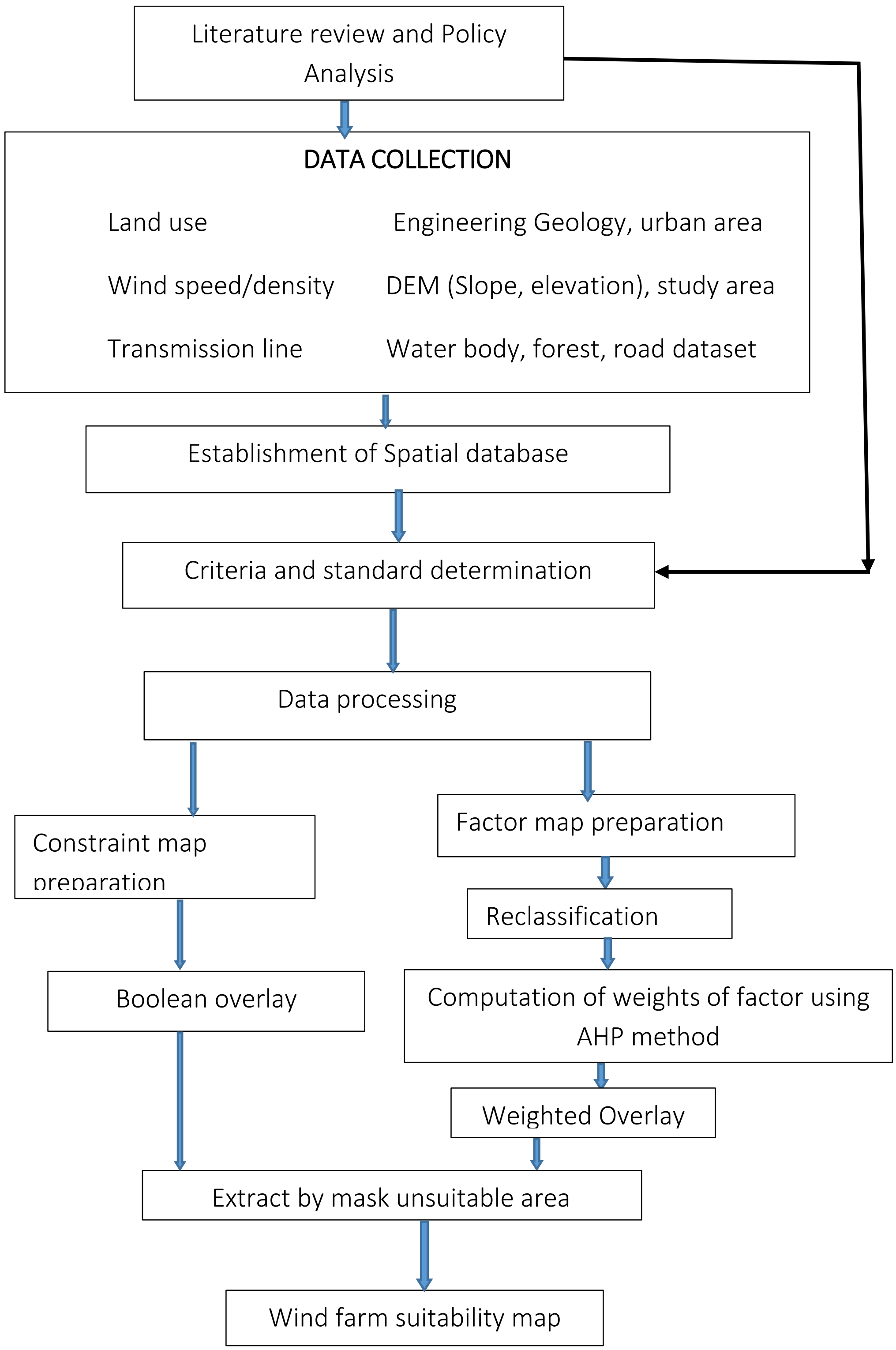


Figure 3.6 General work flow

CHAPTER FOUR: RESULT AND DISCUSSION

4.1 Data Preparation

4.1.1 Geo referencing

Raster data which is obtained by scanning maps usually do not contain the locational information on the surface of the earth and need be geo referenced. In this study the initial data format of road network data set, wind speed and wind power density is in the form Jpg and .ASC respectively. The geo referencing process includes assigning a coordinate system that associates the data with a specific location on the earth in real-world coordinate system. These coordinates used to create control points that are used to build a polynomial transform from one coordinate space to another. The control points are selected in the input raster dataset and the output location are specified by typing in the known output coordinates.

4.1.2 Coordinate system

All layers were projected into WGS 84 UTM Zone 37N and converted into raster data Structure. All of the raster datasets were resampled to a common cell size (30 m), which was based on the coarser cell size of all source datasets.

4.1.3 Geo database

A geo database is a collection of geographic data based on a well-defined model for geographic data types. It contains of layers vector data representing features and raster data representing images and grid surfaces. The purpose of geo database is to make the features in GIS datasets and define a relationship among features that were displayed on maps as layers. Each layer represents particular types of features which have been used for spatial analysis. In this study, personal geo database were created to store, query, and manage both spatial and non-spatial data that could be used for the final analysis to achieve the proposed objectives.

4.2 Modeling in Arc GIS Model Builder

Model Builder is an application used to create, edit, and manage models. Models are workflows that run together sequences of geo processing tools, feeding the output of one tool into another tool as input. Model Builder can also be thought of as a visual programming language for building workflows. ArcGIS Model Builder is graphical environments for building and executing multi-step models with facilities for batch processing and dynamic modeling ((ESRI), 2015). The model is the description of a decision situation to generate a solution to the problem. It used for a given decision problem which is well structured so that all decision problem-solving activities can be automated. The main characteristic of using a Model is the possibility to structure the decision problem and use well established procedures for solving the spatial problems. Model Builder provides an in-built interface where input and tools can be easily dragged and dropped from Arc Map, Arc Catalog and Arc Toolbox modules of ArcGIS Desktop. A process is formed by a tool and its parameters and each of them is represented with different symbols. The connection between data and tools generates a workflow representing a visual documentation of the spatial analysis, where rows indicate the direction to follow. As result, the software is able to automatically run this workflow by following those connections. Figure 4.1 shows the entire process graphically. Refer appendix c for the report of the entire model run.

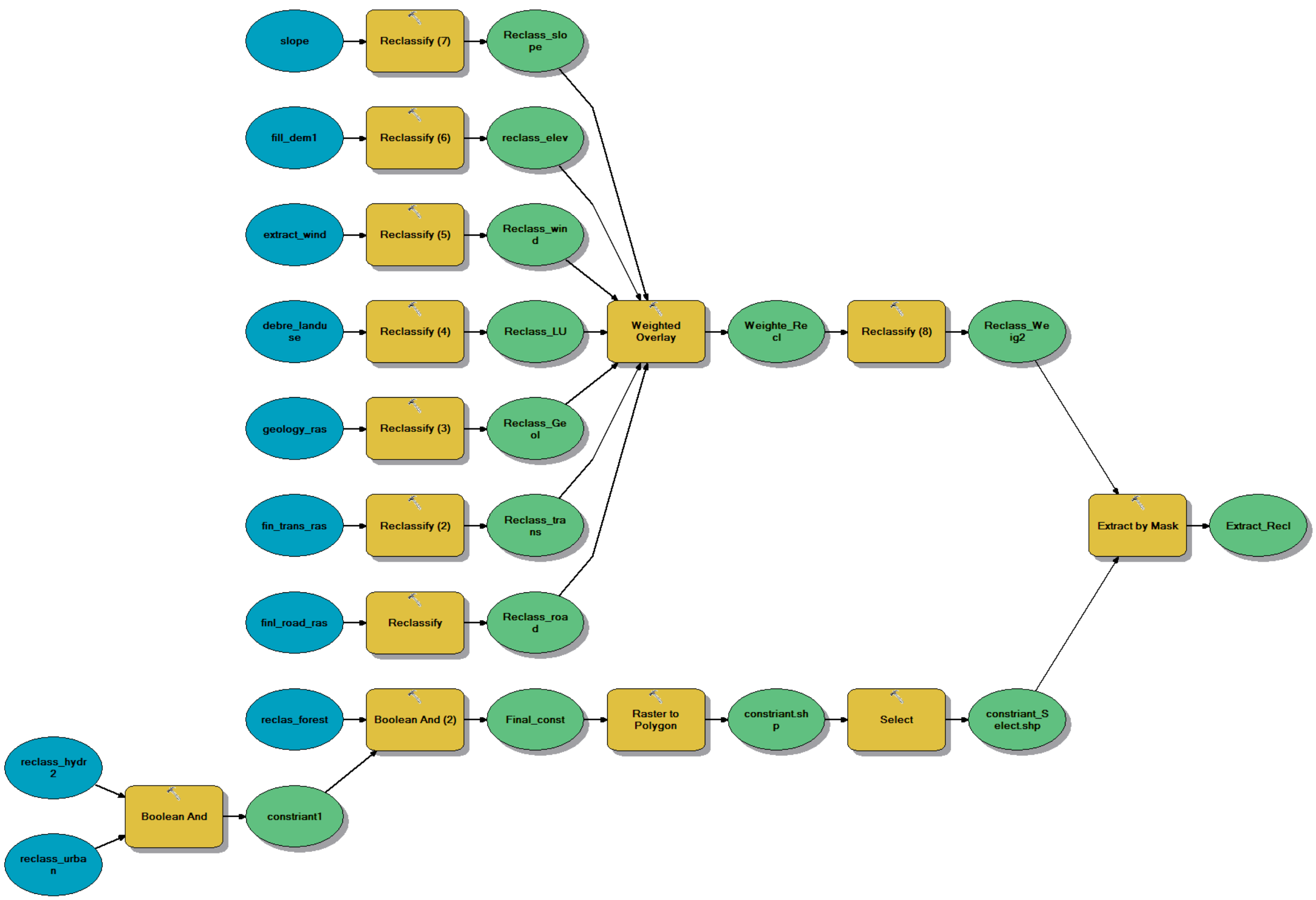


Figure 4.1 wind farm suitability Model

4.2.1 Generation of constraint and factor map

A GIS system, being capable of processing map related data, is the best alternative for decision making when wind farm planning is considered. Hereafter, the factors affecting the selection of wind farm sites are briefly discussed. Factor maps represent the criteria that will affect the optimal site selection. Each pixel has a value ranges from 0 to 255 which the value represents the suitability of each pixel to be the optimal site (Kordi, 2012). Higher value represents higher s suitability of the areas for the optimum wind farm site selection.

