ADAMA SCIENCE & TECHNOLOGY UNIVERSITY

Project Report on

Modelling and Validation of Wind Farm Site Suitability Analysis: Adama II Wind Farm Using GIS Techniques

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February, 2017

Adama, Ethiopia

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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 Adama II wind farm and the results were spatially correlated with the existing wind mills. 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 four different suitability categories. The area under high suitable, more suitable, moderate and not suitable lands stand at 38%, 10%, 16 and 36 %, 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.

Key Words: GIS, MCA/AHP, Site suitability, Validation, Adama Wind Farm II

CHAPTER ONE: INTRODUCTION

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 project 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 Adama II wind farm. 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 50m, 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 spatially correlate the existing wind turbines in Adama II wind farm, using GIS techniques.

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 restricted and highly suitable site for wind farm in the study area
- To validate the results by spatially correlating with the existing wind farm.

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, 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 site to Adama II wind farm. 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 site for Adama II wind farm. 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

Adama Woreda is in the Oromia Region of Ethiopia. The land use practice in watershed can be characterized as an agricultural, Built-up areas, and water bodies and area is rich in biodiversity. The elevation ranges from 1453 meter to 2502 meter from Mean Sea Level (MSL) which has provided habitat of sub-tropical species of vegetation.Part of the East Shewa Zone located in the Great Rift Valley. Adama Woreda is bordered on the south by the Arsi Zone, on the southwest by Koka Reservoir which separates it from Dugda Bora, on the west by Lome, on the north by the Amhara Region, and on the east by Boset; the Awash River, the only important river in this Woreda, defines the Woreda boundaries on the east and south. Mermersa and Galdia Watershed is located between 8˚28'3.77''N to 8˚44'33.39''N latitude and 39˚14'36.87''E to 39˚27'43.87''E longitudes ,figure 1

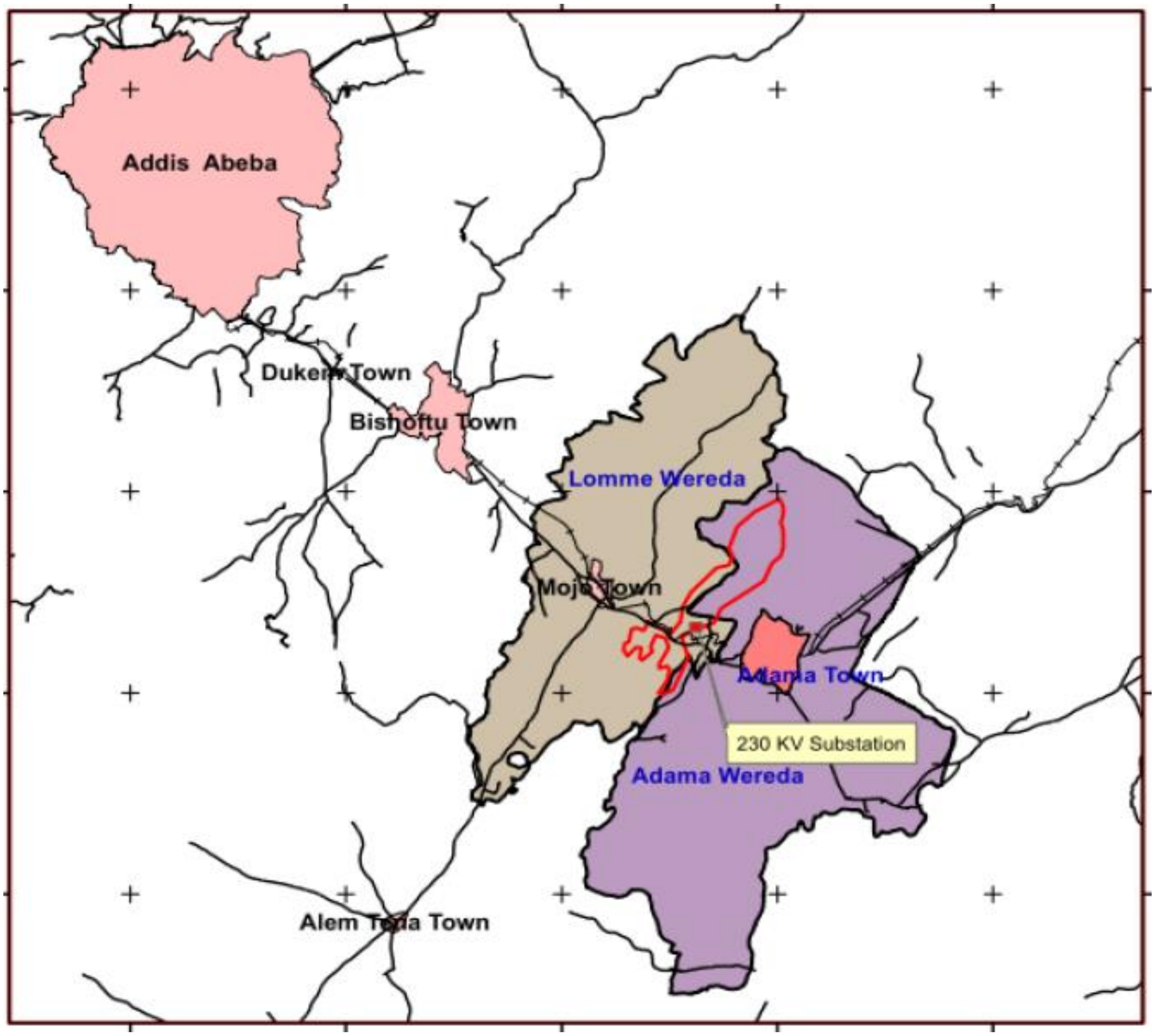

Figure 1. Study area map

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 (figure 2). 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)

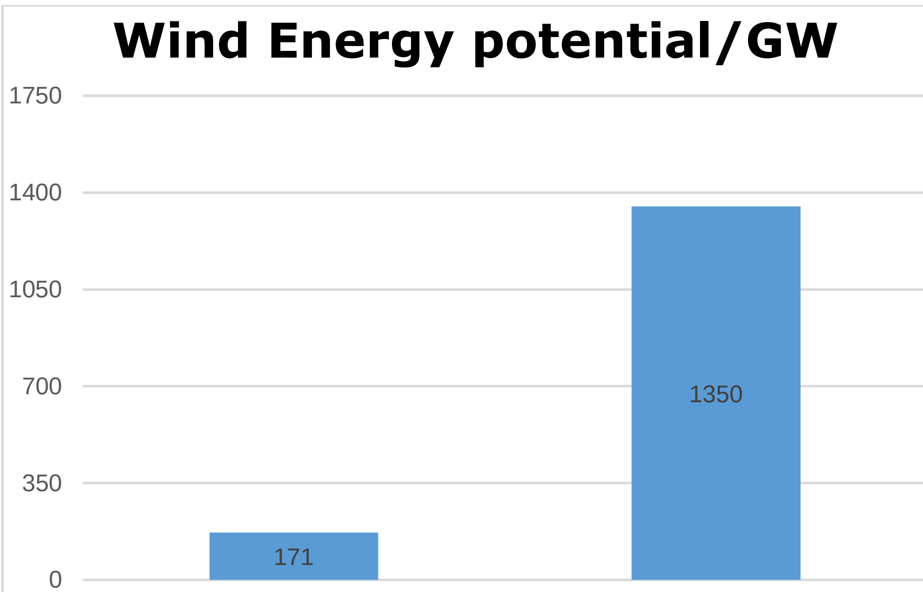

Figure 2. Wind Energy in Ethiopia

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 uses, 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 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: 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).

