SITE SUITABILITY ANAYLSIS FOR WIND FARM DEVELOPMENT USING GEOSPATIAL TECHNOLOGIES, ACASE OF SOME PART OF EAST SHOA AND ARSI ZONE, ETHIOPIA

Nanati Gudisa Gemechu

A Thesis Submitted to The department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geo-Informatics

Office of Graduate Studies

Adama Science and Technology University

September,2022

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled “Site Suitability Analysis Wind Farm Development Using Geospatial Technologies, Acase of Some Part of East Shoa and Arsi Zone, Ethiopia” is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

___Nanati Gudisa___________________ _______________ _______________

Name of Candidate Signature Date

RECOMMENDATION

We, the advisor(s) of this thesis, hereby certify that we have read the revised version of the thesis entitled “Site Suitability Analysis Wind Farm Development Using Geospatial Technologies, Acase of Some Part of East Shoa and Arsi Zone, Ethiopia” prepared under our guidance by Nanati Gudisa submitted in partial fulfillment of the requirements for the degree of Mater’s of Science in Geo-Informatics Engineering. Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

____Roba Gemechu_(PhD)_________	________________	________________
Advisor	Signature	Date

APPROVAL SHEET

I, the advisor of the thesis entitled "Site Suitability Analysis Wind Farm Development Using Geospatial Technologies, A case of Some Part of East Shoa and Arsi Zone, Ethiopia" and developed by Nanati Gudisa, here by certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Advisor	Signature	Date
____________	____________	____________

We, the undersigned, members of the Board of Examiners of the thesis by Nanati Gudisa have read and evaluated the thesis entitled "Site Suitability Analysis Wind Farm Development Using Geospatial Technologies, A case of Some Part of East Shoa and Arsi Zone, Ethiopia" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Geo-Informatics.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

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a.m.s.l	Above Mean Sea Level
AHP	Analytical Hierarchy Process
AOI	Area of Interest
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
BOFED	Bureau of Finance and Economic Development Oromia
CI	Consistency Index
CR	Consistency ratio
CSA	Central Statistic Authority
DEM	Digital Elevation Model
EEP	Ethiopian Electric Power
EGSA	Ethiopian Geological Survey Agency
ERA	Ethiopian Road Authority
ERDAS	Earth Resources Data Analysis System
FAO	Food and Agriculture Organization
EGII	Ethiopian Geospatial Information Institute
GIS	Geographic Information Systems
GPS	Global Positioning Systems
GST	Geospatial Technologies
JPEG	Joint Photographic Expert Graphics
LULC	Land use land cover
MCA	Multi Criteria Analysis
MCDA	Multi Criteria Decision Analysis
MOWIE	Ministry of Water, Irrigation and Energy-Ethiopia
RS	Remote Sensing
TIFF	Tagged Image File Format
USGS	United State Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WLC	Weighted Linear Combination

ABSTRACT

Renewable energy may be defined as any form of energy, that is either derived directly or indirectly from sun or from any source that replenishes itself naturally over a period of time. Being cleaner and climate friendly, wind energy has been increasingly utilized to meet the every growing global energy demands. Wind farm has emerged as a key component of the overall at global level due to its environmental and economic benefits. Despite its multiple benefits, wind energy is under considerable pressure, particularly in rapidly developing countries. In Ethiopia, a wide gap exists between wind resources and actual energy production, and it is imperative to expand the wind energy production. The main objective of this study is to analyze potential sites for wind farm development in Between East shoa and Arsi Zone using Geospatial technologies. Site suitability analysis, by its nature is a complex process and involves of multi-criteria analysis considerations which are technical, environmental and socio-economic factors for wind farm development were identified through a literature review and expert opinion. Several spatial and non-spatial datasets like wind speed, distance to roads, elevation, slope, LULC, geology, distance from transmission line and stream were recognized as the key factors affecting wind farm suitability. The factors were standardized based on suitability rankings. Analytical Hierarchy Process was employed to determine the relative importance of each factor. Suitable sites were identified through weighted spatial overlay analysis in a GIS environment. The study ends with an assessment of proposed sites to the generated suitability site. Therefore, Based on GIS-based (MCA) 11.4%, 15.5%, 56.6%,15.3% and 1.2% very highly suitable, moderately suitable, less suitable, Permanently not suitable and Restricted Area for wind farm development respectively. This study would help in the formulation of appropriate wind farm planning and management policies. It would also give energy planners and stakeholders vital information regarding appropriate sites for the growth of wind farm in the future in study area. Generally, geospatial technologies and application of GIS-based Multi-Criteria Analysis (MCA), AHP, weight overlay has provided an effective methodology to solve a complex decision problem in wind farm site selection process.

Key words: AHP, GIS, Wind Farm, Geospatial Technology, MCA, suitable analysis

CHAPTER ONE: INTRODUCTION

1.1. Background of the study

Increasing use of fossil fuels as energy sources has exhausted due to population growth and has been damaging the environment. Nowadays, scientists have found renewable energy that are sustainable and safest options to prevent greenhouse gases spreading and the world population energy requests. According to (Tester et al,2005), Giving everyone access to energy equally while preserving the environment for future generations is the definition of sustainable energy. As a kind of energy, the renewable energy systems are generally accepted. Sustainable energy has recently attracted attention (Omer, 2008). Utilizing for Utilizing renewable energy sources like wind energy reduce reliance on fossil fuels. Compared to fossil fuels like coal and petroleum, wind energy creates less pollution and damage to the environment. One of wind energy's most significant contributions in order to protect the environment, CO2, SO2, and NO2 emissions must be reduced.

Any sort of energy that derives directly or indirectly from the sun or from any source that naturally replaces itself over time is considered renewable energy (Twidell and Weir, 2015). Due to its low production, operation, and maintenance costs, as well as the ease of access to effective multi-megawatt wind turbines, wind energy is a very promising renewable, sustainable, secure, and economically feasible source of energy that is gaining widespread recognition (Kaplan, 2015). One of its key benefits is that it global availability, as wind blows potentially everywhere around the world and is an accepted and harmless type of renewable energy that can be cost effectively viable, environmentally safe, and can play a significant role in reduction of CO2, SO_2, and NO_2. The other benefit of wind energy is relatively cheap in its production and implementation costs. Compared to biomass, hydropower energy (Field et al., 2008), wind energy has the advantage that it does not consume much agricultural space where is needed for solving other main world problems like food crops production.

In the past wind energy was considered to be a renewable energy source primarily for developed countries, because of its cost but this is slowly changing. Since 2001, wind energy production has risen significantly worldwide and the cumulative installed global capacity increased from 24 Giga Watt (GW) at the end of 2001 to 237 GW at the end of 2011 (The Wind Power, 2013).

Currently, the largest shares in wind energy production in worldwide is found in China installed wind capacity of 342GW, US installed wind capacity of 139GW, Germany installed wind capacity of 64GW (The Wind Power, 2021) and in Africa a is held by Egypt and Morocco where most wind power installations are located with total capacities of 550 Mega Watt (MW) and 1300 MW, respectively, by the end of 2012 (Global Wind Energy Council, 2011).

Wind speed generally decreases as one move from higher latitudes towards the equator. However, local effects like presence of geographic structures such as mountains, valleys and coastal areas might significantly enhance wind speed. As Ethiopia is located close to the equator, there might be a limited wind resource potential. But, the topography has a positive effect for having a good potential on this energy source. capacity increased from 24 Giga Watt (GW) to 237 GW. According to the Ethiopian Rural Energy Development and Promotion Center's 2007 report (the wind areas in Ethiopia located at the escarpment of the main East African Rift, the northeastern escarpment of the country near Tigray Regional State and the eastern part of the country.

The Ethiopian government has recently developed and executed a number of programs to encourage national economic development, most notably the "Sustainable Development and Poverty Reduction Program" (SDPRP). Even though it forms a significant part of the foundation of the national economy, the power industry can significantly advance the growth of other economic sectors through technical innovation and general improvement. Strongly advancing wind power producing projects can boost employment and national tax revenue. According to current distribution of Ethiopian wind energy resources, many future power generation projects may be arranged in some under developed regions to promote local economic development, increase power supply and change the concept of life of local people. Undoubtedly, wind power generation can effectively strengthen the resource advantage and lay a firmer practical foundation for Ethiopian power export. Many areas of Ethiopia are located in the Rift Valley as identified the high wind resource potential areas.
One of these places is the East shoa and Arsi Zone, which has a great potential for wind energy and major geological features that are advantageous for the construction of wind farms. This area attracts stakeholders for the construction of grid-based wind farms. However, choosing site for wind farm development requires more than just checking off a list of desirable features; it also involves integrating and weighing the opinions of numerous stakeholders (Lee et al., 2009; San Cristóbal, 2011). A complex process, site selection for

wind farms involves the technical, socio-economic, and environmental aspects as well as the sub factors of wind speed, lulc, elevation, slope, transmission line, road network, geology and stream. Such complexity requires the use of various decision support tools, including geospatial technologies, GIS, and multi-criteria decision analysis systems, to take into consider various influencing parameter. Geospatial technologies, remote sensing, and GIS are now acknowledged as essential tools for identifying, tracking, assessing, and mapping potential wind farm sites. To choose the ideal location for a wind farm site, numerous geographical data layers and associated variables are used (Fernando et al., 2015).

This study's primary goal is to use geospatial technologies to select suitable site for wind farm development in the Some Part of East Shoa and Arsi Zone. As a result, IDRISI, (GIS) will be used for this study. The considerations were given weight using the Analytical Hierarchy Process (AHP) Weighted overlay and Weighed Linear Combination (WLC), which helped determine the best locations for wind farms in the Some part of East Shoa and Arsi Zone.

1.2. Statement of problem

In this age, we are so heavily dependent on power for industry, agriculture, and in almost every aspect of our daily life and work, that the level of a country's energy consumption is now commonly accepted as a measure of its prosperity or its degree of development. Electricity plays an ever-increasing role in the provision of much needed power, and widespread interest is taken in all the possible sources of energy from which it can be generated (Eyaye,2009).

In recent years, reservoirs cannot normally store water and generate power at full load, due to global warming and frequent appearance of extreme drought. This seriously affects Ethiopian Energy Supply such as power shortage at many places as the energy source of the nation is dominated by hydropower. This issue mainly affects the social and economic development of the country. On the other hand, wind energy resources are not seasonal, which is also constantly available during the dry season, unlike hydropower resources (Ethiopian Electric Power Corporation, 2006). The government of Ethiopia with the collaboration of Chinese Government has prepared solar and wind master plan for Ethiopia in 2012. These encompass a capacity of 1350GW energy from wind farm and out of this, only 171MW is so far produced. However, this wind master plan does not include the specific potential area in the selected sites. Lack of proper site selection and planning and lack of attention to renewable energy used was happened.

Due to the lack of energy resources, special regard to environmental protection and the need of national energy supply security, wind energy, clean and renewable, now receives increasing popularity all over the world (Zeng Xuelan, 2006). The seeming intermittency of winds and the challenge of finding good wind locations, particularly in developing nations, are the two major barriers to the widespread use of wind power. The first difficulty can be reduced by connecting several wind farms. Such a strategy can significantly reduce wind power intermittency by nearly avoiding low wind speed situations (Mentis, 2013).