4.2.1.1 Constraint map

In this study, urban area forest and water body has been identified as constraint. Based on this Constraint maps are created to determine the criteria that are constraints to the wind farm site selection. It is a sort of Boolean map, each pixel has a unique value with 1 or 0. Pixels with value of 0 represent the areas are restricted to be the optimal sites. On the other hand, Pixels with the value of 1 means the areas that may be the optimal sites.

Urban area

Standards have been set for evaluating impacts on the human environment. Noise reduction and safety issues determine a setback of 2600 feet or around 800m from the nearest settlement (National Academy of Science, 2007). A buffer within that distance was set from cities and highways. In this study, 800 m buffer was used to reduce the noise pollution. Accordingly, 95.94% of the total area will be in the analysis whereas the rest 4.06% of the total area is out of analysis.

Table 4.1 Suitable and restricted area coverage

VALUE	COUNT	Area/KM^2	Area/percentage
1 (Suitable)	1278914	1151.03	95.94
0 (restricted)	54173	48.75	4.06
Total		1199.78	100

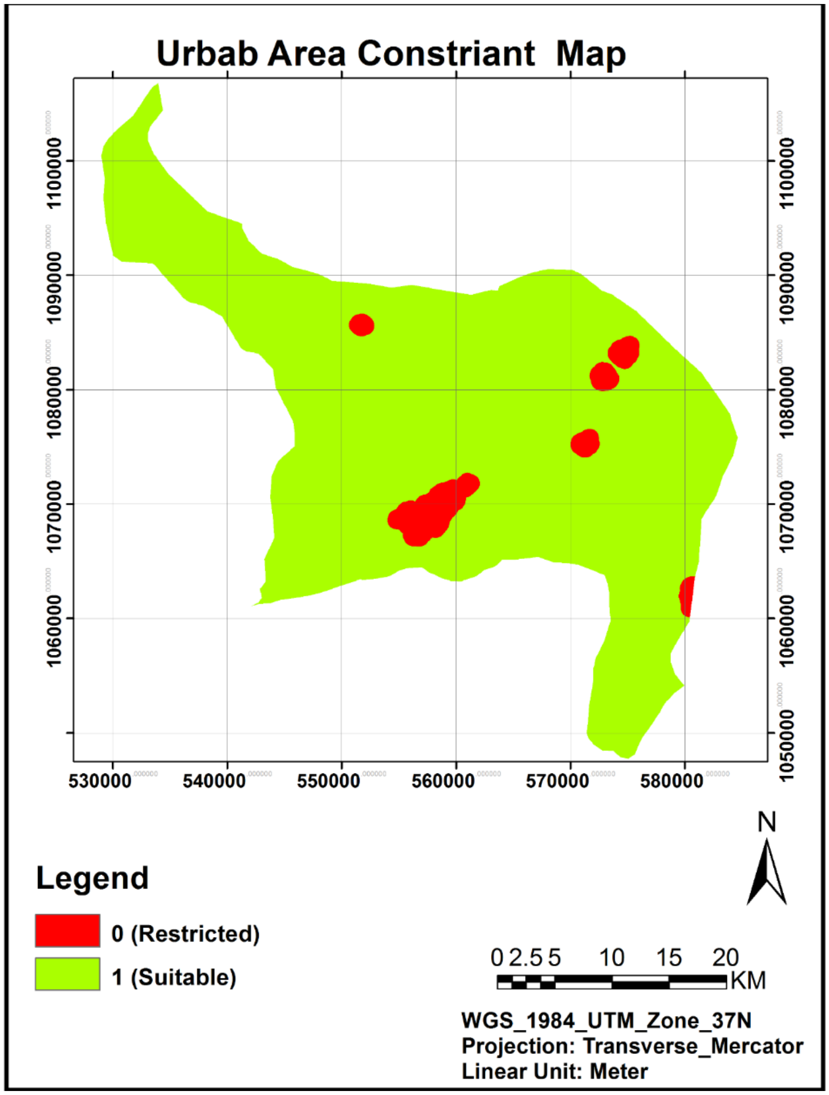


Figure 4.2 urban area constraint map

Source: derived from land use/ land cover map (NGCC)

Forest

Forestry increases turbulence and wind shear; hence, the turbine loading increases and the design conditions might be exceeded. This also may effect operating and maintenance costs over the project lifetime. Also, the forestry reduces the wind speeds above canopy, which leads to reduced energy production; hence, reduced income (Andrew Tindal, 2008). Moreover, According to (Tim Höfer, 2014) the criterion distance from natural environments' comprises forest, habitat and water bodies, etc. These areas serve the protection of nature and wildlife and are therefore excluded from wind energy development. A major concern is the potential collision of birds and bats with wind turbine blades if wind turbines are located too closely to their habitats or migratory routes. In this study 500m buffer distance around the forest area has been considered as constraint so as to avoid environmental pollution and migrant bird collision with wind turbine blades. As it is illustrates in Figure (4.2) and table (4.2) the excluded area covers 22.32% of the total area where as the suitable area covers 77.68% of the total area.

Table 4.2 Forest area coverage

VALUE	COUNT	Area/km2	Area/percentage
1 (Suitable)	1035572	932.02	77.68
0 (Restricted)	297511	267.75	22.32
Total		1199.77	100

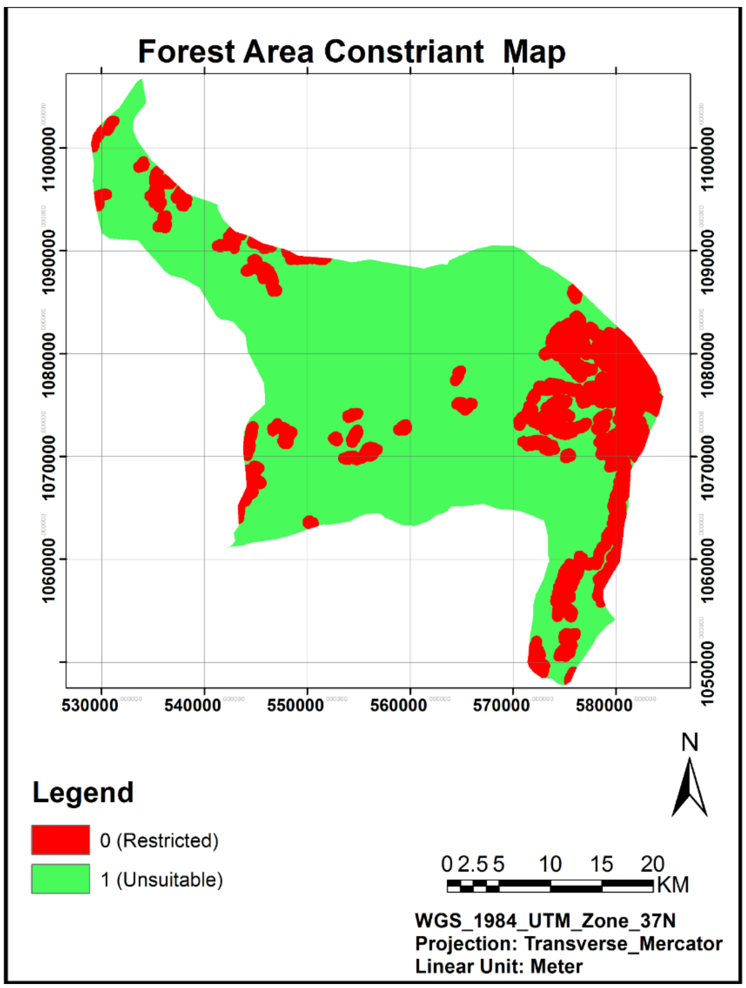


Figure 4. 3 Spatial distribution of restricted forest Area

Source: Derived from land use /land cover map

Water bodies

Any type of water bodies, lakes, sea, rivers, wetlands, floodplains and saline pans are to be protected to preserve the natural wealth and avoid pollution (Baban & Tim , 2000). In this study, 200m buffer around the water body were considered. Therefore, all the water bodies in the study area were excluded with a buffer length 200m around each feature. As it is illustrates in Figure (4.3) and table (4.3) the excluded area covers 5.215% of the total area where as the suitable area covers 94.784% of the total area.

Table 4.3 water bodies buffer area coverage

VALUE	COUNT	Area/Square KM	Area/ percentage
Excluded	69525	62.5725	5.215
Suitable	1263540	1137.186	94.785
Total		1199.7585	100

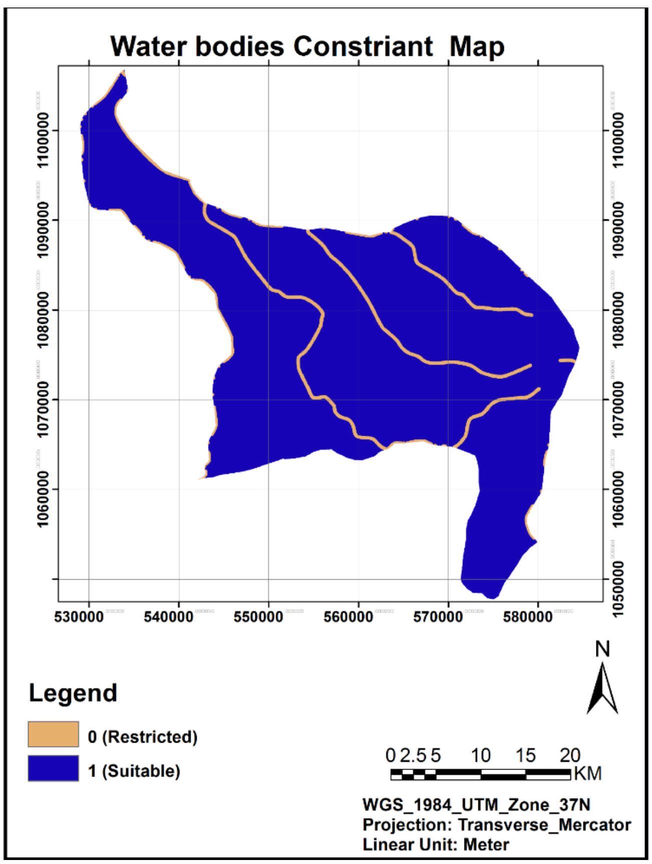


Figure 4.4 Water bodies constraint map

Source: Ministry of water resource and Energy (MOEWR)

4.2.1.2 Factor map

Factor map represents different criteria that could influence the site selection of wind farm. It is represented using consecutive distances, and each pixel get the value from 0 to 255. In this study the following criterion were identified as factor for wind farm site selection.