Table 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

2.2.6 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)

2.2.7 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. 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 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.

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 4 list of data sets and data source

Dataset	**Format**	**Source**	**Resolution**	**year**
Wind speed and wind density	Raster	NREL/https://maps.nrel.gov/	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	2015
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		2015

3.2 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.

3.3 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. 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.

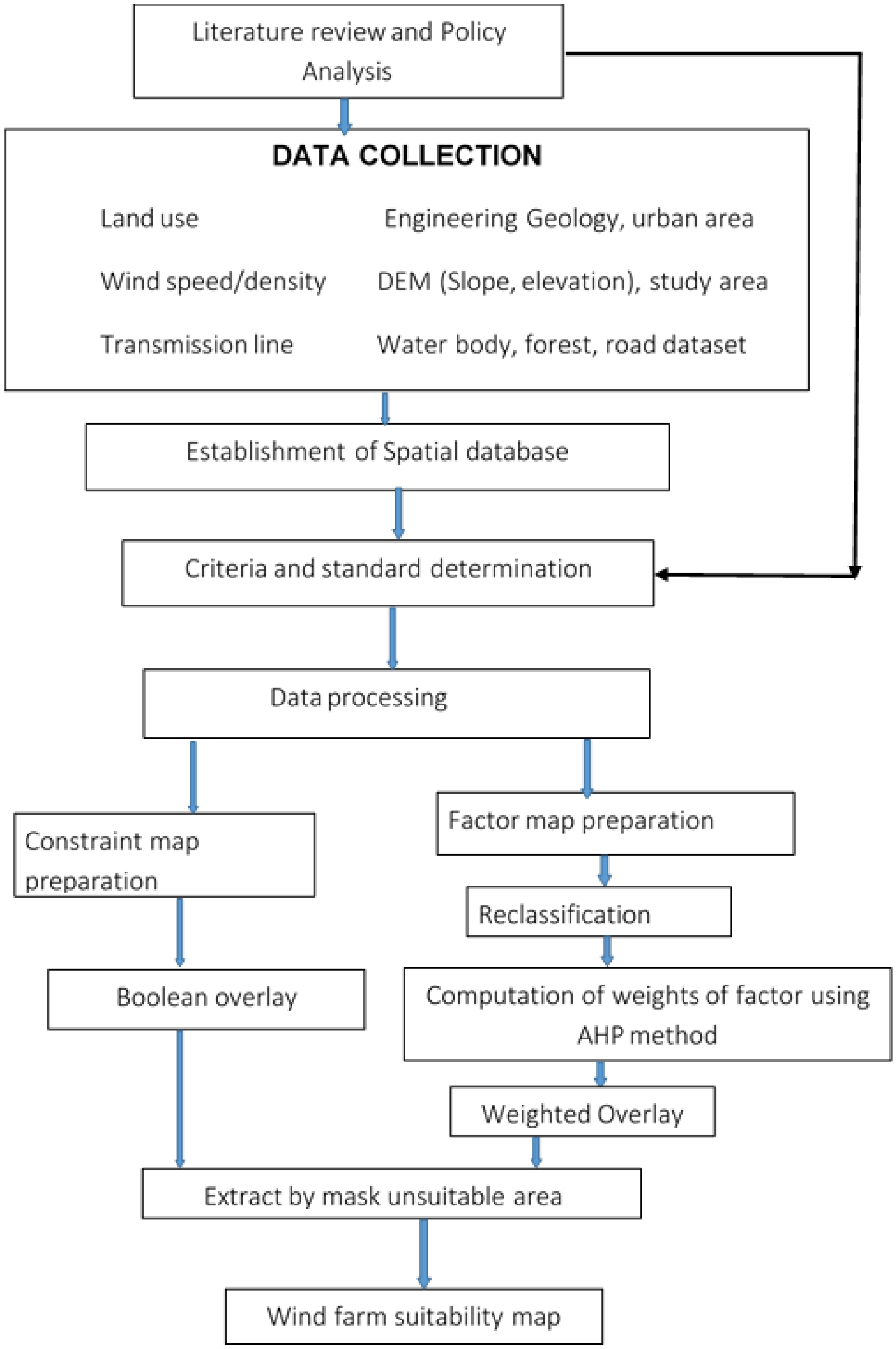

Figure 3. General work flow

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. shows the entire process graphically. Refer appendix c for the report of the entire model run.