Selecting the most appropriate wind farm development is useful to reduce, construction costs, and the environmental impact of the energy on the surroundings. Wind farm development Site selection through the use of remote sensing and GIS geoprocessing, geospatial technology, although a traditional approach of aerial photo interpretation is used, has not been a common practice in Ethiopia. The reason being an insufficient appreciation of the technique as it is relatively new and recently introduced technology in the country and a lack of skilled professionals in the discipline. A 'Wind Farm' is created by a number of large wind turbines, which help to generate wind power. However, construction of wind turbine is greatly affected by location of a site, which can be carried out by multiple site selection criteria. Therefore, site selection for large wind farm requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area for a defined land use (Bennui et al., 2007).

There are several studies performed recently about site suitability analysis for wind farm development at national and international level. Almost all of the researchers did not evaluate wind speed and its direction data, land use land cover, and soil types before select study area for their study. they did not evaluate the suitability of proposed wind farm site to validate its suitability and status. All of them used land sat image for image processing and unsupervised classification for lulc. Almost all of the previous studies did not validate the suitability index of their analysis by comparing with proposed site of their study areas which would have prepared by authorized body for area spatial development and regulation.

Wind farm site selection should be based on long term requirements. This requires reliable and up-to-date database about the natural resources and their distribution over space. With the conventional methods, data obtained are often time consuming and less accessible. Although Ethiopia has potential of wind producing energy power, the tools and methods that have been applied to select the potential areas to install the wind turbines were time consuming and not appropriate (Ebisa,2016). Generally, in this study based on the indicated drawbacks, socio-economic, environmental and technical parameters were deemed and the Analytical Hierarchy Process (AHP) was applied to weigh the criteria as a technique select wind farm. Additionally, GIS, RS and Google Earth technologies were used in order to investigate the potential area of wind farm in Ethiopia in general and particularly for the study area.

1.3. Objective of the study

1.3.1. General Objective

The main objective of this study is to analyze potential sites for wind farm development Some Part of East Shoa and Arsi Zone using Geospatial technologies.

1.3.2. Specific Objective

Specific objectives of this study are:

- ✓ To identify the main factors for site suitability, analyse for wind farm development.
- ✓ To detect suitable site for wind farm by using analytical hierarchy process (AHP) based multi criteria analysis (MCA) methods.
- ✓ To determine optimal Site for wind farm development.

1.4. Research Questions

- ✓ What are the main factors for wind farm development suitability site selection?
- ✓ How do analytical hierarchy process (AHP) based multi criteria analysis (MCA) methods helps to detect site suitability?
- ✓ Which site is the optimal Site for wind farm development in study area?

1.5. Significance of study

Study of suitability analysis is important for country and regional planners and decision makers to assess suitable site for wind farm development by considering various factors.

The significance of the study could be;

- ✓ For researchers, who are doing about wind farm by providing insights on the major factors that affect the wind farm suitable site.
- ✓ It could be used as an input for government, for policy makers for their decision making processes related to selecting potential sites for wind farm.

- ✓ It is also predicted that the method can be applied to other areas for identifying potential wind farm areas with only minor adjustments.
- ✓ It could serve as a starting point for those who want to invest in renewable energy sources.
- ✓ The study also evaluated the suitability of the proposed wind farm site use plan comparing with the final suitability map and the result showed that the proposed wind farm areas were classified into different suitability levels.

1.6. Scope of the study

This study is geographically limited in the Oromia Regional State, Some Part of East Shoa and Arsi Zone Ethiopia. The content scope of this study was selecting the optimal site for wind farm development using geospatial technologies. While thematically, relevant related kinds of literature, reports, and site selection policies have been reviewed to acquire background information, strong theoretical bases, selection of appropriate methodology, identification of gaps in the literature, and to compare the findings in the existing body of knowledge. The GIS tools are used to analysis, and mapping of thematic layers for factor affect the wind farm. MCA and AHP spatial multi-criteria analysis are used to derive weight for the factor and compare the defined wind farm and select the optimal suitability analysis for wind farm development. Weight was developed for criteria based on the AHP-GIS-MCDM. Generally, wind farm site suitability index system, determination of criteria for land-use suitability analysis, geospatial technologies in site suitability analysis, multi criteria evaluation, analytical hierarchy process, weighted overlay analysis, and Weighted linear combination algorithm in Idrisi selva software.

1.7. Limitation of the Study

This study aimed, that analyzing site suitability analysis for wind farm development areas. However, the researcher has been met different obstructing problems that faced when collecting data and visiting sites. The other limitation was due to the availability of data, Absence of accurate population data at kebele level for research works, Absence of accurate rainfall and temperature data for research works and Lack of clear, standards for factors affecting the suitable site selection for wind farm development at the national level. However, this limitation did not affect the result.

1.8. Organization of the Thesis

This thesis is organized into five chapters. The first chapter is the introduction part, which includes background of the study, statement of the problem, objectives of the study, research questions, significance of the study, scope of the study, limitations and Organization of the study. The second chapter is Reviews literature terminologies and technical problem solving methods from the literatures. Primary wind farm site selection related literatures that describe efforts on wind farm at a global, continental, country and local contexts and participatory organizations. Both theoretical and empirical concepts of optimum location analysis are explained in detail. The third chapter gives a description of the study area, materials and software used, data types and data source, data process, data analysis and methodology of the study. The fourth chapter describes about data analysis, results and discussion of the study. The final part presents the conclusion and recommendations.

CHAPTER TWO: LITERATURE REVIEW

2.1. Concepts of Wind Farm

While wind farm A wind farm, also known as a wind park, is a collection of wind turbines that functions and is connected to the electrical grid as a single power plant that produces electricity. A wind farm is often expected to include more than three wind turbines. Modern wind farms can be constructed both on land and offshore and have capacity in the hundreds of megawatts (MW). In contrast to the early use of wind energy for electricity production, where wind turbines were separately connected to the low-voltage to medium-voltage distribution system, modern wind farms are often connected to the high voltage transmission system. As a result, modern wind farms are seen as power plants with control, stability, and power balance duties. Thus, wind farms are required to contribute to the control of voltage, frequency and reactive power needs in the power system and stay on-line during less critical grid faults, and to help maintain the stability of the power system.

production cannot exceed the power given by the instantaneous wind resource, capabilities for regulating the power output at time scales consistent with the power system needs, powering up and down, are also included in order to assist with balancing and stabilizing the power system. The majority of the additional technical problems with wind farms are related to the near proximity of numerous turbines. The close spacing suggests that wind turbines upwind will experience reduced wind speed and more turbulence as a result of energy extraction, which could result in lower efficiency and higher loads on downwind turbines. The connection into the electricity system and connection to the grid are additional technical issues for large wind farms. Large wind farms are highly visible, especially on the ground and along the coast, and this, along with a number of environmental reason to worry, like the potential to disturb migrating birds, is a major factor in wind farm planning and can lead to the selection of locations with much less wind conditions. However, the economic feasibility of any wind project depends on favorable wind conditions, and technologies for accurately predicting wind conditions at specific locations across the world are constantly being improved. (Robert,2011).

Figure 2.1: Wind Farm (Robert,2011)

2.1.2. Source and Types of Energy

Energy sources are available both renewable and non-renewable categories. sources of energy that are mostly based on biomass and are inexhaustible in nature. Fuel wood, petrochemical facilities, agricultural waste like biogas, animal dung, wind, water, tidal, geothermal, and solar energy are a few examples of such energy sources. Non-renewable energy sources include nuclear power, coal, natural gas, and other sources including petroleum (EPA, 2003). The amount of nonrenewable or exhaustible energy sources is limited, because of their long development times and continuous consumption, they are likely to run out at a certain time (Aklilu,2005).

2.2. Overview of Energy Sources and Situation in Ethiopia

Ethiopia uses about 40,000 GWh of energy in overall every year, 92% of which is used by domestic appliances, 4% by the transportation sector, and 3% by industry. Bioenergy, which usually comes from non-sustainable sources for domestic use, thus forms a major part of the energy supply. Hydro energy accounts for 96% of the electricity produced each year, followed by wind energy (4%), 11% of which is exported. The majority of the energy used for transportation, in contrast, is imported in the form of petroleum. Ethiopia is fortunate with availability to renewable energy. These mainly consist of hydro, but also include wind, geothermal, solar, and biomass.

Hydropower: Ethiopia has the second-highest hydropower potential in Africa, with a capacity of up to 45,000 MW (only DRCongo has a higher potential). It is predicted that 30,000 MW, or the production of 162 TWh of power, is economically possible. Thus, the

3.98 TWh of current production represents only a 2.5% exploitation. The terrain in Ethiopia is largely positive for hydropower projects.

Ethiopia is considered to as the "Water Tower of Eastern Africa" due to its ten river basins, among which the Blue Nile, Omo, Wabi Shebelle, and Genale-Dawa are international rivers. Hundreds of streams additionally flow into the major rivers, cutting through the mountainous terrain in all directions. Given that Ethiopia alone accounts for around 86% of the waters in the Blue Nile, this is hardly an exaggeration. Additionally, research by the Ministry of Water Resources (MOWR) estimated that the annual run-off from the principal river basins is in the range of 122 billion cubic meters.

Besides, the mountainous landscape in the western half and some southern parts of the country makes many of the nation's hydro resources suitable for hydro-electricity generation of varying sizes, i.e., ranging from Pico hydro to small and large hydropower plants. Small-scale hydro schemes are particularly suitable in remote areas, which are not connected to the national grid. The total theoretical potential for micro hydropower schemes is 100 MW. The largest project in the pipeline is the controversial dam and hydropower plant Gilgel Gibe III (MW 1870), which recently came close to financial closure with an agreement between Ethiopia and China. Another big hydro project is the renaissance Dam, formerly known as Great Millennium Dam. This Hydro project shall have a maximum capacity of 5.25 GW, starting with 700 MW in 2015.

Solar Energy: Ethiopia has a high potential for the use of solar energy due to its sun irradiation, which ranges from 5000 to 7000 Wh/m2 depending on the area and season. Around 5.2 kWh/m2/day of solar radiation is relatively uniform. Seasonal changes in the values range from 4.55 to 5.55 kWh/m2/day, while the northern part of Ethiopia is still in its development, with values in the range from 4.25 kWh/m2/day in the extreme western lowlands to 6.25 kWh/m2/day in the Adigrat area.

Biomass: Biomass resources include wood, agro-industrial residue, municipal waste and bio fuels. Wood and agricultural as well as livestock residue are used beyond sustainable yield with negative environmental impacts. According to estimates made by a recent study, at the national level, there appears to be a surplus of woody biomass supply. However, the same study revealed that there is a severe deficit of supply when the data is disaggregated to lower local levels. According to this same study, 307 Woredas (districts) out of the total number of 500 Woredas are consuming woody biomass in excess of sustainable yield (Wikipedia and Asress ,2013).

Wind Energy: Wind resources are good in Ethiopia, with speeds ranging from 7 to 9 m/s. Its 10,000 MW wind energy potential is estimated. In 1971, the Ethiopian National Meteorological Services Agency (NMSA) began work on wind data collection about 39 recording stations location placed. Since these stations were established, wind velocity has been measured and data has been made available to users. However, there is great room for improvement regarding the quantity of stations established, the quality of the data (in terms of comprehensiveness), and the distribution of the stations.