Slope

According to “A Geographic analysis of wind turbine placement in Northern California” (Laura C. Rodman, 2006) study; five slope classes defined. Several counties prohibit wind turbines placed on slopes greater than 25% to reduce unwanted turbulence and high construction costs. Steep slopes of a surface can reduce the accessibility of cranes and trucks and increase building costs. Recommendations for the maximum slope threshold range from 10% (Babban S. &., 2001) to 30% (Tegou, Polatidis, & Haralambopoulos, 2010). Even prefer ridge crests and set the threshold for slope to 40°, which corresponds to approximately 84%. Others (Gorsevski, 2013) did not even consider slope as a criterion. In this study, a maximum slope of 25% is assumed. By assuming this specific percentage, lower slopes are preferred and receive higher value scores. Slope of the study area was calculated from DEM (30*30m resolution) and used in GIS environment as a thematic map. Finally, slopes were calculated and reclassified in GIS environment. Accordingly, the area was classified in to five slope classes: 0-5%, 5-10%, 10-15%, 15-25% and >25% refer figure (Fig.4.5).

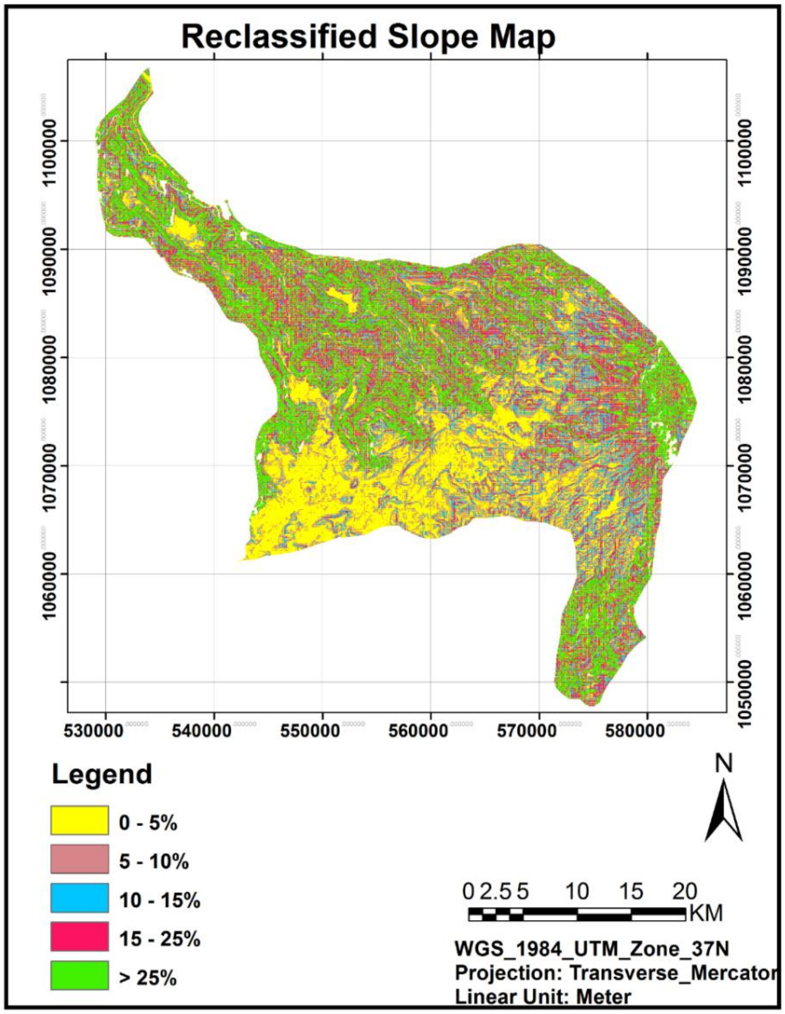


Figure 4.5 Reclassified Slope -Spatial distribution map

Source: derived from Digital Terrain Model (USGS Earth explorer)

Wind power density

This is the most critical site characteristic and, of course, some places have more wind than others. Typically locations with an annual average wind speeds above about 6 m/s (13 mph) at the hub height are considered. Wind maps are a useful screening tool to estimate the wind speed in an area, but may not accurately represent a specific site. The wind power in a given site depends on having sufficient wind speed available at the height at which the turbine is to be installed. Wind power density is a most important factor because it provides information on the most feasible and profitable areas in the region for siting a wind power project (Babban S. &., 2001). And (Bartnicki, 2012) explain that wind power density is a function of the area's average wind velocities and the air densities, which involves land elevations. The wind power density of the study area is between

107 to 574.98W/m². Minimum required wind power density to generate electricity is 200W/m². Wind potential was classified based on the wind power density (W/m²). The wind power density developed by SWERA (NREL, 2015) was downloaded geometrically corrected, projected, resampled and reclassified according to National renewable Energy laboratory (NREL) standard.

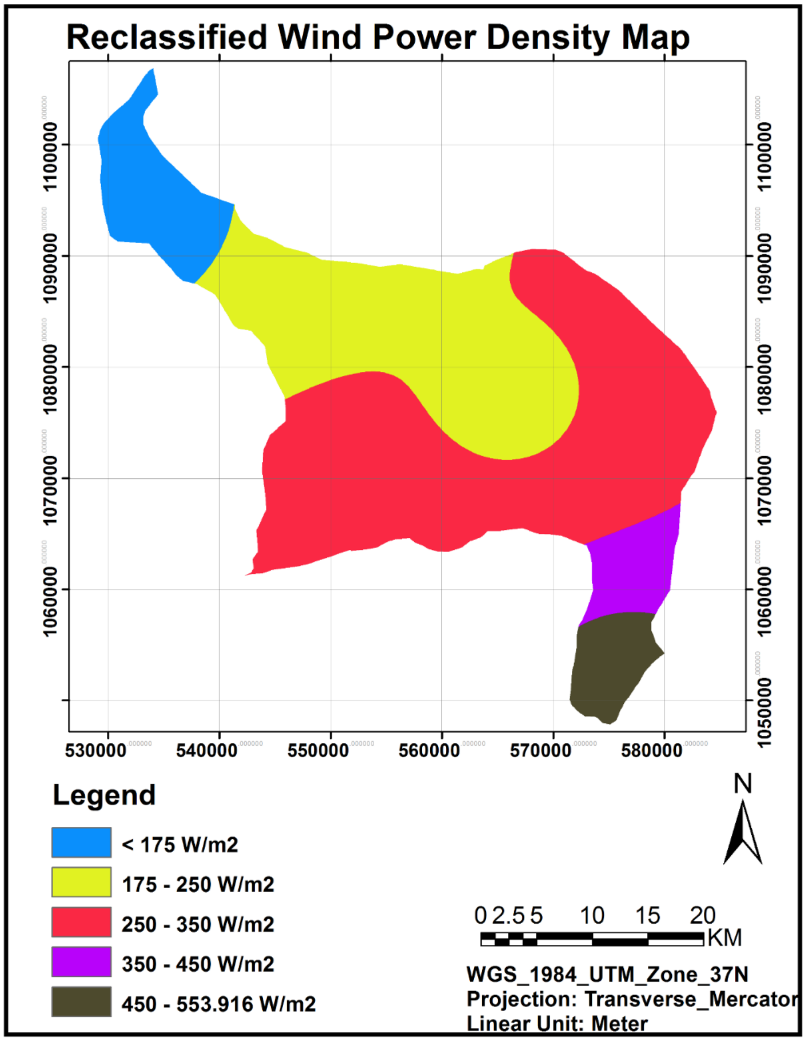


Figure 4.6 Wind power density Spatial Distribution map

Source: National renewable energy laboratory

Elevation

Wind Turbine Placement Analysis study by Washington Department of National Resources claims that high elevations preferred. Natural breaks define classes away from steep slopes and elevation variation. The site should be open and generally at a higher elevation than the surrounding area. Steep hills or cliffs can create turbulence and should be avoided, however, gradually sloping hills can actually cause an increase in wind speed at the top. The topography of a site must also allow access roads to be built for construction and maintenance equipment. In this study, the elevation thematic layer derived from Digital Elevation Model (DEM) 30M resolution. The thematic layer were reclassified in to five classes using arc GIS re classify tool. As it is shown in the following figure 4.7.

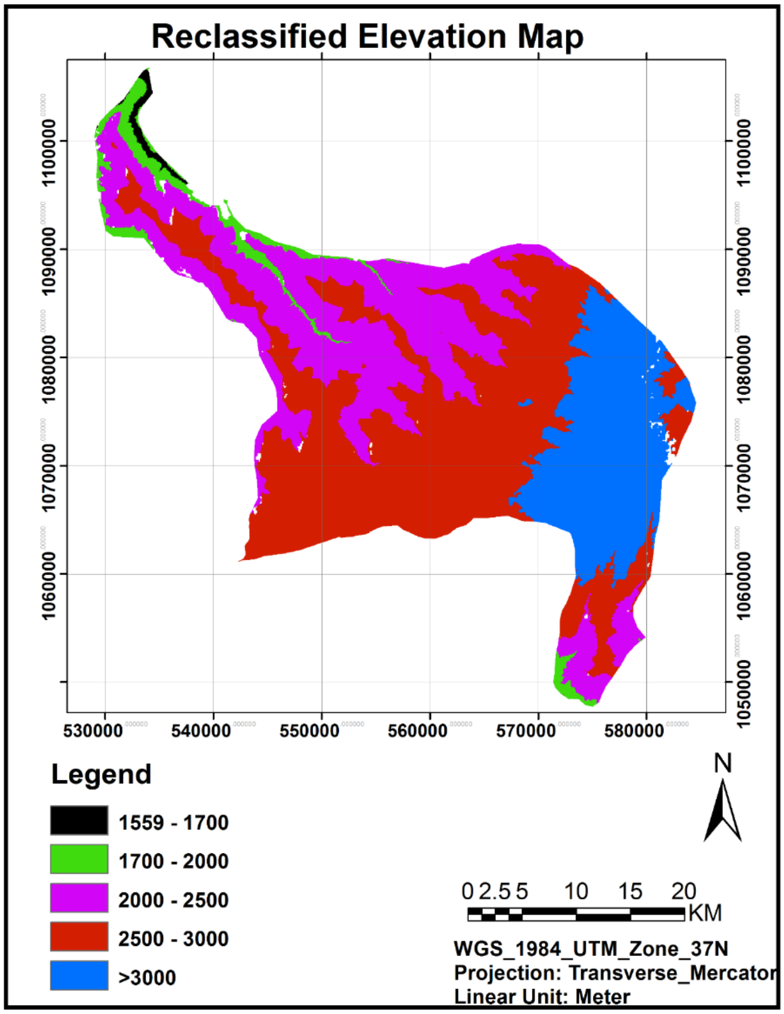


Figure 4.7 Reclassified Elevation Distribution map

Source: Derived from Digital elevation model (USGS Earth explorer)

Engineering Geology

In the study area the engineering geology are classified into two categories: engineering geological rock unit and engineering geological soil unit. Based on their rock mass strength values two engineering geological rock units were identified. These are rock with very high rock mass strength (Rvhi) and rock with high rock mass strength (Rhi). The soil units on the other hand has been identified as eluvial units with characteristics features defining the various units. Rock with very high rock mass strength covers 31.72% of the total area where as rock with high rock mass strength and eluvial soil units covers 67.35 % and 0.93% of the total area respectively.