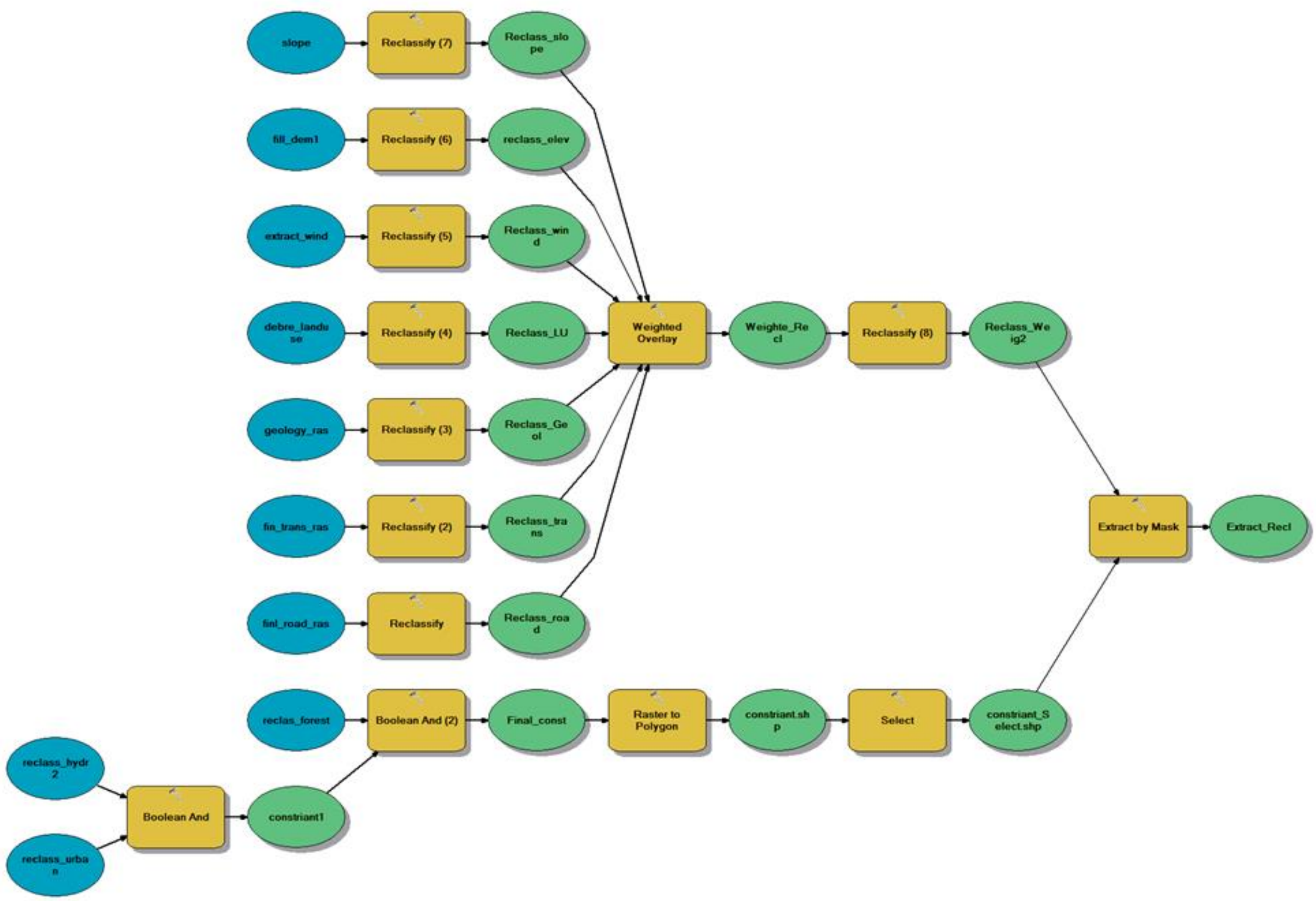

Figure 4. Wind farm suitability Model

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 600m from the nearest settlement (National Academy of Science, 2007). A buffer within that distance was set from cities and highways. In this study, 600 m buffer was used to reduce the noise pollution. Accordingly, 64% of the total area will be in the analysis whereas the rest 36% of the total area is out of analysis figure 5 and table 5.

Table 5 Suitable and restricted area coverage

VALUE	Area/KM^2	Area/percentage
Suitable	50.44	64
Restricted	29.95	36
Total	78.826	100

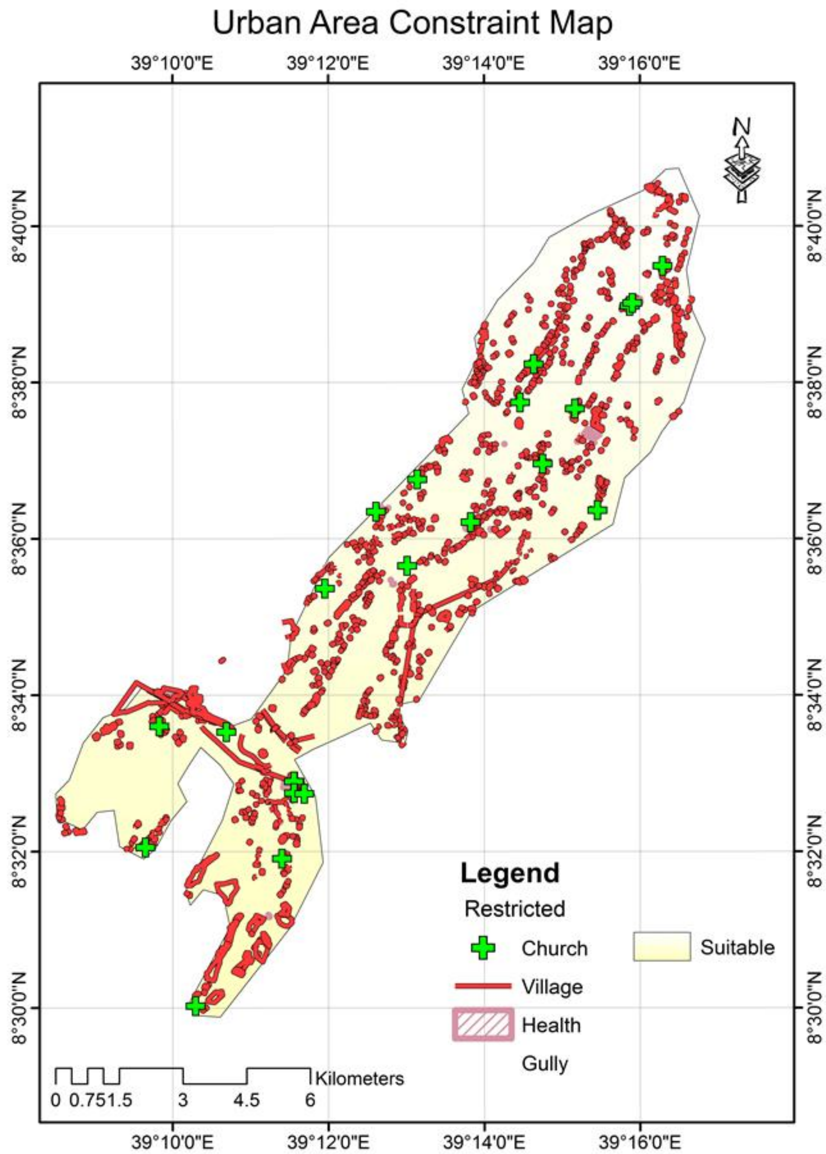

Figure 5. urban area constraint map

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.

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 (6) and table (6) the excluded area covers 24.24% of the total area where as the suitable area covers 75.76 % of the total area.

Table 6 water bodies buffer area coverage

VALUE	Area/Square KM	Area/ percentage
Excluded	19.0174	24.24
Suitable	59.8086	75.76
Total	78.826	100