Geothermal Energy: There are estimated to be 5 GW worth of geothermal resources in Ethiopia, of which 700 MW could be used to generate power. The Rift Valley area is geothermal resources are primarily found, where temperatures of 50 to 300 °C are common at depths of 1,300 to 2,500 m. The only 7.3 MW geothermal power plant that has been operational so far was shut down in 2002 due to a lack of technical maintenance; it had been operational from 1998 to 1999. Operation was resumed, but only at a significantly lower generation rate. Geothermal resources are still being explored(Wikipedia). Approximately 90% of the installed generation capacity is from hydropower, while the remaining 8% and 2% is from wind and thermal sources, respectively.

Table 2.1: Energy Resource Potential of Ethiopia

Resource	Unit	Exploitable Reserve	Exploited Percent
Resource	MW	45,000	<5%
Solar/day	kWh/m2	4 – 6	<1%
Wind: **Power Speed**	GW m/s	100 >7	<1%
Geothermal	MW	<10,000	<1%
Wood	Million tons	1120	50%
Agricultural waste	Million tons	15-20	30%
Natural Gas	Billion m3	113	0%
Coal	Million tons	300	0%
Oil shale	Million tons	253	0%

Source: Ethiopian Electrical Power

2.2.1. Wind Energy Resource Potential in Ethiopia

When compared to hydropower, wind power deployment in Africa has been rather limited, with only about 5.5 GW of installed capacity. The estimated 1300 GW wind potential in

Sub-Saharan Africa could produce several times the continent's current level of energy consumption. The primary energy sources of Ethiopia are biomass, hydropower, and fossil fuels (especially natural gas and coal). The country also has accessibility to geothermal energy and other clean energy sources including wind and solar.

According to the Ethiopian Rural Energy Development and Promotion Center (2007), Ethiopia has a few promising windy areas along the main East African Rift Valley, in the country's northern and eastern escarpment near the Tigray regional state, in the southern part of the country near the Kenyan border, and in the central and eastern parts of Ethiopia, particularly in the south-eastern part of the Somalia region. Highlands with a sharp elevation change from the surrounding land masses are where areas with moderate to high wind resources are most often found. These areas are primarily the Great Rift Valley escarpments that extend to the southern, eastern, north eastern, and central highlands of the country. The country's overall exploitable wind energy potential was estimated to be around 1,350 GW by the Ethiopia Electric Power Report. However, despite the tremendous potential of this energy system, Ethiopian wind farm development is still in its early stages. For grid-based energy generation, wind regions with a wind density of 300 W/m2 and a wind speed of 6.5 m/s or more are suitable for technical and financial reasons.

Ayisha in the eastern part of the country has good potential with an average wind speed exceeding 8 m/s. Currently, Ashegoda, Adama I and Adama II wind farms have been completed and connected to the grid with 324 MW total installed capacities.
The table below lists Ethiopia's current and upcoming wind energy generating stations along with their capacity to generate electricity. Due to the natural cycle of high wind energy availability in the dry season when hydropower reservoirs are low in water and it decreasing in the wet seasons when the reservoirs are rapidly filling with water, wind power will play an essential complementary role with hydroelectric power in the Ethiopian power system. This will increase system reliability including during dry seasons, providing wind power an essential component of the grid's energy mix. Although the government of Ethiopia should design off-grid and micro grid wind farms to reach remote rural areas as well as for the village level rural electrification, it is also preferable if introduced to introduce micro grid wind and solar hybrid systems with the subsidized rate (EEP,2003).

Table 2.2: Existing and Upcoming Wind Farm Power Plants (WPP) With Their Capacity

No.	Project	Generating capacity (MW)	Annual Energy production (GWh)
	Connected to grid		
1	Adama I WPP	51	157
2	Adama II WPP	153	479
3	Ashegoda WPP	120	450
	Total	324	1,086
	Upcoming project		
4	Ayisha WPP	300	592
5	Messobo WPP	42	104
6	Assela WPP	100	197
7	Debre Birhan WPP	100	197
	Grand Total	866	2,176

Sources (EEP)

2.2.2. Energy Transmission and Advantages of Wind Farm Energy Over Other in Case Cost, Simplest, Fastest and Economic in Ethiopia

The mechanical energy of the wind is converted into electrical energy by a wind farm. The kinetic energy of a fluid flows this case; air is transformed into rotary motion by a turbine. A wind turbine's blades move or rotate when the wind blows past them. They operate a generator. The uneven heating of Earth's atmosphere by solar radiation, variations in topography, and the rotation of the Earth combine to form wind energy, an indirect source of solar energy. (Ebisa,2016).

Electrical energy is transmitted in large quantities from a generating location, such a power plant, to an electrical substation. The system of interconnecting lines which facilitate this movement possible is known to as a transmission network. This is distinct from local wiring, often known as electric power distribution, that connects high-voltage substations to customers. The combined transmission and distribution network is a component of the electrical grid, which is used to transmit power. Furthermore, in the world that has become increasingly concerned about climate change caused by the increase of carbon dioxide (CO_2) emissions from burning fossil fuels, a particular emphasis has been placed on renewable sources. Developers are more receptive to renewable energy projects, particularly wind energy, as a result of the worldwide movement toward cleaner, greener electricity and to lower the cost of electricity. In addition to hydropower, modern grid-connected wind turbines are a potential technology because of the excellent correlation between the availability of wind resources and hydrology (EREDPC, 2003). Wind farm energy is having many advantages as economically, wind is an un expensive source of electric power, cheaper than coal plants and new gas plants. wind energy alleviates the price uncertainty that fuel costs add to conventional energy sources (Ebisa, 2016).

One of the biggest benefits is it global availability, as wind comes potentially everywhere around the world. The second benefit is that the cost of producing and implementing wind energy is really cheap. For instance, wind energy has an advantage over biomass energy in that it requires less agricultural area, which could be used to address other major global problems like the production for crop production. Some advantages of wind energy;

- ✓ Excellent conversion efficiency
- ✓ Wind power occupies very little land
- ✓ A green source that is truly economical
- ✓ Maintenance is simple and only occasionally necessary
- ✓ It’s a Clean Fuel Source
- ✓ It’s Sustainable
- ✓ Wind Energy Offers Employment
- ✓ Wind is a domestic source of energy

2.3. Wind farm Site Selection

For grid-based systems, wind energy generation mostly refers to wind farms. Although tall, turbines are also fairly slim. Generally, the base of each tower is just 8 meters wide, and the distance between each turbine is 250 meters. There is a lot of room between each tall, thin tower because rows of turbines are separated half a kilometer apart. Wind speed has a significant impact on how much energy is generated first by wind.

When selecting a site for a large wind turbine, it is important to weigh a variety of goals and take into consideration a wide range of variables to determine whether the area is suitable for a given land use. When choosing a site for a large wind turbine, it is important to weigh a variety of objectives and take into consideration a wide range of variables to assess whether the area is suitable for a given land use. The choice of appropriate project locations encompasses a wide range of crucial elements drawn from the technical, socioeconomic, and environmental factors. Identification of locations for wind energy generation depends on several factors besides the speed of the wind. To list some, proximity to electric transmission line, exclusion of restricted areas such as national parks and visual impacts on areas of outstanding beauty are some of the factors. The size of individual wind generators that are usually considered for medium to large size wind farms have rated power outputs that range from few hundred kilo watts to megawatts. Optimal size of each individual turbine is determined according to factors such as access road, crane capacity, and land use.

Factors responsible for wind farm site selection are wind speed, distance from main roads, the nature of the ground itself, distance from electricity supply line with the explanation of Alpine Wind Harvest Partnership (2005) the required and recommended parameters are: wind speed, Slope, forests, settlement areas, access to roads, landscape, protection areas, and electricity grid and soil stability. Hansen (2006) also lists the following factors when choosing a location for a wind farm: distance from settlements, lakes, roads, power lines, airports, and churches; and wind speed. Some locations need to be in an area with specific geographic requirements and in a healthy environment. Several standards will be established in light of the facility's goals. Also the stakeholders have a point of view that recommends some criteria to be used in the location selection evaluation process.

Site selection is a method for determining the suitability of a piece of land for a certain use. It also determines the best spatial structure for potential future land uses in accordance with the criteria, preferences, or predictions of a particular activity (Collins, Steiner, & Rushman, 2001). Selection of appropriate location was deepened with different measures such as on the local conditions of its surrounding environment. The incoming radiation which reach on the ground as well as the absorbed and scattered radiation can be affected by the atmospheric particles (Hofierka & Cebecauer, 2008). Actors that need to be taken into consideration (Conover, 2000, Eyaya ,2009).

2.4. Role of Geospatial Technology for Wind Farm Development Site Selection

2.4.1. Geospatial Technologies (GST)

Geospatial Technologies is a term used to describe the range of tools contributing to the geographic mapping, analysis of the Earth and human societies. It is a new area of study that combines the Global Positioning System (GPS), Remote Sensing (RS), and Geographic Information Systems (GIS) (GPS). Data that is referenced to the earth uses and used for analysis, modeling, simulations, and visualization by to geospatial technology.

Because most resources are restricted in nature, geospatial technology enables us to make well-informed decisions based on the significance and priority of those resources. Intelligent maps and models that can be interactively queried to provide the necessary outcomes in other technologies can be made using geospatial technology. Technology is involved in the gathering or processing of location-specific data. Due to the operational needs of their usefulness, these specialist information systems should adopt standardized modern technical and technological solutions. Modern geoformation benefits from an integrated strategy using geospatial technologies including GPS data, remote sensing imaging, aerial photography, Google Earth, and GIS.

Remote Sensing: Remote sensing is the process of identifying and keeping track of an area's physical characteristics by measuring the radiation that is reflected and emitted there from a distance (typically from satellite or aircraft). Remotely sensed images are captured by specialized cameras and provide researchers up to date and historical topographic information.

Geographic Information Systems (GIS): is a system made to collect, store, manage, analyze, evaluate, organize, and show different types of geographic data. It can be used as a tool for data visualization in a spatial environment as well as for problem solving and decision making processes. Geographic Information Systems may be examined to determine;

The location of features and relationships to other features.

- ✓ Where the most and/or least of some feature exists.
- ✓ The density of features in a given space.
- ✓ What is happening inside an area of interest (AOI).
- ✓ What is happening nearby some feature or phenomenon.
- ✓ How a specific area has changed over time (and in what way)?

Global Positioning System (GPS): A GPS is the device, which provides information on the geographic coordinates, altitude, time, direction of movement, the distance covered. Navigational System with Time and Ranging is another name for the Global Positioning System (NAVSTAR). A GPS is consisting of users who use specialized GPS receivers to receive a variety of data, a constellation of radio-navigational satellites, a ground control component that oversees satellite functioning, and the GPS system itself. The system was created by the American Department of Defense (DoD) primarily to meet defense requirements, with a secondary goal of serving the general public. A satellite navigation system called GPS is used to locate an object on the ground.

Internet Mapping Technologies: The way geographical data is viewed and distributed is changing because to software like Google Earth and web capabilities like Microsoft Virtual Earth. A wider audience can now access these technologies thanks to improvements in user interfaces, whereas traditional GIS was previously only available to specialists and those with the time to devote to mastering difficult software. So, for accurate findings, employing integrated geospatial tools is preferable. Last but not least, geospatial technologies like Google Earth, Remote Sensing (RS), and Geographic Information Systems (GIS) are becoming into primary tools for solving a variety of geoformation-related challenges.