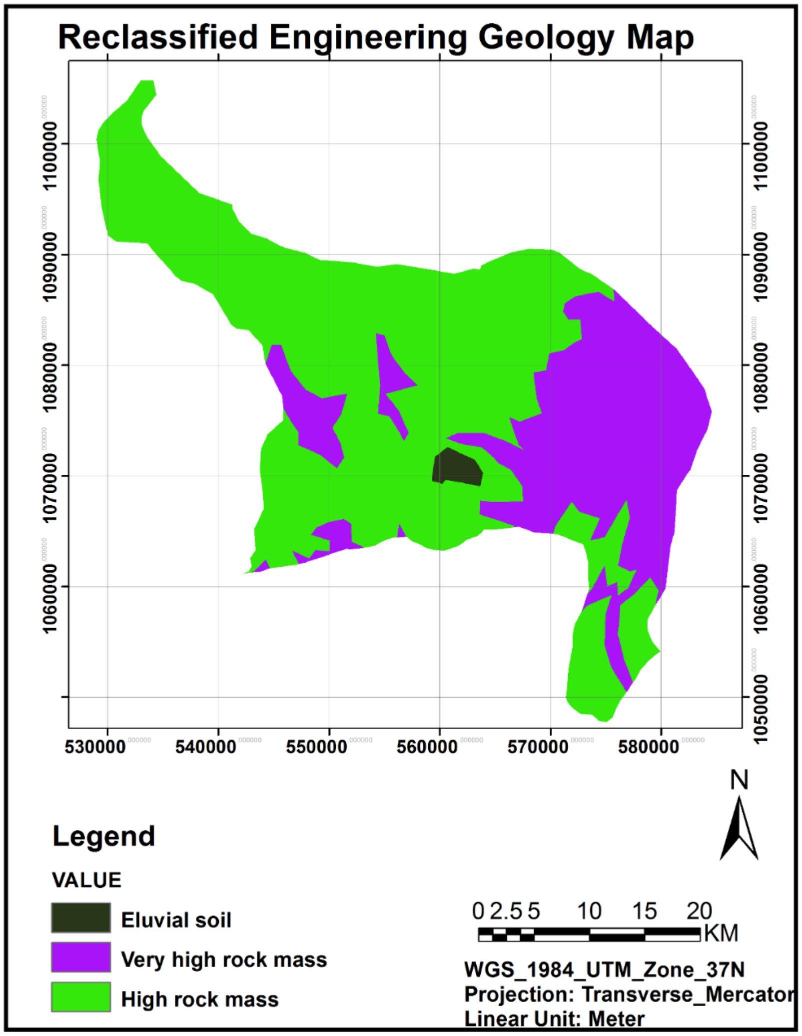


Figure 4.8 Reclassified Engineering geology spatial Distribution map

Source: Ethiopian Geological survey (Engineering Geology Debre Brihan sheet)

Distance from the main road

In order to reduce construction costs for new access roads and to avoid soil sealing , wind farm should be located as closely as possible to the existing road network (Windustry, 2006) in the most wind farm sitting assessments, the area further away from roads are considered less suitable than those closer to roads (Babban, S.M.J, & Parry.T, 2001).in this study, with A distance function (multiple buffers) was used to calculate the distance from the main roads after considering a road buffer area of 200 meters as restricted due to noise and visual effect. Based on the fact area with larger distance from the roads get the lower value score and the value scores increase with decreasing distance. Figure 4.9 Shows distribution of suitable area around the main road.

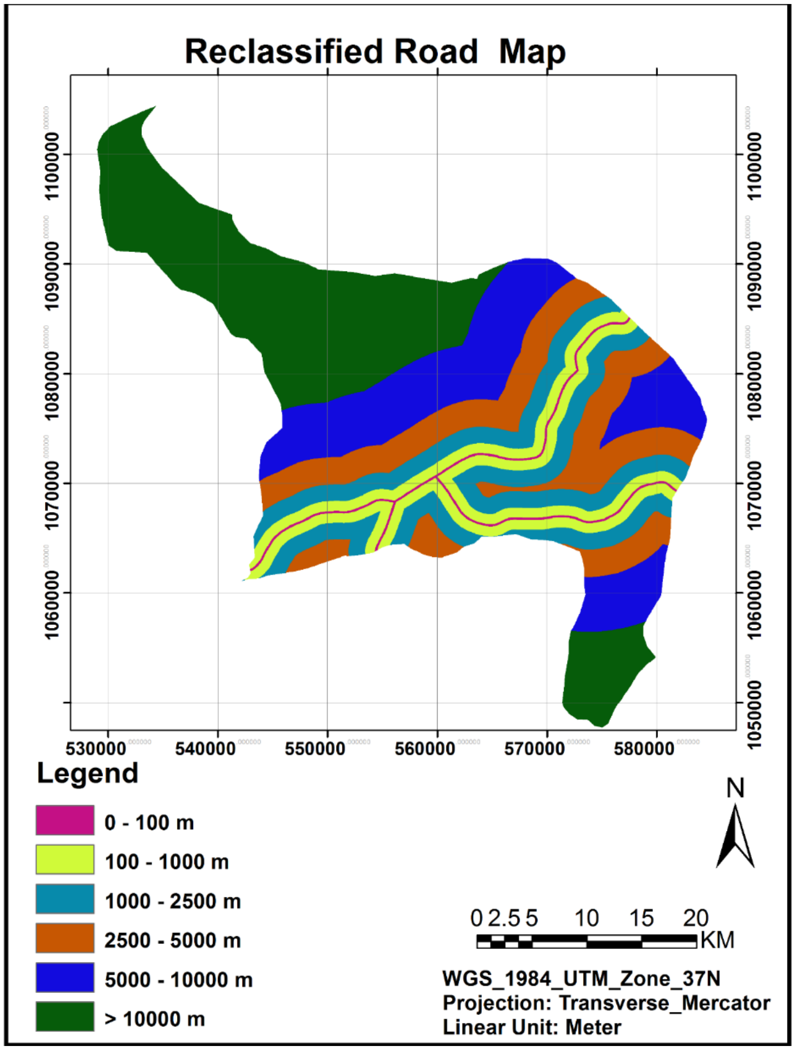


Figure 4.9 Distribution of Suitable Area around the major road

Source: Ethiopian road authority

Distance to transmission line

A distance function (multiple buffers) was used to calculate the distance from the power lines. Electricity generated by a wind turbine must be fed into the electrical grid. Building new transmission lines to move electricity to where it is needed can be very costly, so sites near existing power lines reduce this expense. In order to reduce costs associated with cabling and electricity losses over long transmission distances, wind farms should be located in the proximity of the electricity grid. However, the determined maximum distance of wind turbines to the electricity grid strongly varies throughout the literature. (Tegou, Polatidis, & Haralambopoulos, 2010) Set the threshold to 2,000 m, whereas (Gorsevski, 2013) set it to 20,000 m. The distance to the electricity grid seems to be highly dependent on the location of the study area. Regarding the minimum distance, a distance of one rotor diameter has to be kept between the rotor blade tip and the overhead power line. Therefore, areas within 100 m to the power line are determined as restricted areas. In this study, there are two transmission line 132kw and 230kw passing through the study area. The value score increases with decreasing distance from the grid. Based on the spatial dimension and characteristics of the study area, areas within the range of 100 to 1000 m receive the highest value score of 9, and areas with distances greater than 10,000 m the lowest score of 1.