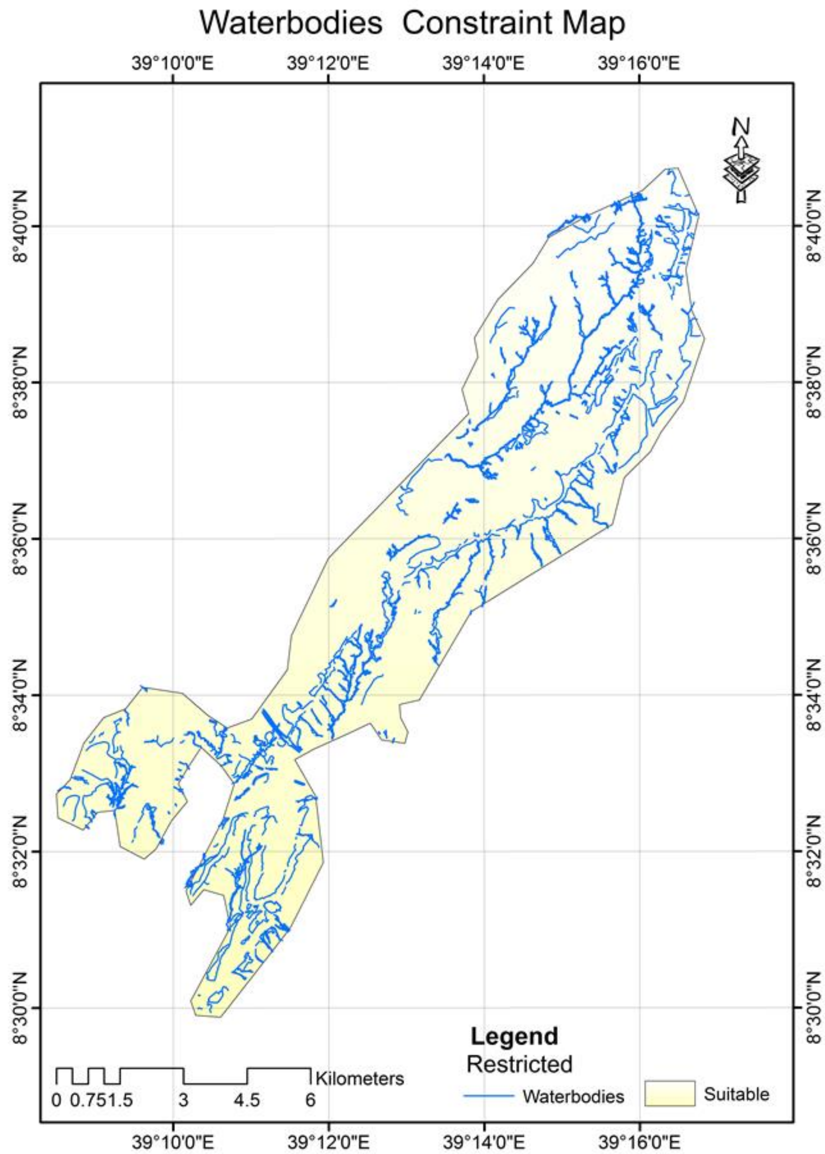

Figure 6. Water bodies constraint map

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

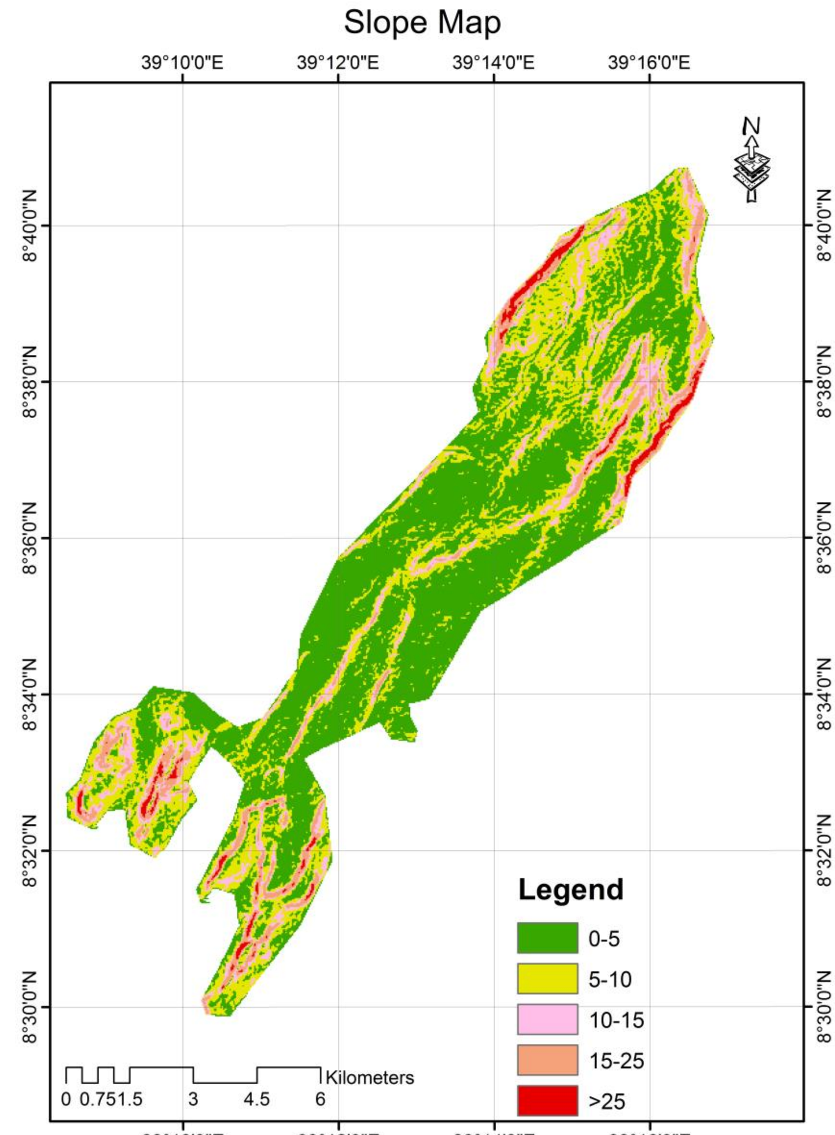

Figure 7 Reclassified Slope -Spatial distribution map

Source: derived from Digital Terrain Model (USGS Earth explorer) 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.7).

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 speed of the study area is between 5.2 to 6.1 m/s (Fig.8). 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.