Geographic information systems link various types of spatial data and their characteristics for usage in various areas of geoformation-related projects, and remote sensing observations (RS) give data on Earth resources in spatial form. The global positioning system and google earth are also important factors in site selection. Google Earth is used as a resource for many types of remote sensing data, as well as three-dimensional representation of modeled wind farm and visual tools for LULC classification.

GPS uses for ground point collection for verification and georeferencing of a different map for wind farm selection. Therefore, this study used the geospatial tools for wind farm site selection in which DEM, geological map, soil, and wind speed, are parameters used for wind farm selection. Since Geospatial technology consists of tools and applications easily handle and analyze such kinds of data easily.

2.5. Application of GIS for Wind Farm Development Site Selection

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, meteorological stations, and the wind resource distribution. 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.

2.6. Application of Remote Sensing (RS) for Site Suitability Analysis

Remote sensing is the capability to gather information without being in direct contact with it (Lillesand et al., 2014). The modern use of the term remote sensing has more to do with technical ways of collecting airborne and space born information. The earth observation from airborne platforms has 150 year of history, although the majority of the innovation and development has taken place in the recent decade's years (Zubair, 2006). According to (Lillesand et al., 2014), the first earth observation using balloons in the 1860s were regarded as an important benchmark in the history of remote sensing. Satellite based remote sensing provides valuable information that can be used in the assessment of the various aspect of atmospheric environment, climatology, meteorology, ecology, agronomy and environmental protection (Kern, 2011).

The essence of remote sensing is measuring and recording of the electromagnetic radiation emitted or reflected from the earth's surface (Hardegree,2006). Remote sensing is one of the incomparable tools for sensing the earth surface to make the interface of object property and measurement analysis as well as inventory of environment and its resources, and has a unique ability of providing the synoptically view of a large area with the capacity of repetitive coverage. One of the most applications of remote sensing in Site suitability analysis for wind farm is where remote sensing data like satellite images are used for extracting wind farm criteria (example; land use land cover and surface water) with saving time and cost.

2.7. Multi-Criteria Decision Analysis (MCDA) for Wind Farm Site Selection

A complex decision-making problem, finding suitable locations for wind farms includes a variety of factors involving several, sometimes conflicting, criteria and numerous goals. The essential idea being that a number of relevant criteria must be identified and assessed in terms of weight, with respect to the influence the criteria have on the final decision. In spatial analysis, this is often accomplished by creating a suitability map that is composed of several layers, each layer representing one of the criteria. The criteria are given a weighted suitability score, and these scores are represented as different classes or categories, which are then symbolized on the map layer showing the suitable areas for that criteria. The layers are then overlaid on the map to present a final site suitability map, from which the user can then identify optimal areas and continue with a more detailed investigation of those sites.

In recent years, the integration of MCDA techniques with GIS has considerably advanced to evaluation/selection the optimum alternative. GIS-MCDA is a process of decision making at which geographic data value judgments are brought together to obtain more information for the decision makers. To combine MCDA and GIS each of the criteria should be represented as a map in the GIS database. In GIS technology, usually the alternatives are a collection of point, line and area objects, attached to which are criteria values (criteria map). GIS can recognize, correlate and analyze the spatial relationship between mapped phenomena, thereby enabling policy makers to link disparate sources of information, perform sophisticated analysis, visualize trends, project outcomes and strategize long-term planning goals. (Mehdi and Hajizade,2014).

2.8. Analytical Hierarchy Process for Wind Farm Suitability Site Selection

AHP, which was proposed by Saaty (1980) is a structured technique for decision making based on a hierarchical framework constructed through mathematical pairwise comparisons. The weights for the decision making criteria are derived from the pairwise comparisons of the relative importance between each two criteria (the sum of the weights equals to 1). The reciprocals of the numbers are adopted to represent the inverse relationship (Mohammad et al., 2009). In a parallel way, AHP has integrated with GIS for land suitability modeling (Malczewski, 2006). AHP helps to capture a mutually subjective and objective aspect of the decision and also for checking the consistency of the decision maker's evaluations, consequently reducing the bias in the decision-making method (Saaty, 1980; Malczewski, 2006).

2.9. Pairwise comparisons method

In the context of the Analytical Hierarchy Process, Saaty (1980) created the pairwise comparisons approach (AHP). To generate a ratio matrix using this technique, pairwise comparisons are made. It takes the pairwise comparisons of the parameters as input and outputs the relative weights of the parameters. To summarize, many ways of allocating weight to criteria have been presented and discussed earlier. However, as a method, their accuracy and dependability are also very diverse. Furthermore, the three techniques have different underlying scales. They range from ordinal (weighting by ranking) to interval (weighting by rating), to ratio scale (pairwise comparison). While the first two methods lack a theoretical foundation, the last one can be quantitatively validated. Wrong weights lead to incorrect suitability analysis conclusions and, as a result, incorrect judgments (Flitter et al., 2013).

Generally, the focus of this study is to selection land use suitability in order to make the best possible wind farm sites decision. Based on the above-mentioned strength toward weighting, weight by pairwise comparison was used to assess the relative importance of the criterion.

Table 2.3: Scale for Pairwise Comparisons (Saaty & Vargas, 1991)

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

The consistency level of the comparison matrix can be computed considering its maximum eigenvalue, namely λmax. Since λmax is substituted for the order of the matrix(n), its difference from n is used to compute the Consistency Index (CI) and the closer to n, the more consistent the judgments.

$$\mathbf{CI} = \frac{\boldsymbol{\lambda}\mathbf{max - n.}}{\mathbf{n - 1}} \text{...Equation(2.1)}$$

Values for RI are as presented in Table 2.3 where the order of a matrix increases to more than three; their consistency issue arises and increases exponentially number of the criteria and alter-natives grows. If CR is more than 0.1, the user is blamed for providing inconsistent comparisons and the tables are returned to them for improvement.

2.10. Criteria for Suitability Site Analysis for Wind Farm Development

The key to a successful examination of site suitability is select the correct criteria (Chakma, 2014). The chosen land use's site selection and the choice of the geographic location are both strongly influenced by criteria. The framework of the APH method was developed using significant criteria that have frequently been used to determine the best site. The most important criteria used for suitability evaluation are the following groups: the first group includes environmental criteria that restrict the analysis to a specific geographic area; the second group includes socio-economic factors; and the third group includes technical factors. On the other hand, selecting criteria may depend on other factors that influence the selection process, i.e. The examined criteria were selected based on the relevant international literatures. Sub-materials criteria like: wind speed, slope, Elevation, LULC, Distance from transmission line, Geology, Stream, Distance from road.

2.11. Review of empirical studies

There are several studies attempts to analysis wind farm development on different period of time as internationally and national began decades ago. Some of them are reviewed as the following:

Dereje Amakelew (2016) conducted research on Wind Farm Site Selection using Multi criteria GIS Modelling: He has used some criteria such as: Wind speed and wind density, Water bodies, Slope, Elevation, Engineering Geology, Distance from the main road, Distance to transmission line, Land use/land cover for Wind Farm Site Selection of the study area by "aiming to provide estimates of the theoretical, geographical, Economic potential and technical Wind Farm Site Selection in Debre Brehan Zuria Wereda , to indicate to identify and map the most suitable wind farm using Multi criteria modelling. He used software and Methods like IDRISI, ArcGIS and the Method of Data Analysis were GIS based multi criteria spatial analysis techniques and AHP approach has been used to address the proposed study. 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.

Eyaya Belay, (2009): He studied how remote sensing and GIS may be used to model the suitability of a site for a wind farm in the case of Adama woreda. He tried to identify and characterize using remote sensing and GIS techniques the most suitable site for establishing wind farm turbines in the research area by using some criteria, such as Wind Speed, Geology, Land Use, Road, Transmission Line, Slope, Distance from Towns, Land Use/ Land Cover. He used methods and tools such as ERDAS IMAGINE 9.1, ArcGIS 9.2, WINDPLOT, IDRISI 15, and weight overlay analysis for data analysis.

Mentis. D (2013), he 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.

Adam & Ruopu (2014) was conducted "A Geospatial Approach for Prioritizing Wind Farm Development in Northeast Nebraska, USA". The sites in the research area that are most suitable for wind energy development were identified using a GIS-based multi-criteria method. This method adopted seven criteria, including proximity to roadways, population density, wind potential, land use, distance to cities, slope, and exclusionary areas. A weighted overlay of geospatial layers corresponding to these criteria was used to model the suitability of wind farm development. 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.

Arun K. (2017), conducted research on Geospatial approach for wind farm site selection – A Kerala Scenario: They have used some criteria such as: Slope, Distance from Roads, Landform, Distance from Urban areas, Distance from Water spread, Distance from urban areas, Distance from archeological sites, Distance from Forest Area. They used software like ArcGIS, they used method analysis like the index was derived as a product of the weight and rank (Index= Weight × Rank) By overlaying index map layers using the Raster Calculator tool, the site suitability for wind farms is found out. The site suitability map was validated by overlaying most suitable sites which were identified by ANERT on to the final map.

Adegbite et al (2020), they conducted research on Spatial framework for site suitability for establishing wind power station in Ibadan city, Nigeria. They used some criteria These criteria included road network, rail network, high speed rail link, settlement, transmission lines, power substations, slope and wind farm. To determine the best location for a wind farm, GIS layers were constructed, and a weighted overlay GIS model was constructed using the selected criteria. Any other spatial location can be successfully updated and used with the proposed GIS-based multi-criteria spatial analysis of a suitable site. They used pairwise comparison analysis with method analysis overlay.

2.12. Image Preprocessing

Generally, a remote sensing images is not used directly in raw from due to the presence of certain geometric errors in it. These errors occur due to the movements of the satellite platforms that carry sensors. The image therefore may have to be geometrically rectified (registered) to exact useful information and image corrections are also known as a preprocessing of remotely sensed images. It is a preparatory phase that improves quality of images and serves as a basis for further image analysis.it is corrected by histogram equalization and haze reduction. Some image corrections are;

Histogram Equalization: Histogram Equalization is a computer image processing technique for increasing image contrast. This is obtained by successfully expanding the intensity range of the image and spreading out the most typical intensity levels. When the useful data is represented by close contrast values, this method typically enhances the overall contrast of the photos. This enables areas with less local contrast to obtain higher contrast.

Haze Reduction: It is the atmospheric effects can cause imagery to have a limited dynamic range, generally perceived as “haziness” or reduction contrast. This function sharpens the imagery using either a tasseled convolution approach.

After image correction image classification is followed. There are two types of image classification; this are supervised classification and un supervised classification and for this study is we used supervised classification.

Supervised Classification: Is predicated on the idea that a user can choose representative sample pixels from an image, instructing the image processing software to use these training sites as a guide for classifying all other pixels in the picture. The user's knowledge is taken into consideration while selecting training sites, also referred to as testing sets or input classes. The threshold for how similar other pixels must be to be grouped together is likewise determined by the user. These limits are frequently established using the training area's spectral properties plus or minus a defined increment (typically depending on the "brightness" or strength of reflection in specific spectral bands). The user can additionally choose how many classes an image will be separated into. In order to provide final output analysis and classified maps, many analysts combine supervised and unsupervised classification processes (Eyaya, 2009). Calculate the accuracy rating of image classification using the Maximum Likelihood Classification algorithm.