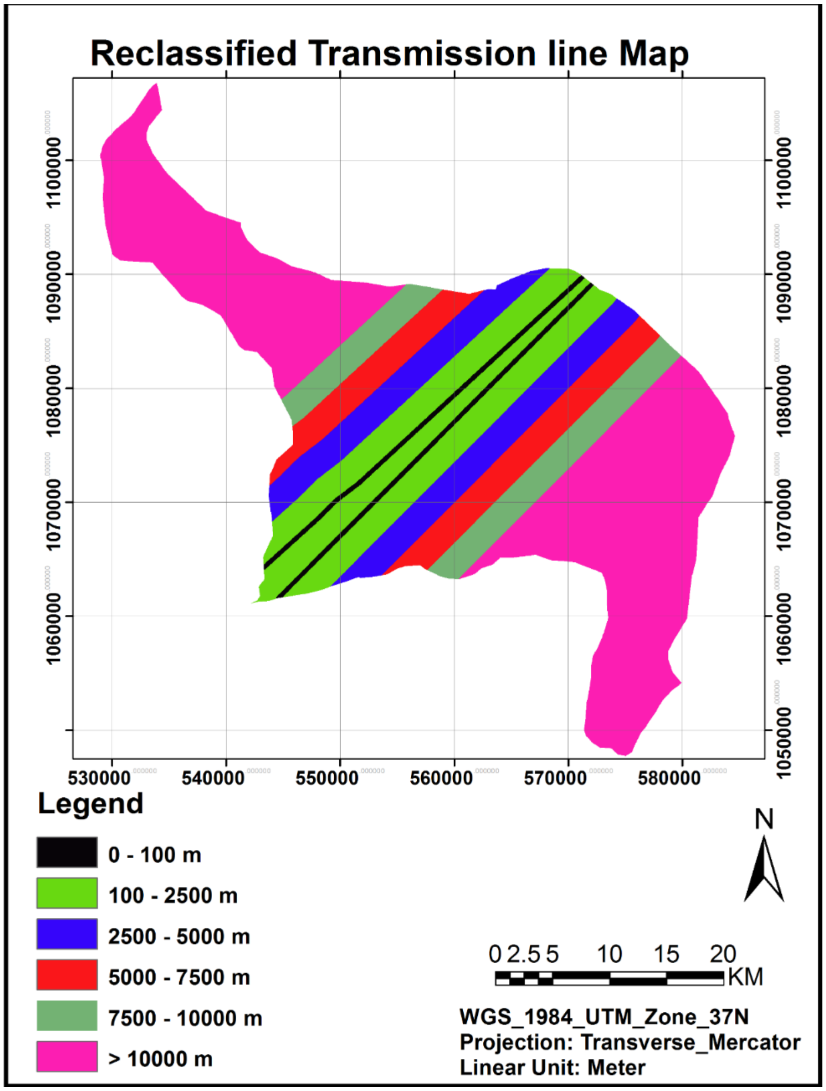


Figure 4.10 Distribution of Suitable Area around transmission lines map

Source: Ethiopian Electric power

Land use/land cover

Land cover data from 2010 with 30m resolution was obtained from the National Geomatics Center of China (NGCC) portal. The Mosaic tool was used to combine the raster along with the Clip tool to cut the data to the study area boundary. The suitability of an area for the siting of wind turbines also depends on the prevalent land cover type. From a social acceptance point of view, some land cover types can be considered to be more preferable than others. It is widely recognized in the literature that 'shorter' vegetation is preferable to 'taller' species. Thus, agricultural land, barren land, grassland, and shrub land can generally be considered to be most suitable, whereas forestland is considered to be less suited (e.g. (Gorsevski, 2013); (Laura C. Rodman, 2006); (Tegou, Polatidis, & Haralambopoulos, 2010). An exception is the study by (Babban S. &., 2001), in which the development of wind energy on agricultural land is prohibited. In this study, the global30 land cover (National Geomatics center of china, 2015) data were used. Figure 4.8 shows all land cover types dominant in the study area and the associated value scores.

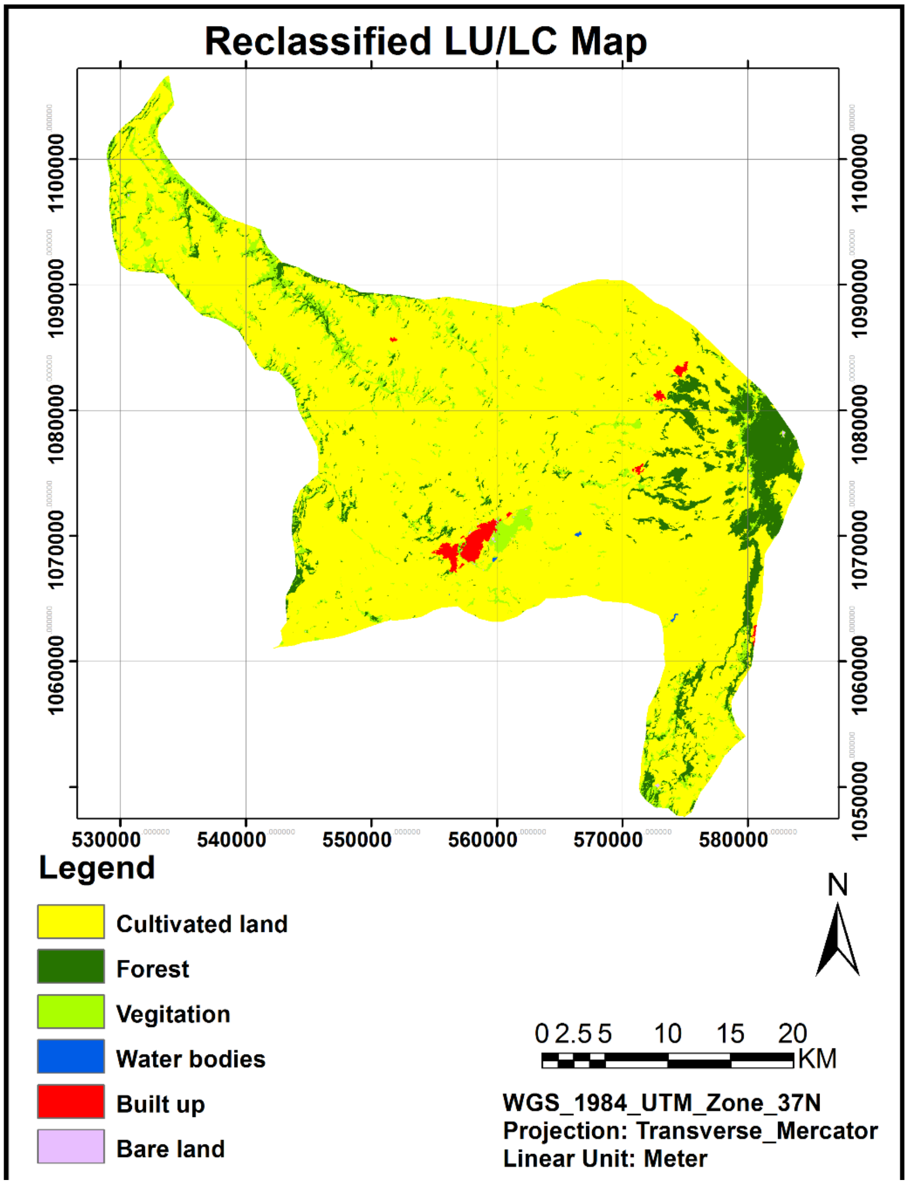


Figure 4.11 Reclassified Land use/ land cover map

Source: National Geomatics Center of China

4.3 Determination of weight using AHP

The Pairwise Comparison Matrix used for the present study was developed based on the review of relevant literature. The decision making process in the multiple criteria problems is a subjective process depending on the decision maker vision. For each factor, the attributes were standardized by transforming the original values to a suitability value using suitability scale from 1 - 9 (Saaty T. , 1997). The higher value is more favorable and vice versa. Areas with a higher suitability will have a higher score (Bartnicki, 2012)

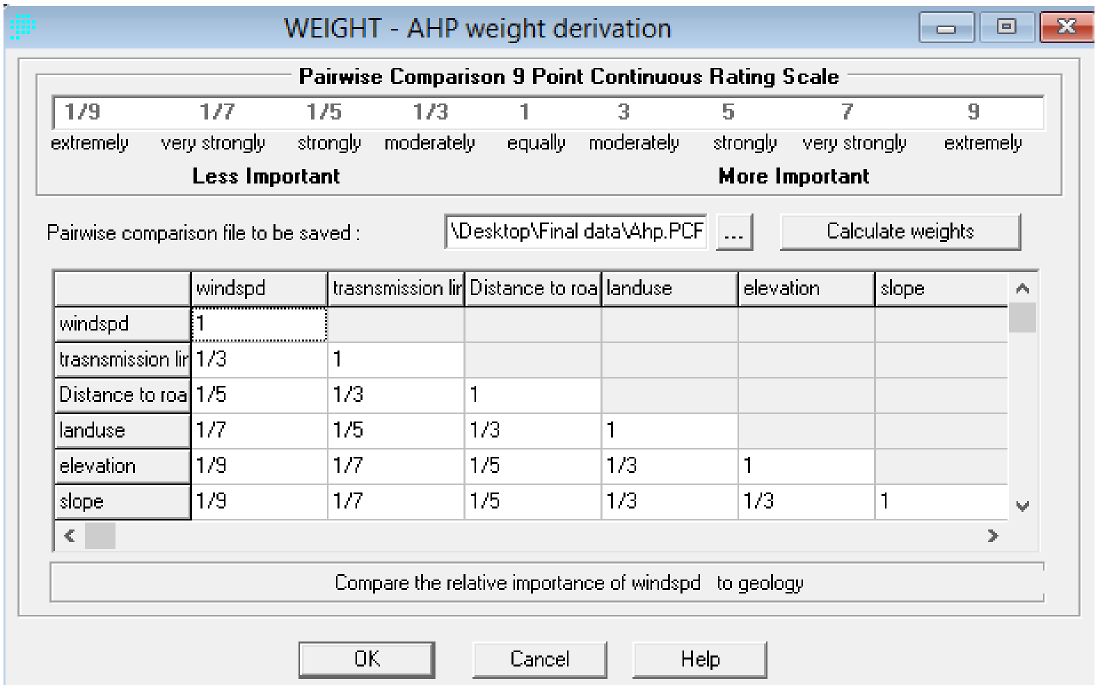


Figure 4.12 Weight derived by AHP method

Table 4.4 the eigenvector of weights

Factor	Weight
Wind speed	0.4347
Transmission line	0.2491
Distance to road	0.1371
Land use	0.0768
Elevation	0.0460
Slope	0.0333
Geology	0.0230

The consistency ratio (CR) indicates the probability that the matrix ratings were randomly generated. As a general rule, a CR greater than 0.10 should be re-calculated. The result is a CR 0.08 which indicates a reasonable level of consistency in the pairwise comparisons.

4.4 Overlay Analysis

The overlay analysis task can be divided into two parts. In a first part, factors were overlaid using different weights (weighted overlay of factors using AHP approach). In a second process, non-suitable areas were excluded with the means of Boolean overlay (Boolean overlay of constraints).

4.4.1 Boolean overlay of constraints

The Boolean overlay of constraints, the three Boolean constraint layers, incorporating the settlement, water bodies and forest area raster were employed. By performing the Boolean and overlay operation, the resulting raster of the Boolean over lay operation is presented in figure 4.10 and table 4.9.