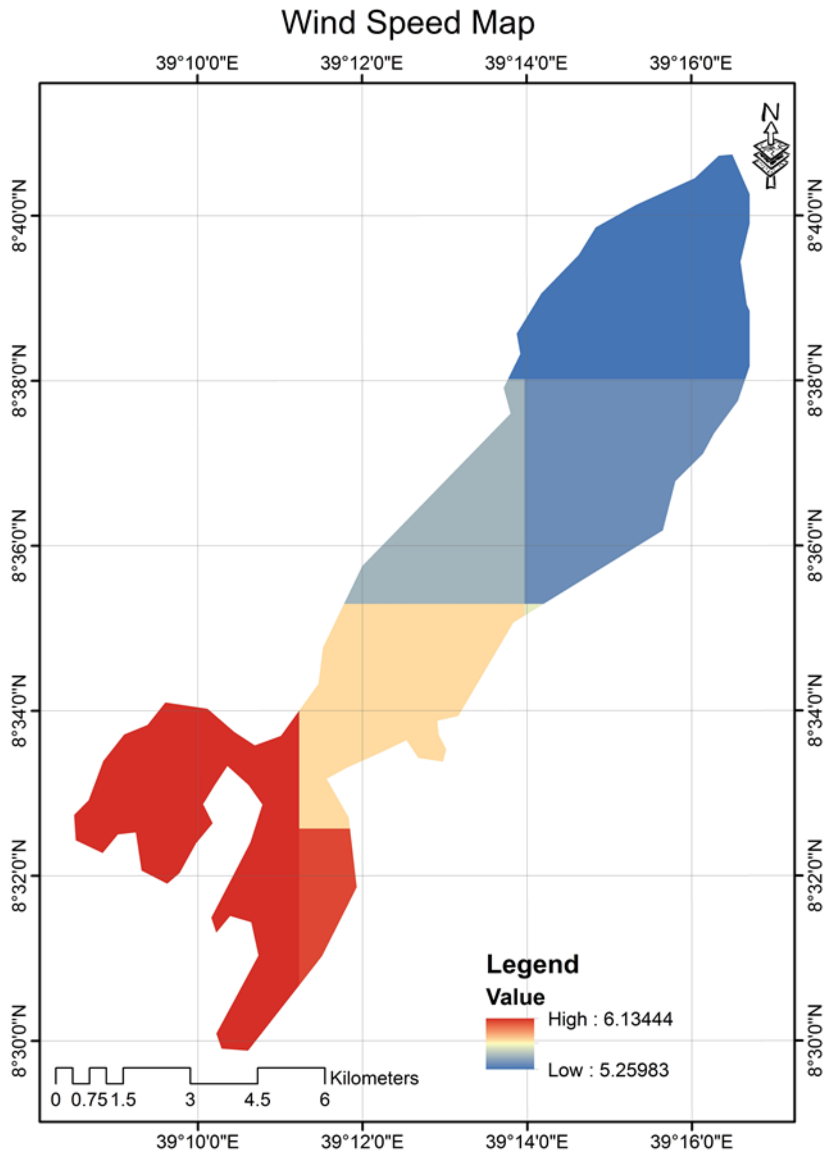

Figure 8. Wind power density Spatial Distribution map

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

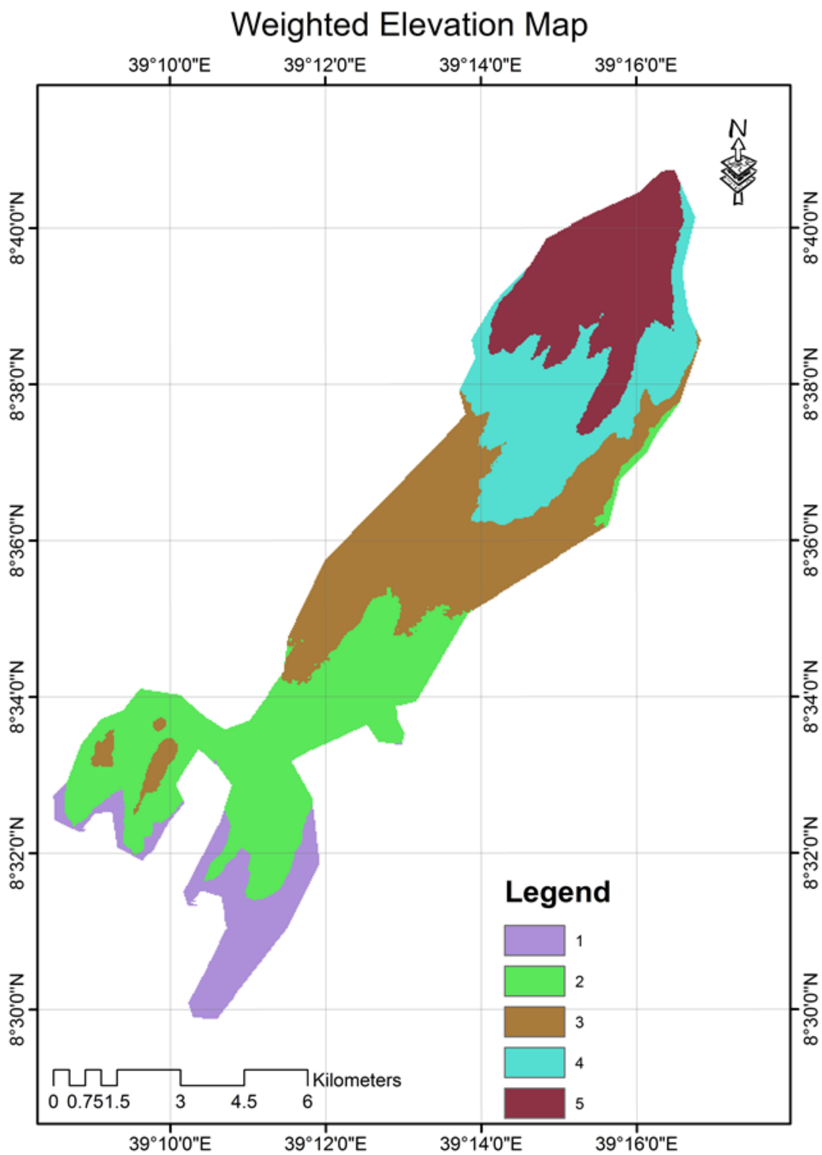

Figure 9. Weighted Elevation map

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

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 9.

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

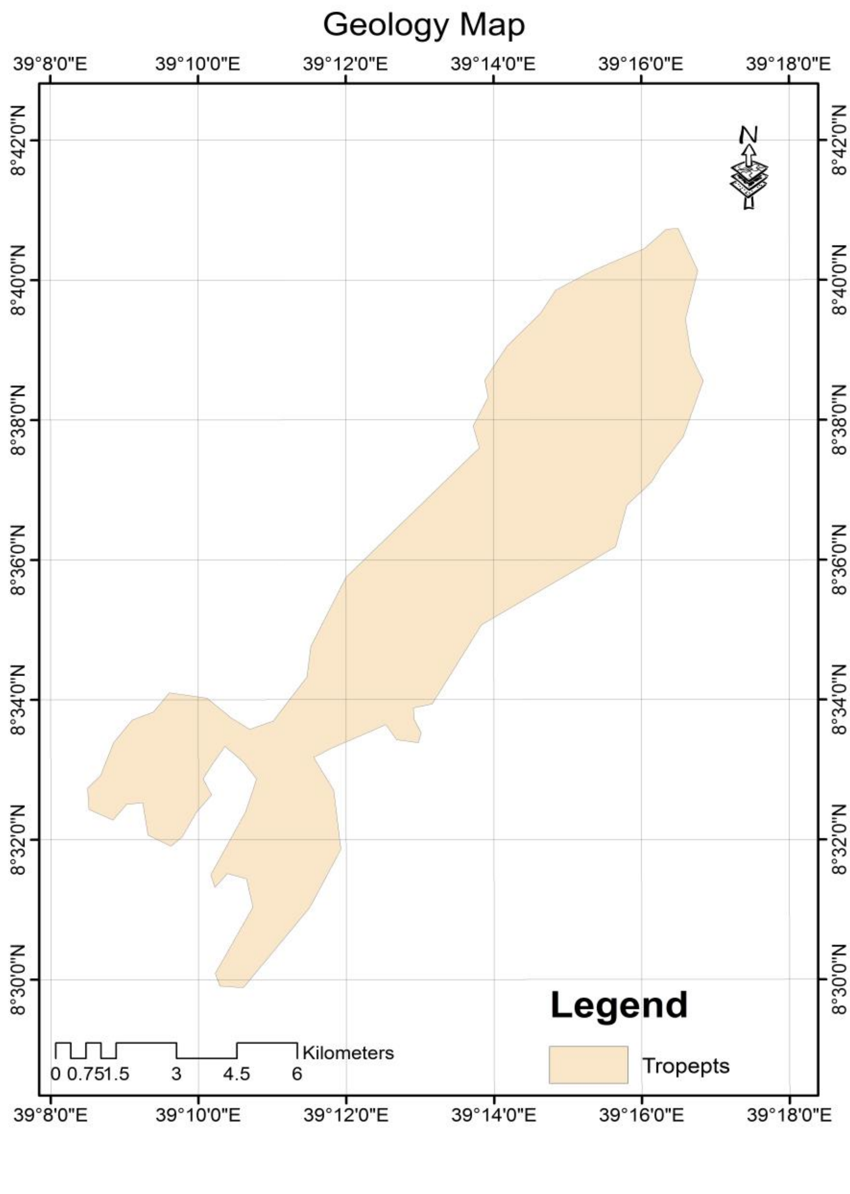

Figure 10. Reclassified Engineering geology spatial Distribution map

Source: Ethiopian Geological survey

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 Tropepts units with characteristics features defining the various units. Rock and very high rock mass with eluvial soil unit's covers100 % of the total area respectively figure 10.