2.13. Weighted Overlay in Site Suitability Analysis

A set of instruments could be used in combination with the Weighted Overlay tool to complete the generic overlaying analysis stages mentioned above (ESRI, 2015). The Weighted Overlay tool weights the input roasters, adds them all together, and scales the input data on a specified scale (the default is 1 to 9). The more favorable locations for each input criterion will be re-classed to the higher values such as 9. The weights applied to the raster in the Weighted Overlay tool must equal 100%. Each cell's values are added up and weighted after layers are multiplied by the appropriate multiplier. Overlay determines these areas to be the best because it assumes that more beneficial factors produce greater values in the output raster. The weighted overlay technique combines many and different inputs into a single analysis by applying a common measurement scale of values. Models of capabilities select the optimal or preferable settings for a given phenomenon. Suitability analysis could be used to solve a variety of issues, such as:

- ✓ Where should a new wind farm development be sited?
- ✓ Where is the most likely location for economic growth?
- ✓ Which sites are appropriate for wind farms?
- ✓ Where are the areas where mud landslides are most likely to happen?

2.14. Research and Knowledge Gaps

There are several studies performed recently about site suitability analysis for wind farm development at national and international level.

All researchers did not evaluate wind speed and wind speed direction data, land use land cover, and soil types before select study area for their study. they did not evaluate the suitability of proposed wind farm site to validate its suitability and status. All of them used land sat image for image processing and unsupervised classification for lulc. In case of this study we used sentile2A and supervised classification for land use land cover classification. Analyzing site suitability for wind farm areas should be considered in a broad context, encompassing specific technical, environmental and socio-economic factors of the study area. From the literature reviews it was found that there are no uniform criteria for wind farm site suitability analysis. Researchers selected their own criteria for wind farm site suitability analysis according to their objectives, subjective judgment, and theoretical knowledge, as well as their local knowledge. However, many of the studies relied on a small amount of evaluation criteria, which reduces the ability to incorporate enough evaluation criteria to represent a wide range of human decision-making and reasoning. In criteria determination, most of previous study did not evaluate data which data available for their study for wind farm suitability site identification. Almost all of the previous studies did not validate the suitability index of their analysis by comparing with proposed site of their study areas which would have prepared by authorized body for area spatial development and regulation. From principles of site suitability analysis, the final results of suitability analysis for site should be compared with proposed land use plans, comprehensive plan, zoning or other site controls that further gives detail pictures of land use control tools and remove unavailable land. This research tried to fill this gap of knowledge by comparing the final suitability map with existing proposed site to validate its suitability. this is not experienced well before in suitability analysis of site uses for some particular purpose. Additionally, there was not conducted any study in my study area related to Site Suitability Analysis for wind farm Development Using Geospatial Technologies.

2.15. Conceptual Framework

As stated under theoretical frame work different scholars, researchers, reports, journals used different methods and different results to solve the problems for wind farm site selection analysis. Under this conceptual framework this researches brief explain how the gap that the study identified and solved, which materials and methods are used for this study. Theory comes from one of the different fields that deal with the interaction of humans with their environment (e.g., economy, sociology, political, ecology, and social psychology). Suitable site selection for wind farm process considers some parameters such as technical, environmental and socio-economic consideration. Technical consideration analysis encompasses any spatial analysis of the area like proximity to slope, elevation, wind speed. The socio-economic consideration like land use land cover, distance from water body, construction cost, noise. Environmental is an important parameter for suitability analysis such as distance from road, distance from Transimation line, existing wind farm. Wind farm is increasingly gaining attention as a source of Renewable Energy benefits.

Different authors like (Eyaya ,2009, Dereje,2016, Ebisa,2016, Bennui2007, saraswat2021, Baseer,2017 and etc, defined multi-functionality of wind farm as composite functions that include environmental, socio- economic, technical benefits. Generally, there are many determinant factors (main factors and sub factors) that affect wind farm development. Main factors are environmental, technical and socio-economical. Sub-factors include road, slope, type, stream, Transimation line LULC, wind speed, elevation, geology (soil) etc. This study used geospatial analysis tool like GIS, weight overlay analysis function to integrate the criteria. AHP spatial multi-criteria evaluation pair comparison was used to evaluate the alternative defined. The remote sensing data are used to extract different factors used for selecting suitable site for wind far development.

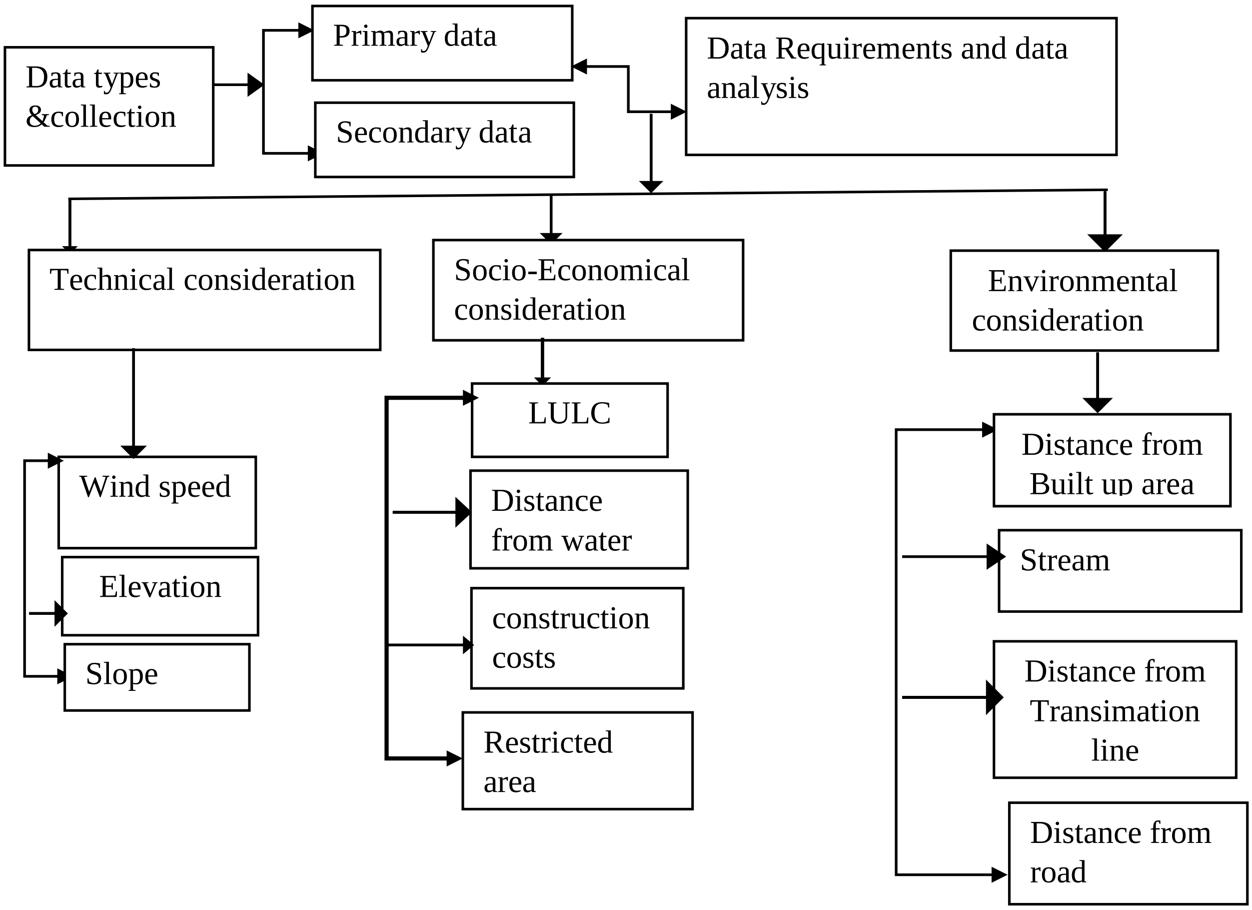


Figure2.2 Conceptual Framework Diagram from Literature and by The Author

CHAPTER THREE:MATERIALS AND METHODS

The chapter discusses the way the research is conducted from how literatures are reviewed to the final data discussion stage.

3.1. Description of Study Area

3.1.1. Location

The study area is located in the Oromia regional state in the main rift valley of Ethiopia. Its partial Dodota sire, partial Hitosa, partial Adama wereda, partial Ziwaydugda, partial Tiyo, and partial Dugdabora parts. However, Dodota, Ziwaydugda, and Hitosa account up the vast majority of the study area. Geographically, the research area is located between latitudes 39° 14′ 40″ and 38° 57′ 51″ N and longitudes 8° 18′ 31″ and 8° 1′ 52″ east. The study area covers a total of 947.089589km^2, or94708.960152 hectares.

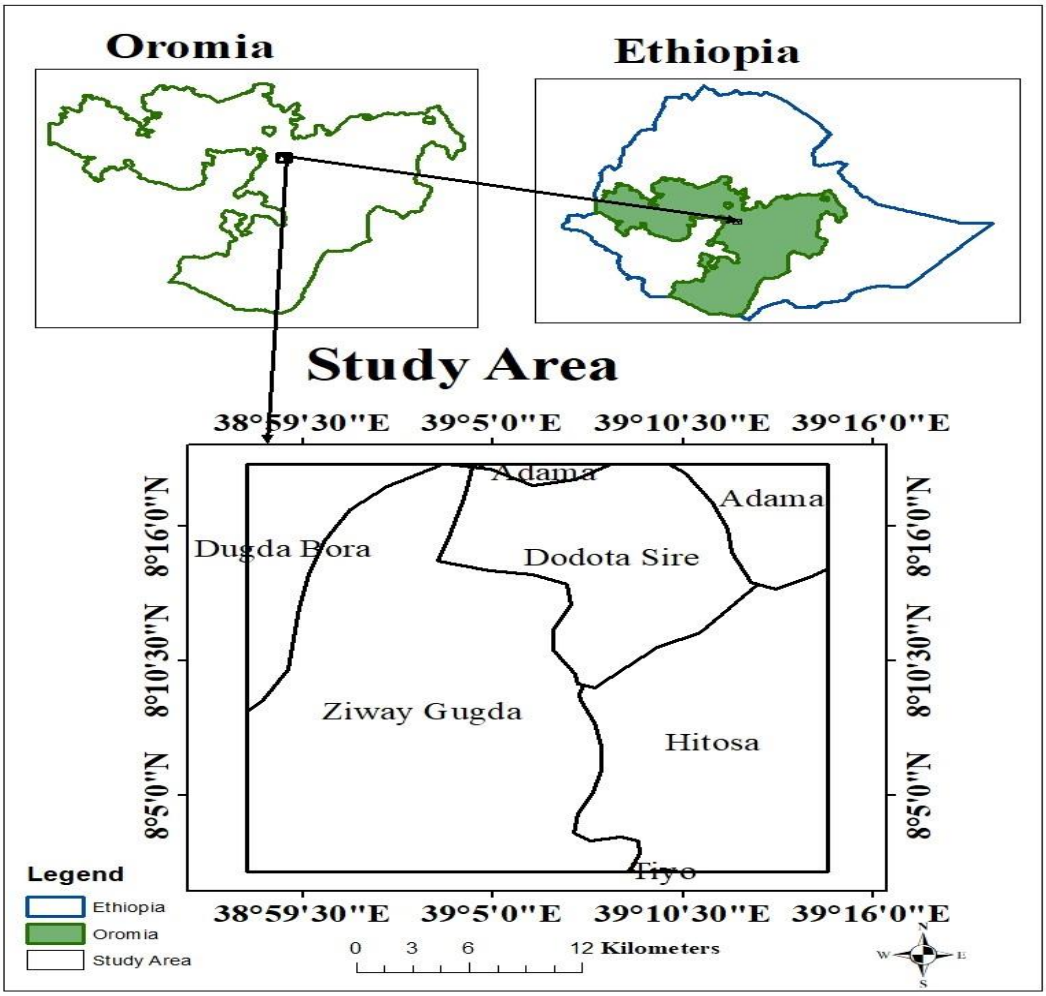


Figure 3.1: Location Map of Study Area

3.1.2. Topography

The study area is elevated on average between 1588 and 2515 meters above mean sea level. The southeast and a small portion of the northeast are where the study area's highest elevation is found.