Table 4.5 Area covered by suitable and excluded class

VALUE	COUNT	Area/ square KM	Area /percentage
Un suitable	401417	435.2753	30.39930147
Suitable	919064	764.1576	69.60069853
Total		1199.4329	100

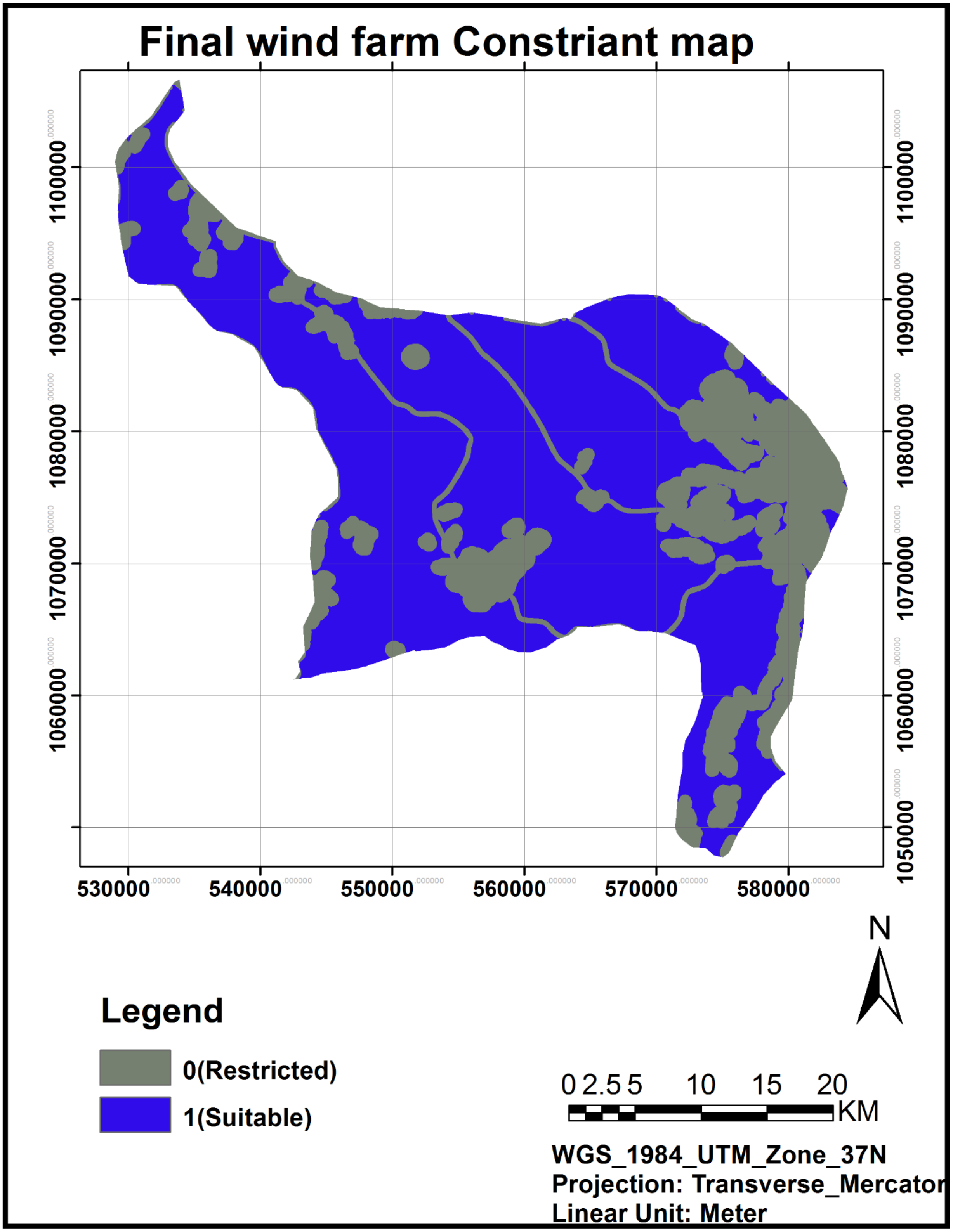


Figure4.13 Final constraint map

4.4.2 Weighted overlay of factors

In this study weighted overlay analyses in GIS were applied, in order to get the most suitable wind farm site. The weighting and rating scheme was also carefully designed through a comprehensive literature review of related studies. The following table 4.10 Shows factor weight and suitability score.

Table 4.6 Final weight and score of factor

Factor	Weight/100%	Sub	Suitability	COUNT	Area/KM2	Area/percentage
Wind power density	43.47	107- 174	1	315371	283.83	23.62
		174-200	3	21960	19.76	1.64
		200-300	5	290331	261.30	21.75
		300-400	7	434329	390.90	32.53
		400-574.918	9	273124	245.81	20.46
Land use/Land cover	7.68	Cultivated	5	1136229	1022.61	90.18
		forest	1	110981	99.88	8.81
		vegetation	7	1345	1.21	0.11
		water body	Restricted	401	0.36	0.03
		built up	3	10434	9.39	0.83
		bare land	9	632	0.57	0.05
Distance to Transmission line	24.91	0 - 100	Restricted	34099	30.69	2.56
		100 - 2500	9	250911	225.82	18.82
		2500 - 5000	7	175897	158.31	13.19
		5000 - 7500	5	142048	127.84	10.66
		7500 - 10000	3	124312	111.88	9.33
		> 10000	1	605805	545.22	45.44
Distance to major road	13.71	0 - 100	Restricted	17049	15.30	1.30
		100 - 1000	9	149475	134.50	11.30
		1000 - 2500	7	215550	194.00	16.20
		2500 - 5000	5	238378	214.50	18.00
		5000 - 10000	3	270615	243.60	20.40
		> 10000	1	436578	392.9	32.9
Elevation	4.60	1559-1700	1	7652	6.89	0.62
		1700-2000	3	47623	42.86	3.88
		2000-2500	5	370940	333.85	30.22
		2500-3000	7	556119	500.51	45.30
		>3000	9	245236	220.71	19.98
Slope	3.33	0-5%	9	385103	346.59	31.46
		5-10%	7	181107	163.00	14.80
		10-15%	5	152917	137.63	12.49
		15-25%	3	240028	216.03	19.61
		>25%	1	264877	238.39	21.64
Engineering Geology	2.3	Eluvial Soil	3	12340	11.11	0.93
		Very High	7	422611	380.35	31.72
		High rock	9	897327	807.59	67.35

4.5 Final Wind farm suitability map

For illustration, interpretation and statistical analysis purpose, the output raster layer of the overlay were reclassified according to the following (figure4.15) and unsuitable area has been extracted by mask to get the final wind farm suitability map. Figure 4.15 shows the final suitability map for the wind energy site in the study area. The map has five categories of suitability scores: Restricted poor, Moderate, Good and Very good. Approximately 29.2% of the land area in the study area fell into the Very good category. Accordingly, the total area coverage of suitability for good, moderate, poor and restricted classes 35.7%, 9%, 21.5% and 4.6% respectively. Most of the area within the study area have very good suitability scores, indicating substantial land potential for wind farm site. Refer Table 4.7 and figure 4.15

Table 4.7 Total area coverage of each suitability class

Suitability class	COUNT	Area/KM^2	Area/Percentage
Restricted	40344	36.3	4.6
Poor	187203	168.5	21.5
Moderate	77848	70.1	9.0
Good	310621	279.6	35.7
Very Good	253558	228.2	29.2
Total		782.6	100.0