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 sui

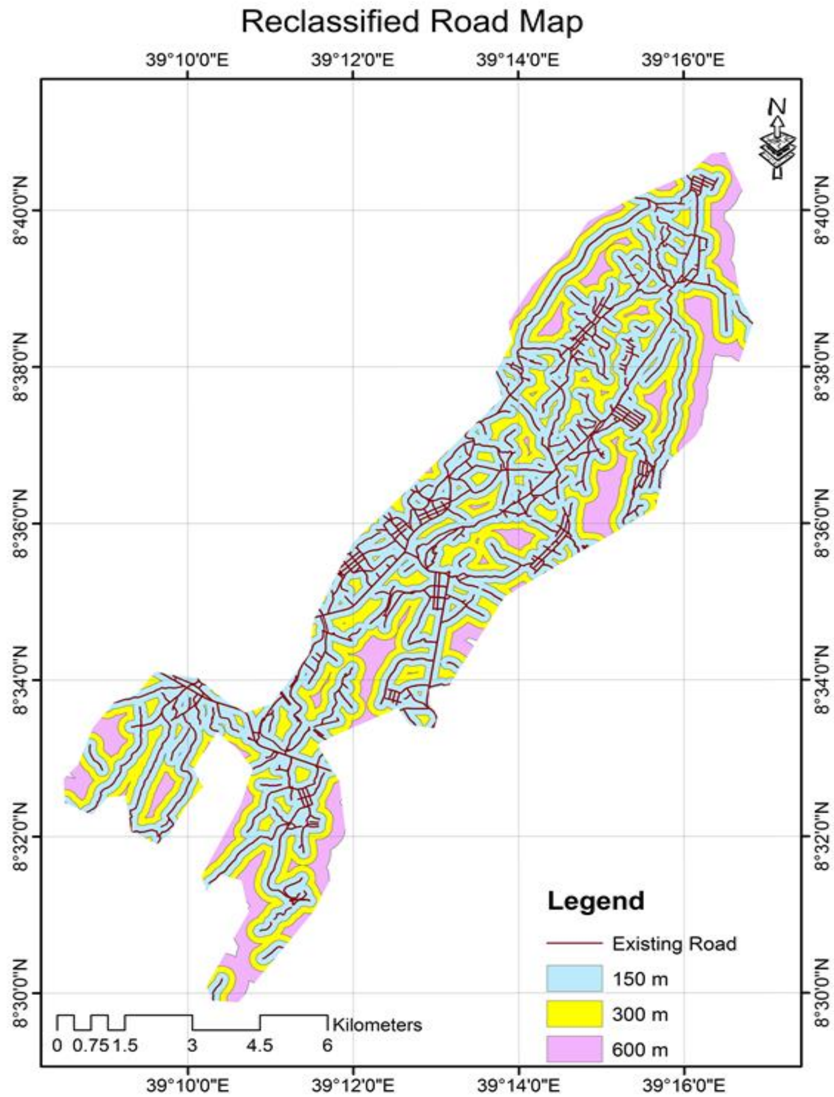

Figure 11 Distribution of Suitable Area around the major road

Source: Ethiopian road authority

table 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 150 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 11 Shows distribution of suitable area around the main road.

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 150 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 150 to 300 m receive the highest value score of 9, and areas with greater the distances the score lowest of 1 (figure 12).

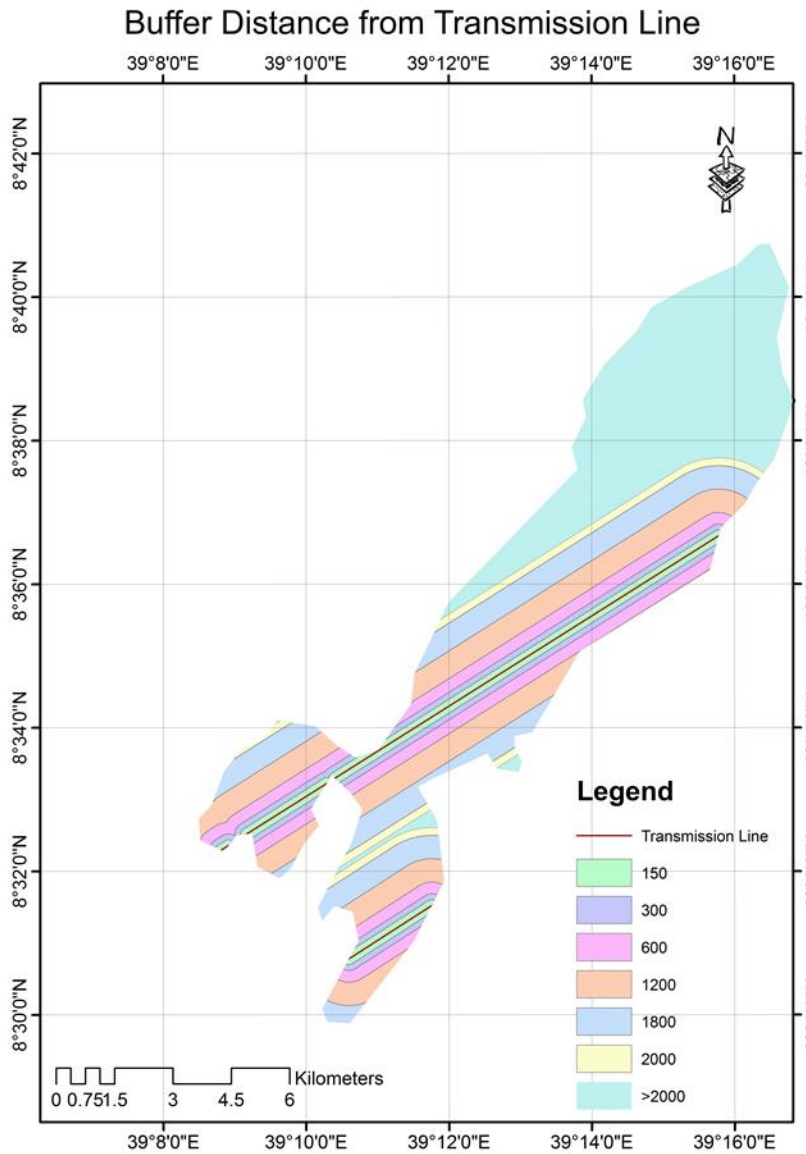

Figure 12. Distribution of Suitable Area around transmission lines map

Source: Ethiopian Electric power

4.3 Determination of weight using AHP

The Pairwise Comparison Matrix (figure 13) 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 (Table

7) 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)