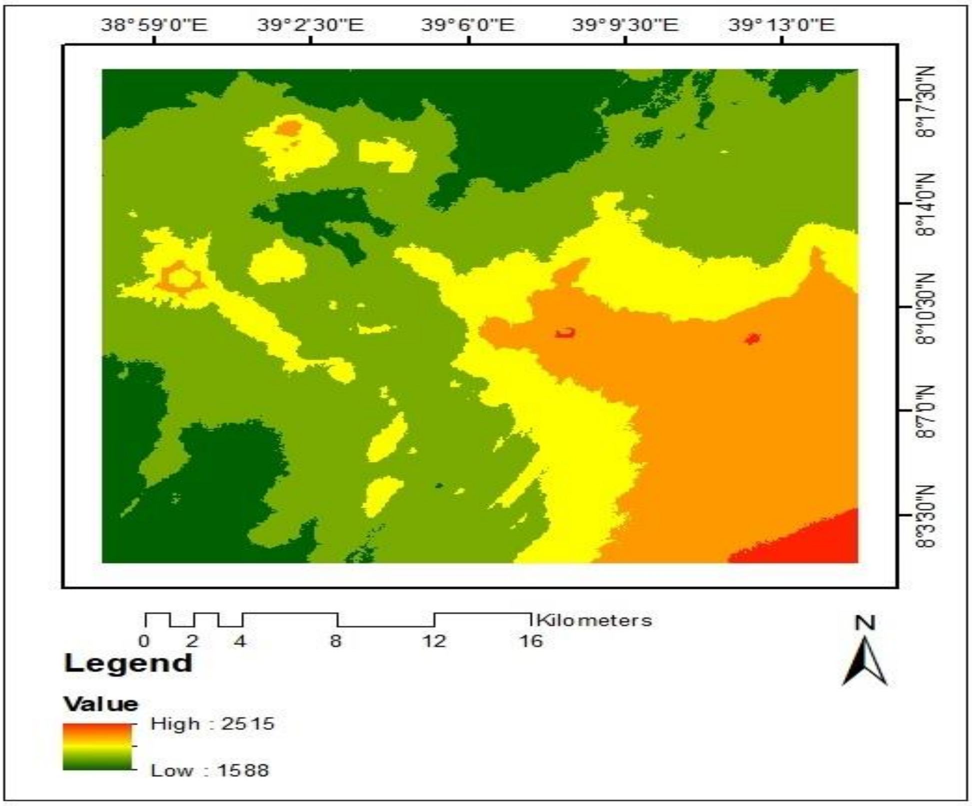


Figure 3.2: Topographic Map of Study Area

3.1.3. Demographics of Study Area

Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), The study area is located between several areas this are of partial Dodota sire, partial Hitosa, partial Adama wereda, partial Ziwaydugda, partial Tiyo and partial Dugdabora.

Dodota Sire: The Arsi Zone consists Dodota Sire, which is located in the Great Rift Valley. The former Dodota Sire woreda, which was separated into the Dodota and Sire woredas, includes this area. This woreda had a total population of 64,310 according the 2007 national census, of which 32,378 men and 31,932 women, Additionally 19,130 people, or 29.75% of its population, lived in cities.

Bora: One of the wereda of Ethiopia's Oromia Region State is called Bora. It belongs to the former wereda of Dugda Bora. It is located in the Great Rift Valley and is a part of the East Shewa Zone. Bote serves as the administrative center of Bora (AlemTena). This woreda had a total population of 58,748 according to the 2007 national census, of which 30,487 men and 28,261 women made up the population. 11,403 people, or 19.41% of its population were urban dwellers.

Tiyo: Is a woreda in Oromia Region. Tiyo, which is a part of the Arsi Zone, is surrounded by Munesa to the south, Batu Dugda to the west, Hitosa to the northeast, and Digeluna Tijo to the southeast. Asella, one of the towns in Tiyo, serves as the woreda and zone's administrative center. This woreda had a total population of 86,761 according to the 2007 national census, of which 43,463 men and 43,298 women made up the population; 6,525 people, or 7.52% of its population were urban dwellers.

Ziway Dugda: Ziway Dugda, is a part of the Arsi Zone in the Great Rift Valley, is surrounded on the south by Munesa, on the west and north by the Misraq Shewa Zone, on the east by Hitosa, and on the southeast by Tiyo. On the western edge of this woreda's territory is Lake Ziway, which it shares with the Misraw Shewa Zone. Ogolcho, one of the villages in this woreda, serves as its administrative center include Chefe Jile. According to the 2007 national census, this woreda had a total population of 120,862, 60,379 men, 60,483 women, and 4,506 (or 3.73%) urban residents.

Adama Wereda: Awash River, the only significant river in this woreda, defines the woreda boundaries on the east and south. Adama wereda is a portion of the East Shewa Zone located in the Great Rift Valley. Adama Zuria 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 Awash Melkasa, Shewa Alemtena, Sire Robi, Sodere, and Wenji Gefersa are more towns in this woreda. This woreda had a total population of 155,349 according to the 2007 national census, 79,013 men and 76,336 women; 26,322 or 16.94% of its population were urban dwellers.

Hitosa Wereda: One of the wereda's in Oromia Regional State is Hitosa Wereda. Hitosa was separated from wereda of Lude. Hitosa, which is a part of the Arsi Zone, is bounded on the east by AlemTena, the west by Batu Dugda, the northwest by the East Shewa Zone, the south by Digeluna Tijo, and the northwest by Tiyo. Iteya serves as the woreda's administrative center; other settlements include Borujawi and Ligaba. The total population of this woreda was 124,179. In accordance with the 2007 census, there were 61,734 women and 62,335 men.

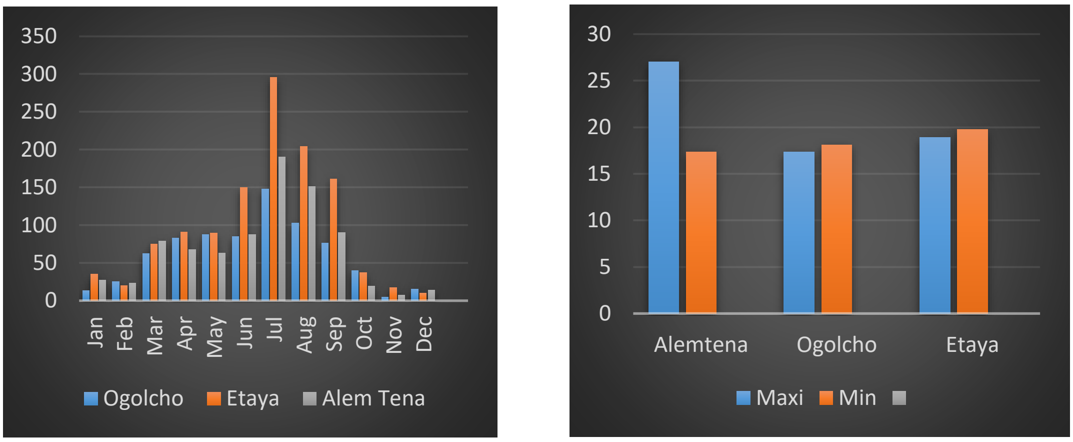
Table 3.1: Population of Study Area

Name of area	Year	Men	Women	total
Dodota	2007	32,378	31,932	64,310
Bora	2007	30,487	28,261	58,748
Tiyo	2007	43,463	43,298	86,761
Ziway Dugda	2007	60,379	60,483	120,862
Adama wereda	2007	79,013	76,336	155,349
Hitosa wereda	2007	62,335	61,734	124,179.

Source (CSA,2007)

3.1.4. Rainfall and Temperature of Study Area

Effective rainfall was calculated based on mean annual rainfall of Etaya, Ogolcho (Habura) and AlemTena and temperature are also for Etaya, Ogolcho (Habura) and AlemTena. The most significant determinants in characterizing the climatic condition of a specific location are temperature and rainfall. The average annual rain falls of the study area is 10 years, and the temperature is also for 10 years the maximum and minimum.



a. Rainfall *b.* Temperature

Figure 3.3: Rainfall and Temperature of Study Area

3.2. Materials and Software Used

There are some software and materials were used for this study. The softwares are ArcGIS software, ERDAS Image version 2015, Google earthPro7.3, Microsoft Word and Excel 2019, Hand held GPS, Idris Selva 32 and IBSPSS statistics were used.

Erdas Imagine version 2015, which is used for image processing, registration (checking ground truth of images), correction and finally classification of images and check accuracy

assessment as well as kappa coefficient for classified images. Microsoft Word2019 this software was used for Writing paper and reporting results. Google Earth software was used for Verification of timely updates image and generate coordinate points for the images.
Idris Selva, version 32, is a free software integrated raster-based GIS and image processing software package for the analysis and presentation of digital spatial data for basic and advanced spatial analysis surface and statistical analysis, decision support, and change and time series analysis, primarily for weighted overlay analysis by AHP. Table 3.2 shows that the software used description and its purposes.

Table 3.2: Software Used and Materials Used

Material name	Version	PURPOSE/USE
ArcGIS	10.8	For preparation of all thematic layer for the research works, Creating geo-database and An attribute analysis of the criteria and result find.
ERDAS IMAGINE	2015	For image preprocessing and land use land cover classification, Study area subset, and mosaicking. Geometric, Radiometric and atmospheric correction and Accuracy assessment for LULC
Google earth	7.3	Used for visual interpretation tools for LULC classification
Microsoft Word and Excel	2019	Integrating attribute data and compositing thesis
Hand held GPS	Accuracy at3 m	To collect exist coordinate
IDRISI selva	32	To assign weight for each factor
IBSPSS statistics	22	For tabulations and graphical representations

3.3. Data use and Data Source

Different data were gathered from different organizations and field observation. There are two types of data. Those were primary data and secondary data sources were used in this study; it included both spatial and non-spatial data from actual fieldwork and secondary (ancillary) data.

3.3.1 Methods of Data Collection

In order to conduct this study, a step-by-step method were followed from data collection to analysis. First of all, preliminary studies of literatures were done and factors affecting the wind farm suitability were identified. Those factor affecting site suitable analysis for wind farm development are land use land cover, wind speed, slope, elevation, stream, geology, distance from road and distance from Transimation line. Most of parameters were obtained from secondary source and others were collected from primary source.