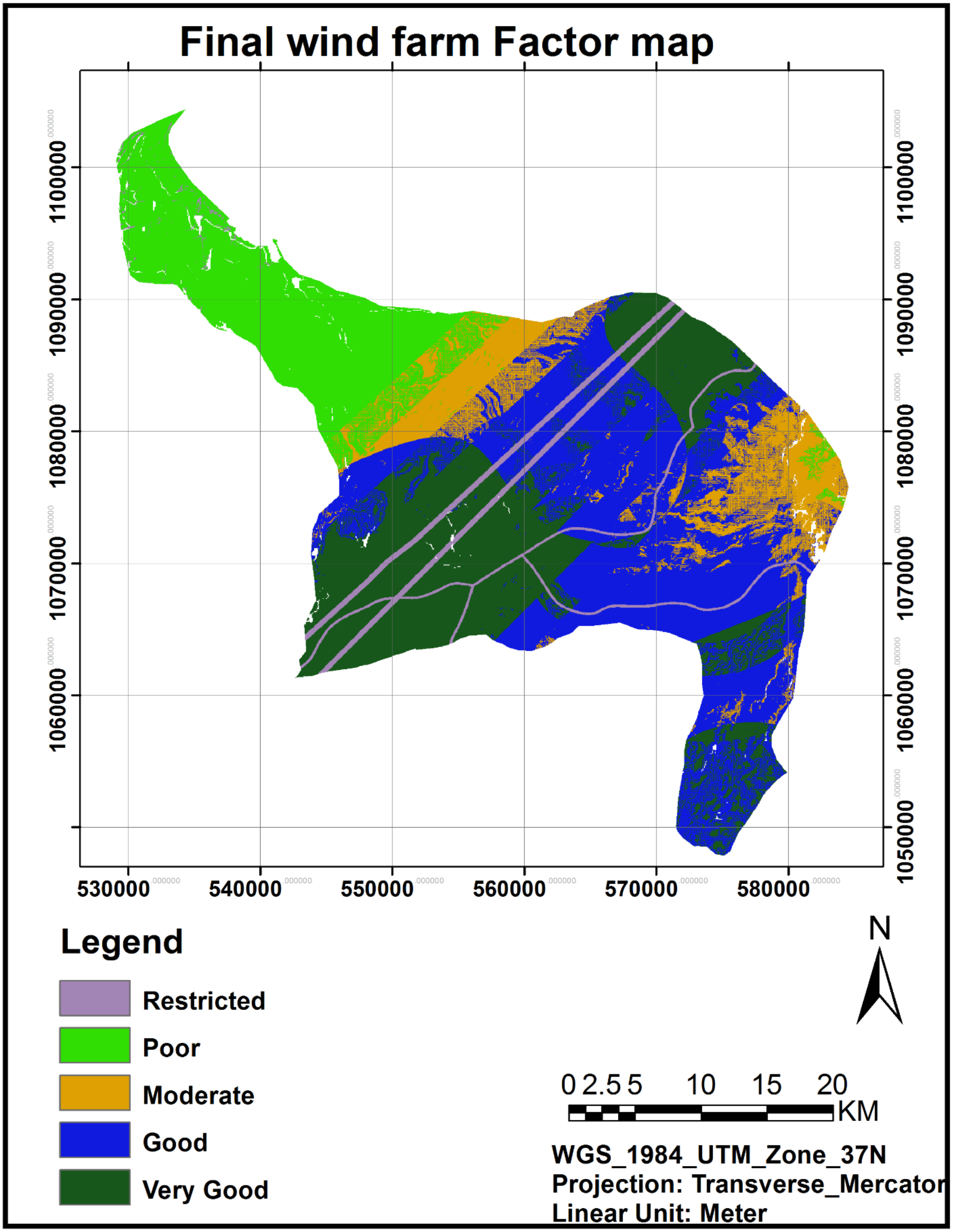


Figure 4.14 Final wind farm factor map

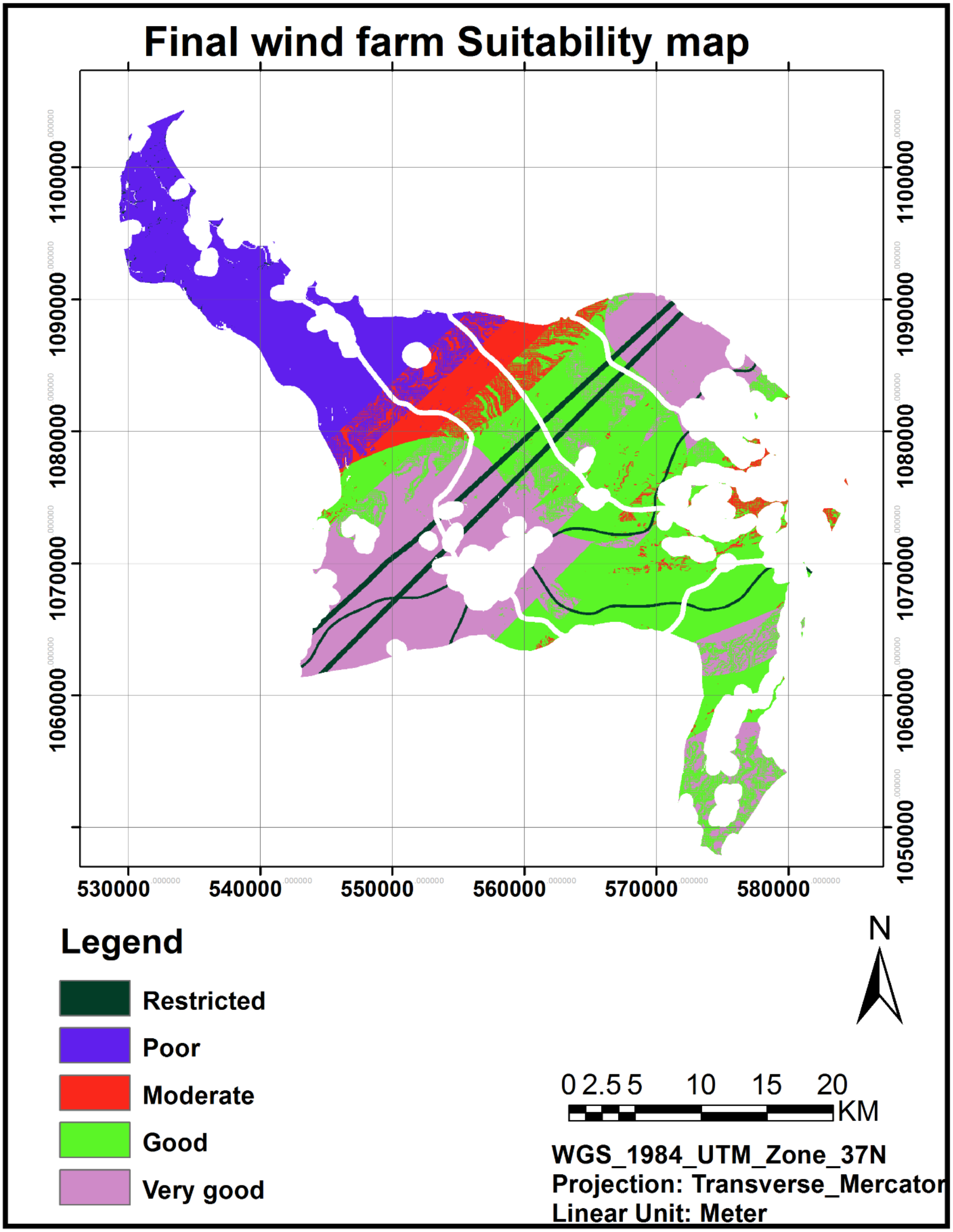


Figure 4.15 Final wind farm suitability map

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

GIS has been widely used as a cost-effective spatial decision support tool in various studies to select the best wind farms site. The aim of this study was to identify and map the most suitable wind farm site using Multi criteria modelling, in Debre Brihan Zuria Wereda.

To achieve the stated objectives a suite of physical, Environmental and economic factors were selected as criteria to model suitable locations for wind farm site, including wind potential, land use, distance to major roads, slope, Elevation, transmission lines, urban area, water bodies, engineering geology and forest area.

In this study, settlement, water bodies and forest considered as constraint whereas wind power density, transmission line, road network, engineering geology, elevation, slope and land use considered as factor.

Boolean overlay and weighted over lay using AHP approach were used to model the final wind farm suitability map.

The final wind farm site suitability map (figure 4.15) reveals that the study area was divided into five different suitability categories. The area under extreme very good, good, moderate, poor, and restricted lands stand at 29.2%, 35.7%, 9%, 21.5% and 4.6% respectively. Most of the area within the study have very good suitability scores, indicating substantial potential for wind farm site. The method proven in this study, if used with care, may be applicable to other regions of the country with similar background.

5.2 Recommendations

In this study an attempt is made to develop GIS based multi criteria model to conduct wind farm site suitability analysis in Debre Brihan Zuria Wereda. The study shows that the use of a GIS for wind farm site suitability analysis is appropriate and a necessity in wind farm development planning. To make the proposed system workable, the following recommendations are forwarded.

- Wind speed and direction data are the crucial information's needed for wind farm site selection but this information is poor in spatial distribution (5Km resolution) and the height is limited to only 50 M above ground level where as the standard turbine height is 80M. Therefore, spatially high resolution wind speed data should be used to improve the result. The concerned institution should work on gathering and compiling information necessary for such activity.
- The present study considers major environmental, and economic factors for wind farm site selection. However, other factors such Fertility of soil, land value, and landscape aspects influence wind farm site selection and therefore, should be included as evaluating criteria.
- Due to lack of information on habitats of birds and bats the suitability analysis doesn't consider path of birds and bats movement as a criteria. Therefore, it should be included in the future as evaluation criteria to bring about a very precise result.
- Web-based mapping applications should be developed for wind energy siting and to show potential for improving information dissemination, increasing public participation and awareness in wind farm development.
- The present study developed based on elsewhere scenario because of there is no sitting criteria and standards. Therefore, the concerned institution should work on preparation of standards and necessary documents for wind farm sitting.

REFERENCE

Baban, S. M., & Tim , P. (2000). Developing and applying a GIS-assisted approach to locating wind farms in the UK. *Renewable Energy*, 59-72.

Adam , M., & Ruopu , L. (2014). A Geospatial Approach for Prioritizing Wind Farm Development in Northeast Nebraska, USA. *ISPRS International Journal of Geo-Information*, 969-979.

Adams, R. (1985). *Meteorological Wind and Solar Energy Applications in Ethiopia, (A Reportfor the World Meteorological Organization).*

AndrewTindal.(2015,December12).Retrievedfrom http://www.glgarradhassan.com/assets/downloads/Wind_Power_in_Forests.pdf

Babban, S. &. (2001). Developing and aplying A GIS assisted approach to locating wind farms in the UK. *Renewable Energy*, pp. 59-71.

Babban, S.M.J, & Parry.T. (2001). Developing and aplying A GIS assisted approach to locating wind farms in the UK. *RENEWABLE ENERGY*, 59-71.

Bartnicki, N. a. (2012). *An Integrated GIS Approach to Wind Power Site Selection in Huron County,Ontario.* Guelph: Department of Geography, University of Guelph,.

Belay, E. (2007). *MODELING SITE SUITABILITY FOR WIND FARM USING REMOTE SENSING AND GIS,A case of Adama wereda ,Ethiopia.* Addis abeba: AAU.

C.Archer. (2005). Evaluation of global wind power. *Journal of geophysical Research*.

China, H. (2012). *Master Plan Report of Wind and Solar Energy in the Federal Democratic Republic of Ethiopia.*

D. L. Sisterson, B. B. (1983). “Difficulties in using power energy assesment,". *Solar Energy Vol31.*, pp. 201-204.

D.M. Heimiller & S.R. Haymes. (2001). Geographic Information Systems in Support of Wind Energy Activities at NREL. *39+ AIAA Aerospace Sciences Meeting.* Reno, Nevada.

EEPCO. (2006). *The Wind Energy Projects in Ethiopia.* Addis abeba, Ethiopia: Ethiopian Electric and Power Corporation.

F. Bañuelos-Ruedas, C. A.-C.-M. (2010, Oct). “Analysis and validation of the methodology used in the extrapolation of wind speed data at differen theights,”. *Renewable and Sustainable Energy Reviews, vol. 14, no. 8,*, pp. 2383–2391.

Fairley, P. (2000, July / August). Wind power for pennies. . *Technology Review*, pp. 40–45.

Geological Survey of Ethiopia. (2010). *Engineering Geology of Debre brihan.* Addis abeba.

Global Wind Energy Council. (2011, september). Retrieved September 21, 2015, from http://gwec.net/wpcontent/uploads/2012/06/Annual_report_2011_lowres.pdf: http://gwec.net/wpcontent/uploads/2012/06/Annual_report_2011_lowres.pdf

Gorsevski, P. V. (2013). A group-based spatial decision support system for wind farm site selection in Northwest Ohio. *Energy Policy*, 374–385.

Hoogwijk M., 2. (2004). On the Global and Regional Potential of Renewable Energy Sources, ,. 256.

Hydro china corporation. (2012). *Master Plan Report of Wind and Solar Energy in the Federal Democratic Republic of Ethiopia.*

Kordi, M. &. (2012). Effects of increasing fuzziness on analytic hierarchy process for spatial multicriteria decision analysis. *Computers, Environment and Urban system, 36(1)*, 45_53.

Kyoto. (1997). *Kyoto Protocol to the United Nations Framework Convention on Climate Change.* Kyoto.