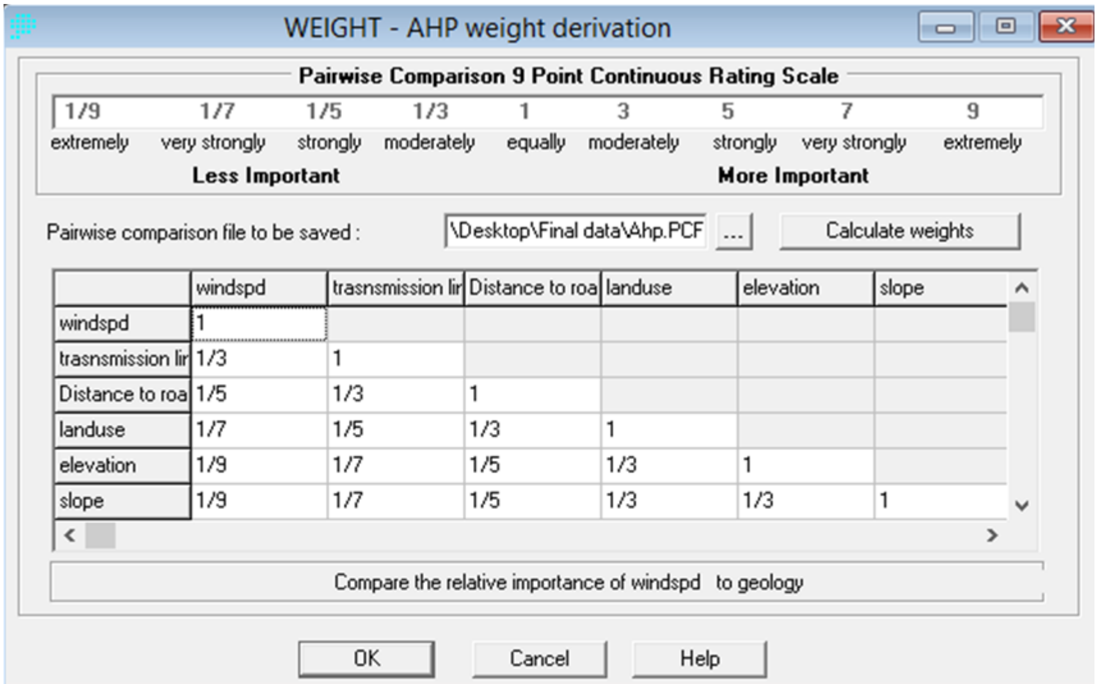

Figure 13. Weight derived by AHP method

Table 7. 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-

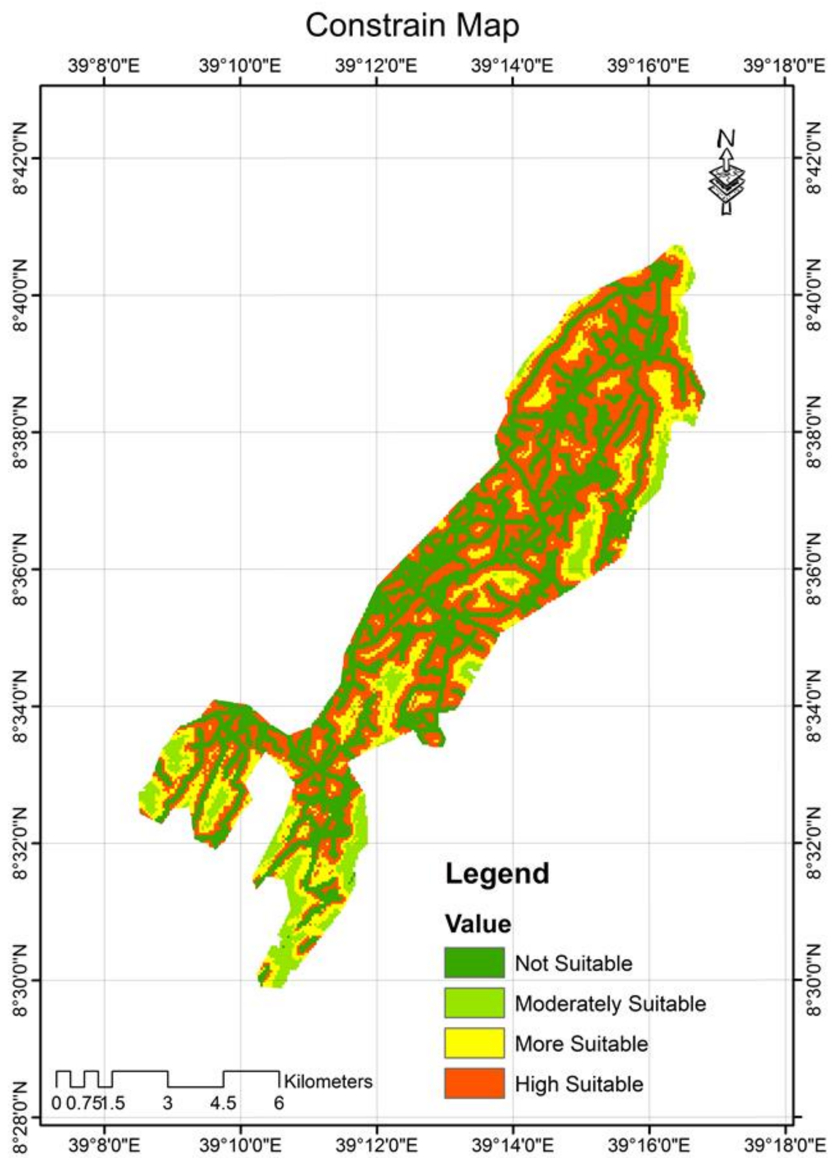

Figure14 Final constraint map

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 8.

Table 8. 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

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 9 Shows factor weight and suitability score.

Table 9 Final weight and score of factor

Factor	Weight/100%	Sub classification	Suitability score	Area/KM2	Area/percentage
Wind power density	43.47	< 5.2	1	23.34	29.62
		5.24-5.49	3	6.6	8.38
		5.49-5.76	5	5.5	7.33
		5.76-5.99	7	12.6	16.32
		5.99-6.134	9	28.37	36.35
		Cultivated land	5	1022.61	90.18

Land use/Land cover	7.68	forest	1	99.88	8.81
		vegetation	7	1.21	0.11
		water body	Restricted	0.36	0.03
		built up	3	9.39	0.83
		bare land	9	0.57	0.05
Distance to Transmission line	24.91	0 - 150	Restricted	3.12	4.5
		150 - 300	9	3.86	4.9
		300 - 600	7	8.24	10.46
		600 - 1200	5	18.74	23.78
		1200-1800	3	21.8	27.67
		> 1800	1	42.55	57.22
Distance to major road	13.71	0 - 150	Restricted	12.45	16.3
		150 - 300	3	24.7	31.46
		300 - 600	1	39.41	49.1
Elevation	4.60	<1840	1	7.1226071	9.0365480290853
		1840-1905	3	22.97	29.144
		1905-2011	5	21.086	26.75
		2011-2119	7	14.100	17.88
		>2119	9	13.53	17.171
Slope	3.33	0-5%	9	41.142	52.198
		5-10%	7	23.55	29.87
		10-15%	5	7.95	10.08
		15-25%	3	4.77	6.063
		>25%	1	1.39	1.77
Engineering	2.3	Tropepts Soil	9	78.82	100

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 (figure4.14) and unsuitable area has been extracted by mask to get the final wind farm suitability map. Figure 4.14shows the final suitability map for the wind energy site in the study area. The map has five categories of suitability scores: Not Suitable, Moderate, More and High. Approximately 36% of the land area in the study area fell into the Very good category. Accordingly, the total area coverage of suitability for More, moderate and Not suitable are 16 %, 10 % and 38 % respectively. Most of the area within the study area have very good suitability scores, indicating substantial land potential for wind farm site. Refer Table 10 and figure 15

Table 10 Total area coverage of each suitability class

Suitability class	Area/KM^2	Area/Percentage
Not Suitable	29.95	38
Moderate	7.88	10
More Suitable	12.611	16
High Suitable	28.37	36
Total	78.82	100.0