Primary data: The primary data were obtained through field observation and field survey directly by researcher and other surveyors at time of data collection.

Secondary data: Secondary data source were gathered and gain from Literature, reports and policies, spatial data from various governmental offices. Such data were geologic map, DEM, stream, road network, satellite image, transmission line and wind speed; as it mentioned in table 3.3 show some of the data are in TIFF, vector, shape file and raster format. So, the two scenes were georeferenced, mosaicked, clipped and digitized to convert the data to vector format.

Geological Map from Ethiopian Geological Survey Agency data was, georeferenced and clipped by study area boundary. LULC were obtained from satellite image of sentinel 2022 year by supervised image classification. Slope and elevation were generated from DEM download from Free ASTER resolution 12.5. The following table 3.3 describes data required, types of data used this study, resolution, data format, and data where gathered.

Table 3.3: Data Source and Data Types

Data required	Data type	Sources	Data Format (Scale)	Resolution	Purpose
Wind speed	Secondary data	Global wind speed atlas	TIFF		To know winds peed average(direction of wind speed)
Sentinel,2A (2022 year)	Secondary data	USGS	TIFF	10m	To digitized Land use land cover map
Road network	Secondary data	ERA	Shape file	1m	Modify existing road Network
Stream/Rives	Secondary data	MOWIE	Shape file	1m	For extraction of stream for study area
DEM	Secondary data	Free ASTER	Raster	12.5m	For extraction of slope and elevation
Meteorological data	Secondary data	National meteorological agency	Float		For climate data and rainfall data
Geological Map	Secondary data	EGSA	1:200,000 (Jpeg)		To extract a geological map of study Area
Transmission Line	Secondary data	EEP(energydata.info)	Shape file		For extraction of transmission line
Wereda and Villages Boundary	Secondary data	BOFED	shape file		For study area boundary delineation.

3.4. Method of Data Processing

Once the data were collected from different sources the next step is processing of collected data for further analysis. Data process methods used in this study are georeferencing, projection and transformation systems, mosaicking, clipping, digitization, image classification and accuracy assessment.

3.4.1. Projection and Transformation

For this thesis we use different data; so we projected coordinate system i.e. UTM WGS_1984 ZONE 37 N. The data are converted in to shape files and they are projected to the coordinate system similar to the spatial reference system of base map, which is Projected Coordinate System. All layers were projected into WGS 84 UTM Zone 37N and converted into raster data Structure. This can be done in projection and transformation from spatial analyst tool in ArcGIS.

3.4.2. Mosaicking

A mosaicking is the process of combining or merging two or more adjacent images and scanned map to make them single scene. The main objective of mosaicking is to merge more than one scene of image or scanned map that covers the study area. In this study the two scenes of DEM, satellite image were mosaicked together.

3.4.3. Clipping

Clip is the process of cut the features in area of interest from image, scanned map, digital map and any GIS layers. To clip features in study area overlay a boundary of study area on target features to be clipped and perform GIS operation. In this study most of data collected were clipped in ArcMap 10.8 by using study area boundary. Accordingly, satellite image, geological map, road network and DEM used in this study were clipped.

3.4.4. Digitization

Digitization is the process where features on a map or image are converted into digital format for use by a GIS. This can be done by either manual or automation technique. Road network and transmission line used in this study are digitized from google earth in kml format and converted to shape file in ArcMap 10.8.

3.4.5. Geodatabase Development

A geodatabase is the physical storage of geographic information (spatial, aspatial, metadata, and relationship) inside a relational database management system. It contains layers' vector data representing features and raster data representing images and grid surfaces. Among the databases used in Esri's ArcGIS program, file Geodatabase have been chosen as an appropriate geodatabase for this particular research work. A geodatabase is a container that is used to enter, store, and manage feature datasets and feature classes. It is similar to a folder.

The database is designed to include comprehensive data, including information about each of main factors and sub factors transmission line, the road network, elevation, slope, wind speed, geology, stream; when optimum location for wind farm suitability is assessed in a raster GIS environment, each land unit in the database is valued according to its priority in land for wind farm site selection and each thematic layer represents its unique in the evaluation process. Following the File Geodatabase creation, feature dataset is also created to hold the feature classes like land use map, road map, slope map and others with the same steps followed in feature dataset creation. Having finished feature class creation, domain and topology are adjusted by clicking the right mouse on feature classes and pointing to topology and domain respectively.

3.4.6. Image Pre-Processing

After the data were downloaded from USGS earth explorer the satellite image **(**Sentinel,2A) 2022 year was processed using by ArcGIS 10.8 and ERDAS IMAGINE 2015 software. After data were collected the study started the process of manipulating, store, sorting etc in ArcGIS and all the data image (map) was prepared using WGS 1984, UTM Zone 37N. Also, layer stacking, radiometric correction, subset, mosaic, image enhancement using panchromatic band (pan sharpened) were carried out. These images are to be modified to give the best possible result.

3.4.7. Image Classification

Image classification is the process of classifying and identifying sets of pixels or vectors within an image in accordance with predetermined rules. It is a key component of remote sensing images and is used in a variety of applications, including identifying the types of farm land, waterbodies, and metropolitan areas from satellite images. Using the fundamental photogrammetric elements (color, tone, texture, size, shape, structure, association, and shadow), prior knowledge of the study area, and field observation, satellite images were classified and analyzed. Drive signatures were subsequently classified using the maximum-likelihood classification algorithm in the supervised classification type of the ERDAS IMAGE software based on a set of training polygons. Supervised classification is based on the quality and quantity of training samples to produce good quality classification results. In this study the images were classified in to five major land-use/land-cover classes such as built up area, bare land, forest land, farm land, and water body.

3.4.8. Accuracy Assessment

Once an image is classified into a thematic map, its accuracy should be determined before the map is used. Accuracy assessment was employed for determining whether the output map meets or does not meet level of acceptance. Error matrices are a common method of expressing classification accuracy, and were created to compare category by category basis, the reference data (ground truth) and the corresponding results of classification (Lillesand et al., 2008). In this study the accuracy of the classification results for was calculated from Error matrices.

After creating the error matrix for each classification, user accuracy, producer accuracy, overall accuracy and Kappa coefficient were computed. By dividing the amount of pixels in each category that were classified correctly by the number of pixels that were classified in that category (Lillesand et al,2008) claim that user accuracy may be determined (the row total). The number of successfully classified pixels in each category (on the major diagonal) is multiplied by the quantity of pixels used in the training set for that category to determine the accuracy of the producer (the column total). The overall accuracy is determined by dividing the diagonal sum by the sum of the rows or columns. To check the accuracy of LULC used in this study, overall accuracy was computed from error matrix.

Producer's Accuracy (Errors of omission): Producer's Accuracy quantifies the percentage of pixels from sample data that are correctly classified, or infers omission errors for a specific class. The percentage of correctly classified pixels in each category (along the principal diagonal) multiplied by the total number of pixels in the training set used for that category was used to determine the accuracy of the producer (the column total). It is calculated as:

$$\mathbf{producur's\ accuracy} = \frac{\mathbf{Ci}}{\mathbf{Ct}} \times \mathbf{100}\% \quad 3.1$$

Where, Ci = correctly classified sample locations of the reference data or column and Ct = total number of sample locations of the column.

User's Accuracy (Commission error): user's accuracies are computed by dividing the number of correctly classified pixels in each category by the total number of pixels that were classified in that category (the row total). This result is a measure of commission error. It is calculated as:

$$\mathbf{User's\ accuracy} = \frac{\mathbf{Ri}}{\mathbf{Rt}} \times \mathbf{100}\% \quad 3.2$$

Where, Ri = correctly classified samples in the row and Rt = total number of samples in the row.

Overall Accuracy: Overall accuracy was computed by dividing the total diagonal (i.e., the sum of the correctly classified sample units) by the total number of sample units in the error matrix. This value is the most commonly stated accuracy assessment statistic.

$$\mathbf{Overall\ accuracy} = \frac{\mathbf{Sd}}{\boldsymbol{n}} \times \mathbf{100}\% \quad 3.3$$

Where, Sd = sum of values along diagonal and, n = total number of samples.

Kappa Coefficient: Kappa coefficient is an additional measure for agreement or accuracy. The major diagonals and the chance agreement, which are indicators of the agreement or correctness between the remote sensing-derived classification map and the reference data, were utilized to calculate kappa. The row and column totals demonstrated this. The range of kappa values is +1 to -1. Positive values, however, were expected since there should be a positive correlation between the remotely sensed categorization and the reference data. Three categories were used by Landis and Koch (1977) to classify the possible kappa ranges: a value greater than 0.80 (i.e., 80% and above) represent strong agreement; a value between 0.40 and 0.80 (i.e., 40%–80%) represents moderate agreement; and a value 0.40 (i.e., 40% and below) represents poor agreement.

$$\mathbf{K}^{\wedge} = \frac{\sum_{\mathbf{i=1}}^{\mathbf{n}} \boldsymbol{xii} - \sum_{\boldsymbol{i=1}}^{\boldsymbol{r}} (\boldsymbol{xi} + .\mathbf{x} + \ \mathbf{i})}{\boldsymbol{N^2} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{r}} (\boldsymbol{xi}+.\boldsymbol{x} + \boldsymbol{i})} \quad 3.4$$

Where r = number of rows in the error matrix; Xii = number of observations in row i and column i (on the major diagonal); Xi+ = total of observations in row i (shown as marginal total to right of the matrix); X+i = total of observations in column i (shown as marginal total at bottom of the matrix) and N = total number of observations included in matrix.

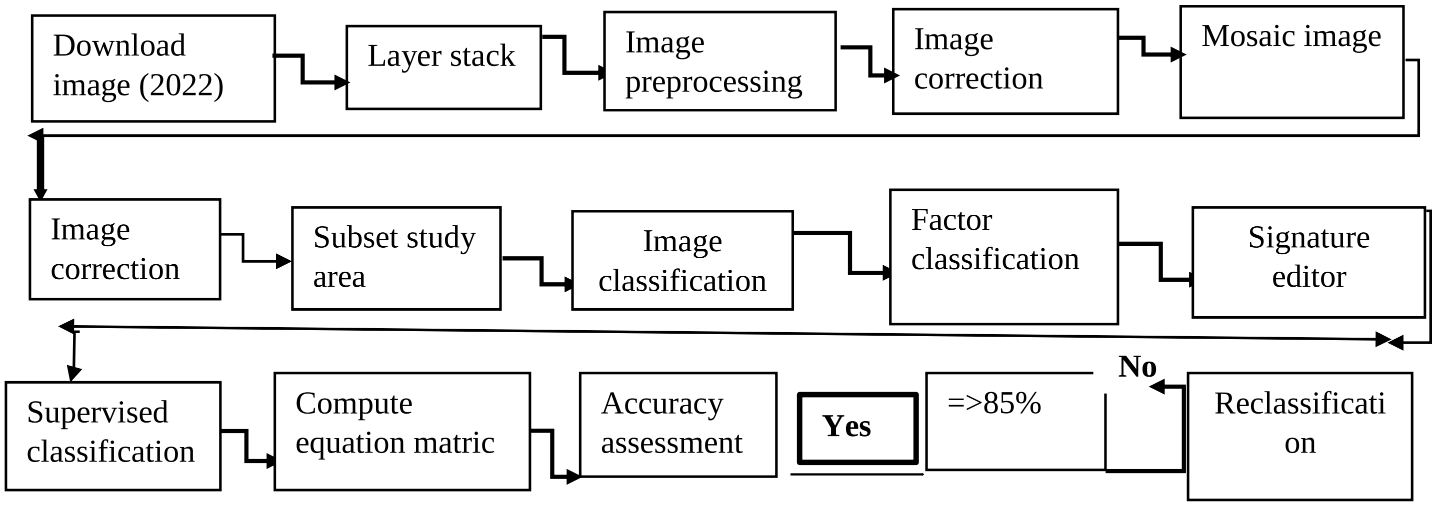


Figure 3.4: Flow Work for Image Process

3.5. Data Analysis Methods

The data analysis process of site suitability analysis for wind farm development involves numerous factors with complicated correlations. Therefore, the Geospatial technique with multi-criteria spatial analysis techniques and the Analytic Hierarchy Process (AHP) approach has been used to select suitability site of study area. The methodological procedure for identification of optimal site for wind farm development.