Laura C. Rodman, R. K. (2006). A geographic analysis of wind turbine placement in Northern California. *Energy Policy*, 2137–2149.

MANUCHEHR , F., ALI , T., & MEHRAN, S. (2013). The Wind Energy Potential Zoning Using GIS And Fuzzy Mcdm Based Approach; Study Area: Zanjan Province-Iran. *Third international Geographic syimposium*, (pp. 71-82).

Mentis, D. (2013). *Wind Energy Assesment in Africs A GIS based approach.* Stockholm: Division of Energy Systems Analysis.

Mentis, D. (2013). *Wind Energy Assessment in Africa,A GIS-based approach.* STOCKHOLM: KTH School of Industrial Engineering and Management.

Mentis, D. (22013). *Wind Energy Assessment in Africa; GIS approach.* STOCKHOLM: KTH School of Industrial Engineering and Management.

Ministry of Water and Energy. (2013). *Ethiopia's Renewable Energy Power Potential and Development Opportunities.* Abu Dhabi.

Monique Hoogwijk & Wina Graus. (2008). *GLOBA L P OTENTI A L OF RENEWA BLE ENERGYS OUR C ES : A LI TERA TURE A S S ES S MENT.* NREL.

National Academy of Science. (2007). Environmental Impacts of Wind-Energy Projects. *National Research Council of the National Academies.* Washington, D.C: The National Academia Press.

National Geomatics center of china. (2015, December 4). Retrieved from 30mglobal land cover system: http://www.globallandcover.com

NREL. (2015, November 29). *SWERA*. Retrieved from https://maps.nrel.gov/swera/

portal, E. G. (2015, may 13). *Ethiopian Governmet portal*. Retrieved may 13, 2015, from www.ethiopia.gov.et/stateamhara

PowerCorporation, E. E. (2006). *The Wind Energy Projects in Ethiopia.* Addis Abeba.

Saaty, T. (1980). The Analytic Hierarchy Process. *McGraw-Hill,* , 20-25.

solomon Feleke et al, B. G. (2014). Wind power potential Assessment in Debre birhan University. Debre Brihan: Debre Brihan University.

T. Burton, D. S. (2001). *Wind Energy hand book.* Wiley online library.

Tegou, L., Polatidis, H., & Haralambopoulos, D. (2010). Environmental management framework for wind farm siting: Methodology and case study. 2134–2147.

Tim Höfer, Y. S. (2014). *Wind Farm Siting Using a Spatial Analytic Hierarchy Process Approach: A Case Study of the Städteregion Aachen.* Mathieustrasse : E.ON Energy Research Center.

Tsoustos, Frantheskaki, & Gekas. (2005). Enviromental impact from solar the solar energies resource. *Energy policy*, 289 -296.

UNDP/WEC. (2010). World Energy Assessment. *UNDP*. Washington DC.

United Nation Enviroment program. (2012). *Solar and Wind Energy Assessment Facility.*

William P., & Marry A. (2004). William P., Marry A. (2004). Principle of Environmental Science. Iniquiry and application.

Wind Energy Series. (1997, January). Siting Issues for Wind Power Plants. *Wind Energy Series*.

Windustry. (2006). community wind tool box. In *community wind handbook.* Minneapolis, US.

Wolde-Ghiorgis, W. (1974). *Wind Survey in Ethiopia.* Addis Ababa: Department of Electrical Engineering, Faculty of technology,AAU.

Appendix's

Appendix A: Model Report (variable and process)

Generated on: Sat Jan 30 16:41:05 2016

Variables

- slope

  *Data Type:*Raster Layer
  *Value:*slope

- Reclass_slope

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- reclass_elev

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- extract_wind

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- Reclass_wind

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- debre_landuse

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- Reclass_LU

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- geology_ras

*Data Type:*Raster Layer
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- Reclass_Geol

*Data Type:*Raster Dataset
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- fin_trans_ras

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- Reclass_trans

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- finl_road_ras

*Data Type:*Raster Layer
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- Reclass_road

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- Weighte_Recl

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- Reclass_Weig2

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- reclass_urban

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reclass_hydr2

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constriant1

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reclas_forest

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Final_const

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constriant.shp

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constriant_Select.shp

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Extract_Recl

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Processes

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Parameters:

Name	*Direction*	*Type*	*Data Type*	*Value*
Input raster	Input	Required	Composite Geodataset	slope
Reclass field	Input	Required	Field	Value
Reclassification	Input	Required	Remap	0 5 1;5 10 2;10 15 3;15 25 4;25 75.57110595703125 5
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\Reclass_slope
Change missing values to NoData	Input	Optional	Boolean	false

Reclassify (6)

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*Tool Source:*C:\Program Files (x86)\ArcGIS\Desktop10.0\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx\Reclass\Reclassify

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Reclassification	Input	Required	Remap	1559 1700 1;1700 2000 2;2000 2500 3;2500 3000 4;3000 3704 5
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Reclassify (5)

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Name	*Direction*	*Type*	*Data Type*	*Value*
Input raster	Input	Required	Composite Geodataset	extract_wind
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Input raster	Input	Required	Composite Geodataset	debre_landuse
Reclass field	Input	Required	Field	VALUE
Reclassification	Input	Required	Remap	10 1;10 20 2;20 40 3;40 60 4;60 80 5;80 90 6
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Change missing values to NoData	Input	Optional	Boolean	false

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Input raster	Input	Required	Composite Geodataset	geology_ras
Reclass field	Input	Required	Field	VALUE
Reclassification	Input	Required	Remap	1 1;1 2 2;2 3 3
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\Reclass_Geol
Change missing values to NoData	Input	Optional	Boolean	false

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Parameters:

Name	*Direction*	*Type*	*Data Type*	*Value*
Input raster	Input	Required	Composite Geodataset	fin_trans_ras
Reclass field	Input	Required	Field	VALUE

Reclassification	Input	Required	Remap	0 1;1 2;2 3;3 4;4 5;5 6
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\Reclass_trans
Change missing values to NoData	Input	Optional	Boolean	false

Reclassify

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*Tool Source:*C:\Program Files (x86)\ArcGIS\Desktop10.0\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx\Reclass\Reclassify

Parameters:

Name	*Direction*	*Type*	*Data Type*	*Value*
Input raster	Input	Required	Composite Geodataset	finl_road_ras
Reclass field	Input	Required	Field	VALUE
Reclassification	Input	Required	Remap	0 1;1 2;2 3;3 4;4 5;5 6
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\Reclass_road
Change missing values to NoData	Input	Optional	Boolean	false

Weighted Overlay

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Weighted overlay table	Input	Required	Weighted Overlay Table	('C:\Users\ya\Desktop\Model\Reclass_slope' 5 'VALUE' (1 9; 2 7; 3 5; 4 3; 5 1;NODATA NODATA); 'C:\Users\ya\Desktop\Model\reclass_elev' 6 'VALUE' (1 1; 2 3; 3 5; 4 7; 5 9;NODATA NODATA); 'C:\Users\ya\Desktop\Model\Reclass_wind' 43 'VALUE' (1 1; 2 3; 3 5; 4 7; 5 9;NODATA NODATA); 'C:\Users\ya\Desktop\Model\Reclass_LU' 7 'VALUE' (1 5; 2 1; 3 7; 4 1; 5 3; 6 9;NODATA NODATA); 'C:\Users\ya\Desktop\Model\Reclass_Geol' 2 'VALUE' (1 3; 2 7; 3 9;NODATA NODATA); 'C:\Users\ya\Desktop\Model\Reclass_trans' 24 'VALUE' (1 Restricted; 2 9; 3 7; 4 5; 5 3; 6 1;NODATA NODATA); 'C:\Users\ya\Desktop\Model\Reclass_road' 13 'VALUE' (1 Restricted; 2 9; 3 7; 4 5; 5 3; 6 1;NODATA NODATA));1 9 1
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Input raster	Input	Required	Composite Geodataset	C:\Users\ya\Desktop\Model\Weighte_Recl
Reclass field	Input	Required	Field	VALUE
Reclassification	Input	Required	Remap	0 1 1;1 3 2;3 4 3;4 5 4;5 7 5

Output raster	Output	Require d	Raster Dataset	C:\Users\ya\Desktop\Model\Reclass_Weig 2
Change missing values to NoData	Input	Optional	Boolean	false

Boolean And

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Input raster or constant value 2	Input	Required	Composite Geodataset	reclass_hydr2
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\constriant1

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Parameters:

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Input raster or constant value 1	Input	Required	Composite Geodataset	C:\Users\ya\Desktop\Model\constriant1

Input raster or constant value 2	Input	Required	Composite Geodataset	reclas_forest
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\Final_const

Raster to Polygon

*Tool Name:*Raster to Polygon
*Tool Source:*C:\Program Files (x86)\ArcGIS\Desktop10.0\ArcToolbox\Toolboxes\Conversion Tools.tbx\From Raster\RasterToPolygon

Parameters:

Name	*Direction*	*Type*	*Data Type*	*Value*
Input raster	Input	Required	Composite Geodataset	C:\Users\ya\Desktop\Model\Final_const
Output polygon features	Output	Required	Feature Class	C:\Users\ya\Desktop\Model\constriant.shp
Simplify polygons	Input	Optional	Boolean	true
Field	Input	Optional	Field	VALUE

Select

Tool Name: Select
Tool Source: C:\Program Files (x86)\ArcGIS\Desktop10.0\ArcToolbox\Toolboxes\Analysis Tools.tbx\Extract\Select

Parameters:

Name	*Direction*	*Type*	*Data Type*	*Value*
Input Features	Input	Required	Feature Layer	C:\Users\ya\Desktop\Model\constriant.shp

Output Feature Class	Output	Required	Feature Class	C:\Users\ya\Desktop\Model\constriant_Select.shp
Expression	Input	Optional	SQL Expression	"GRIDCODE"= 1

Extract by Mask

*Tool Name:*Extract by Mask
*Tool Source:*C:\Program Files (x86)\ArcGIS\Desktop10.0\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx\Extraction\ExtractByMask

Parameters:

Name	*Direction*	*Type*	*Data Type*	*Value*
Input raster	Input	Required	Composite Geodataset	C:\Users\ya\Desktop\Model\Reclass_Weig2
Input raster or feature mask data	Input	Required	Composite Geodataset	C:\Users\ya\Desktop\Model\constriant_Select.shp
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\Extract_Recl