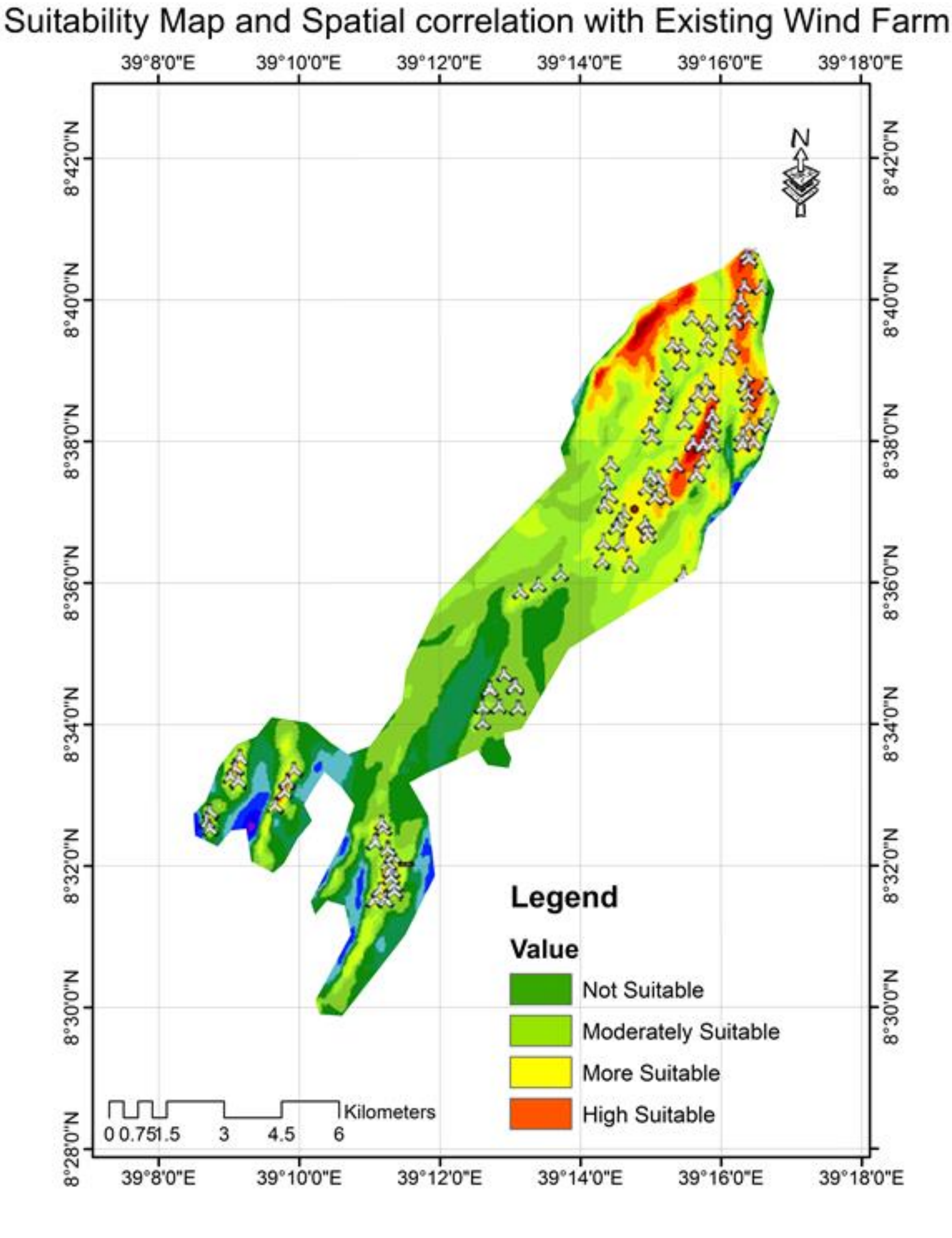

Figure 15. Final wind farm suitability map

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 of Adama II wind farm

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 4.14) reveals that the study area was divided into five different suitability categories. The area under extreme High Suitable, More Suitable , moderate, and not suitable lands stand at 36 %, 16 %, 10% and 38 % respectively. Most of the area within the study have high 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. Moreover the obtained results were cross checked with the existing wind turbines , a close spatial correlation was observed . This shows the reliability of results.

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 Adama II wind farm. 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.

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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

  *Data Type:*Raster Dataset
  *Value:*C:\Users\ya\Desktop\Model\Reclass_slope

- fill_dem1

  *Data Type:*Raster Layer
  *Value:*fill_dem1

- reclass_elev

  *Data Type:*Raster Dataset
  *Value:*C:\Users\ya\Desktop\Model\reclass_elev

- extract_wind

  *Data Type:*Raster Layer
  *Value:*extract_wind

- Reclass_wind

  *Data Type:*Raster Dataset
  *Value:*C:\Users\ya\Desktop\Model\Reclass_wind

- debre_landuse

*Data Type:*Raster Layer
*Value:*debre_landuse

⪢Reclass_LU

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\Reclass_LU

⪢geology_ras

*Data Type:*Raster Layer
*Value:*geology_ras

⪢Reclass_Geol

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\Reclass_Geol

⪢fin_trans_ras

*Data Type:*Raster Layer
*Value:*fin_trans_ras

⪢Reclass_trans

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\Reclass_trans

⪢finl_road_ras

*Data Type:*Raster Layer
*Value:*finl_road_ras

⪢Reclass_road

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\Reclass_road

⪢Weighte_Recl

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\Weighte_Recl

⪢Reclass_Weig2

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\Reclass_Weig2

⪢reclass_urban

*Data Type:*Raster Layer
*Value:*reclass_urban

reclass_hydr2

*Data Type:*Raster Layer
*Value:*reclass_hydr2

constriant1

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\constriant1

reclas_forest

*Data Type:*Raster Layer
*Value:*reclas_forest

Final_const

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\Final_const

constriant.shp

*Data Type:*Feature Class
*Value:*C:\Users\ya\Desktop\Model\constriant.shp

constriant_Select.shp

*Data Type:*Feature Class
*Value:*C:\Users\ya\Desktop\Model\constriant_Select.shp

Extract_Recl

*Data Type:*Raster Dataset
*Value:*C:\Users\ya\Desktop\Model\Extract_Recl

Processes

⋎Reclassify (7)

*Tool Name:*Reclassify
*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	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)

*Tool Name:*Reclassify
*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	fill_dem1
Reclass field	Input	Required	Field	VALUE
Reclassification	Input	Required	Remap	1559 1700 1;1700 2000 2;2000 2500 3;2500 3000 4;3000 3704 5
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\reclass_elev
Change missing values to NoData	Input	Optional	Boolean	true

⋎Reclassify (5)

*Tool Name:*Reclassify
*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 extract_wind

Reclass field Input Required Field VALUE

Reclassification Input Required Remap 1 1;1 2 2;2 3 3;3 4 4;4 5 5

Output raster Output Required Raster Dataset C:\Users\ya\Desktop\Model\Reclass_wind

Change missing values to NoData Input Optional Boolean false

⪢Reclassify (4)

*Tool Name:*Reclassify
*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 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

Output raster Output Required Raster Dataset C:\Users\ya\Desktop\Model\Reclass_LU

Change missing values to NoData Input Optional Boolean false

⪢Reclassify (3)

*Tool Name:*Reclassify
*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 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

Reclassify (2)

*Tool Name:*Reclassify
*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 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

*Tool Name:*Reclassify
*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

*Tool Name:*Weighted Overlay
*Tool Source:*C:\Program Files (x86)\ArcGIS\Desktop10.0\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx\Overlay\WeightedOverlay

⩡Parameters:

Name *Direction* *Type* *Data Type* *Value*

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

Output raster Output Required Raster Dataset
C:\Users\ya\Desktop\Model\Weighte_Recl

⩡Reclassify (8)

*Tool Name:*Reclassify
*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
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 Required Raster Dataset
C:\Users\ya\Desktop\Model\Reclass_Weig2

Change missing values to NoData Input Optional Boolean false

⩡Boolean And

*Tool Name:*Boolean And
*Tool Source:*C:\Program Files (x86)\ArcGIS\Desktop10.0\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx\Math\Logical\BooleanAnd

Parameters:

Name	*Direction*	*Type*	*Data Type*	*Value*
Input raster or constant value 1	Input	Required	Composite Geodataset	reclass_urban
Input raster or constant value 2	Input	Required	Composite Geodataset	reclass_hydr2
Output raster	Output	Required	Raster Dataset	C:\Users\ya\Desktop\Model\constriant1

Boolean And (2)

*Tool Name:*Boolean And
*Tool Source:*C:\Program Files (x86)\ArcGIS\Desktop10.0\ArcToolbox\Toolboxes\Spatial Analyst Tools.tbx\Math\Logical\BooleanAnd

Parameters:

Name	*Direction*	*Type*	*Data Type*	*Value*
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