3.5.1 Buffering

Buffering is a spatial analysis also called proximity analysis. It is used to generate areas of a given distance around the specified criteria that has been used for wind farm development site selection. In this study buffer zone was created for road network based on the specified distance for each factor.

3.5.2 Rasterization

Rasterization can be defined as the process of converting information in vector format to raster format. As mentioned under data preparation section most of data used in this study were digitized from secondary sources. Those data in vector format which were converted to raster format in ArcMap 10.8 for further analysis.

3.6.3. Reclassification

The reclass tools are used to allow the researcher to reclassify or change input cell values to alternative values. In this study, all thematic layers were converted to raster, and then raster reclassification using reclass tool of ArcGIS 10.8 was adopted to reclassify the old value to the new one. The reason behind reclassifying raster data was to:

- ✓ Replace new values with the old ones based on new information;
- ✓ Group certain values and
- ✓ Reclassify values to a common scale of measure.

3.6. Site selection process in multi-criteria analysis method

Geographic information systems (GIS) based multi-criteria analysis (MCA) techniques have been used in solving site selection problems. Site selection process for wind farm development involves various environmental, technical, and socio-economic aspects. GIS based MCA is a process that transforms and combines geographical data and value judgments (the decision maker's preferences) to obtain information for decision making (Malczewski,2006). (Taha & Daim,2013) suggest that GIS-based MCA provides a flexible tool that can handle and integrate a variety of parameters assessed in different ways and so provide helpful support to the decision-maker in pointing at appropriate sites. ArcGIS has been used by MCA in this thesis as a method determine appropriate sites for wind farms. In order to support the decision-making process for selecting a suitable site for the establishment of wind farm, this study applied GIS-based multi-criteria suitability analysis applying the analytical hierarchy process (AHP).

In this study, to select a suitable site for wind farm using GIS-based multi-criteria analysis the following six main steps were used (Eastman et al., 1995):

- Set the goal/define the problem
- Determination of criteria and sub-criteria
- Criteria standardization and factor map generation
- Determination of weighting for each factors
- Aggregate the criteria
- Validate/verify the result

3.6.1. Set the goal/ define the problem

In this study the main aim of GIS based Multi-Criteria Analysis (MCA) was to produce a map showing suitable sites for wind farm development in study area.

3.6.2. Determine the Main Criteria and Sub-Criteria

There were no universally agreed criteria/factors for wind farm development. There were many factors affecting the development of wind farm. This study identified three main factors and eight factors/criteria as being relevant to the site suitability of wind farm development for study area by synthesized different literature review, personal experience, expert opinion, available data and based on previous related studies researched by different researchers. Different literature suggests a variety of factors that may influence wind farm development. According to some researchers (Dereje,2016; Bennui et al, 2007; Baseer et al, 2017; D. Sarpong and P. E. Baffoe, 2015; Okechukwu et al, 2019; Eyaya, 2009; Ebisa, 2016; Usman et al,2020; Arun K, 2017). were all considered different parameters/factors for selection of suitable site for development of wind farm like; Elevation, wind speed, land use land cover, distance from main road, distance from highway, Safe distance from airports, Slope of terrain, Impact on birds, Noise, Visual Impacts, Proximity to National Grid, Water Pollution, Geology and etc were often used for wind farm suitability site selection.

In this study based on the existing situation and availability of data from study area, Site Suitability analysis for wind farm development was carried out based on the three main criteria were: environmental, technical and Socio-economic whereas sub-criteria were; distance from roads, LULC, Geology (soil type), slope, Elevation, distance from transmission line, stream and wind speed.

3.6.3. Criteria Standardization and Factors Map Generation

It's essential to standardize the data in GIS-based multi-criteria decision-making analysis, in order to integrate the data measured in different units and mapped in scale of measurement in different ways such as ordinal, interval, nominal and ratio scales (Pereira and Duckstein,1993). Even though there are different methods that can be used to standardize criterion, linear scale transformation is the most frequently used technique (Malczewski,2003). In this study for factors standardization, all the vector maps of the factors were converted to raster data formats. Then using the Spatial Analyst tool in ArcMap, the raster maps were reclassified. According to (FAO,2006) and different literatures (authors) site suitability classification, the datasets were highly suitable, suitable, moderately suitable, less suitable, and not suitable.

For criteria standardization in this study, all the vector maps of the criteria were converted to raster maps data formats. After that using the Spatial Analyst tool in ArcMap the raster maps were reclassified into five classes with the values that range from 1 to 5, where the value of 5 was taken as reclassified Very High Suitable (S5) to permanently unsuitable (s1); where S5, S4, S3, S2 and S1, represents the very highly suitable, highly suitable, suitable, moderately suitable and less suitable conditions for wind farm development respectively. This method enables all measurements to have an equivalent value before any weights are applied. However, it was important to note that there were some variables that did not fulfill the whole range of the criteria. Once all the criteria maps were standardized, a weight of each criteria map was calculated using AHP.

3.6.4. Determine Weights of Factors Using Analytical Hierarchy Process Method

GIS-Based MCDM were solving the spatial problem. Assigning criteria weights for each factor is an important component of GIS-Based multi-criteria decision-making analysis. The purpose of weighing is to express the importance or preference of each factor relative to one another factor effect on wind farm. In this study, the AHP using pair-wise comparison matrixes were used to calculate weights for the criteria maps.

Analytic Hierarchy Process (AHP) is a widely used method in MCDM and was introduced by Saaty (1980). AHP is a decision support tool, which can be used to solve complex decision problems. It uses a multilevel hierarchical structure of objectives, criteria, sub-criteria, and alternatives uses the fundamental scale of absolute numbers to express individual preferences or judgment. Analytical hierarchy process (AHP) methodology has been widely used for multi-criteria decision-making regarding site suitability analysis of different land uses. The AHP method determines the weight of importance of different factors influencing site suitability based on pairwise comparisons of the factors considering their relative significance (Kordi and Brandt, 2012). Weighting is an important component of site suitability analysis as it affects the output and is complicated as the considered factors interact with each other.

In this study, to select a suitable site for wind farm development the AHP was carried out in the following three steps:

- ✓ Pair-wise comparison of criteria
- ✓ Calculating criterion weights
- ✓ Calculating consistency ratio (CR)

A. Pair-wise comparison of criteria

Pair-wise comparison of criteria was performed first and results were put into a comparison matrix. A Pair-wise comparison matrix was constructed, where each criterion was compared with the other criteria, relative to its importance, on a scale from 1 to 9 which is suggested by Saaty (1980).

Table3.4: AHP Scale of Relative Importance

Intensity of relative importance	**Definition**	**Explanation**
1	Equal Importance	Two activities combine equally to the objective.
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favour one activity over another.
7	Demonstrated importance	An Activity is strongly favored and its dominance is demonstrated in practice.
9	Extreme Importance	The evidence favoring one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed.
1/3,1/5,1/7,1/9	Reciprocal values of the previous appreciation	

Source: Saaty (1980)

According to Saaty (1980), the values in the matrix need to be consistent, which means that if x is compared to y, it receives a score of 9 (extreme significance), y to x should score 1/9 (less significance) and something compared to itself gets the score of 1 (equal significance). In this study the pairwise comparison matrices were developed by taking into account the information provided by various literatures (Yousef et al. 2014; Yirgalem,2021).

B. Calculating criterion weights

The weights of all factors are calculated by normalizing the eigenvector associated with the maximum eigenvalue of the (reciprocal) ratio matrix. Manually the computation of the criterion weights involves the following operations: (a) summing the values in each column of the pairwise comparison matrix; (b) dividing each element in the matrix by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix and (c) computing the average of the elements in each row of the normalized matrix that is, dividing the sum of normalized scores for each row by the number of criteria. In this study the computation of the criterion weights was calculated by using GIS and IDRISI Selva software.

C. Calculating consistency ratio (CR)

After the pair-wise comparison was filled and the weight of the factors was determined, a consistency ratio (CR) was calculated to identify inconsistencies and develop the best-fit weights in the complete pair-wise comparison matrix. Consistency ratio of 0.1 or less is acceptable to continue the AHP analysis (Saaty, 2008). But if a consistency ratio is greater than 0.1, then there are inconsistencies in the evaluation process and the AHP method may not yield a meaningful result (Saaty, 2007). A consistency ratio was calculated for the matrix to verify the degree of credibility of the relative weights, by using the following formula:

$$\mathbf{CR} = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (3.1).}$$

where CR=Consistency ratio, CI = referred to as consistency index, RI = is the random consistency index whose value depends on the number (n) of factors being compared). The consistency index (CI) was calculated by the following formula:

$$\boldsymbol{CI} = \frac{\boldsymbol{\lambda}\mathbf{max-n}}{\mathbf{n-1}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (3.2).}$$

Where λ max is the principal Eigen value; n is the number of factors. λmax = Σ of the products between each element of the priority vector and column totals.

Table 3.5: Random Consistency Index (RI)

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	00	0.58	0.9	1.12	1.24	1.24	1.41	1.45	1.49

Source: Saaty (1980)

3.6.5. Weighted Overlay Analysis

After developing and establishing the criterion maps, factors, and weights, a multi-criteria analytical result was used. In multi-criteria analysis, weighted linear overlay, Boolean overlay, and ordered averaging are the three most commonly used decision rules (Jiang and Eastman, 2000; Malczewski, 2003). In this study, the standardized layers were combined using the weighted linear combination (WLC) method. In this technique, factors or parameters (Xi) are multiplied by weight of the parameters (Wi) to get composited weights and then summed. WLC technique is a straightforward linear method calculating composite weights. WLC multiplies and sums up the layers to produce suitability maps for wind farm development. This can be done by using the following formula to derive the intended map (i.e., wind farm development suitability map for study area).

$$\boldsymbol{S = \sum_{i=1}^{n}(wixi)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (3.3)}$$

where S = Suitability, Wi = relative importance or weight of factors / parameters i,

Xi = parameters i, and n = total number of parameters related to the study.

3.6.6. Validate/verify the result

Validating or verifying the result was the final step and it helps to assess the reliability of the output and usually assessed by ground truth verification and sensitivity analysis. According to (Saraswat et al 2021, Yirgalem, 2021).

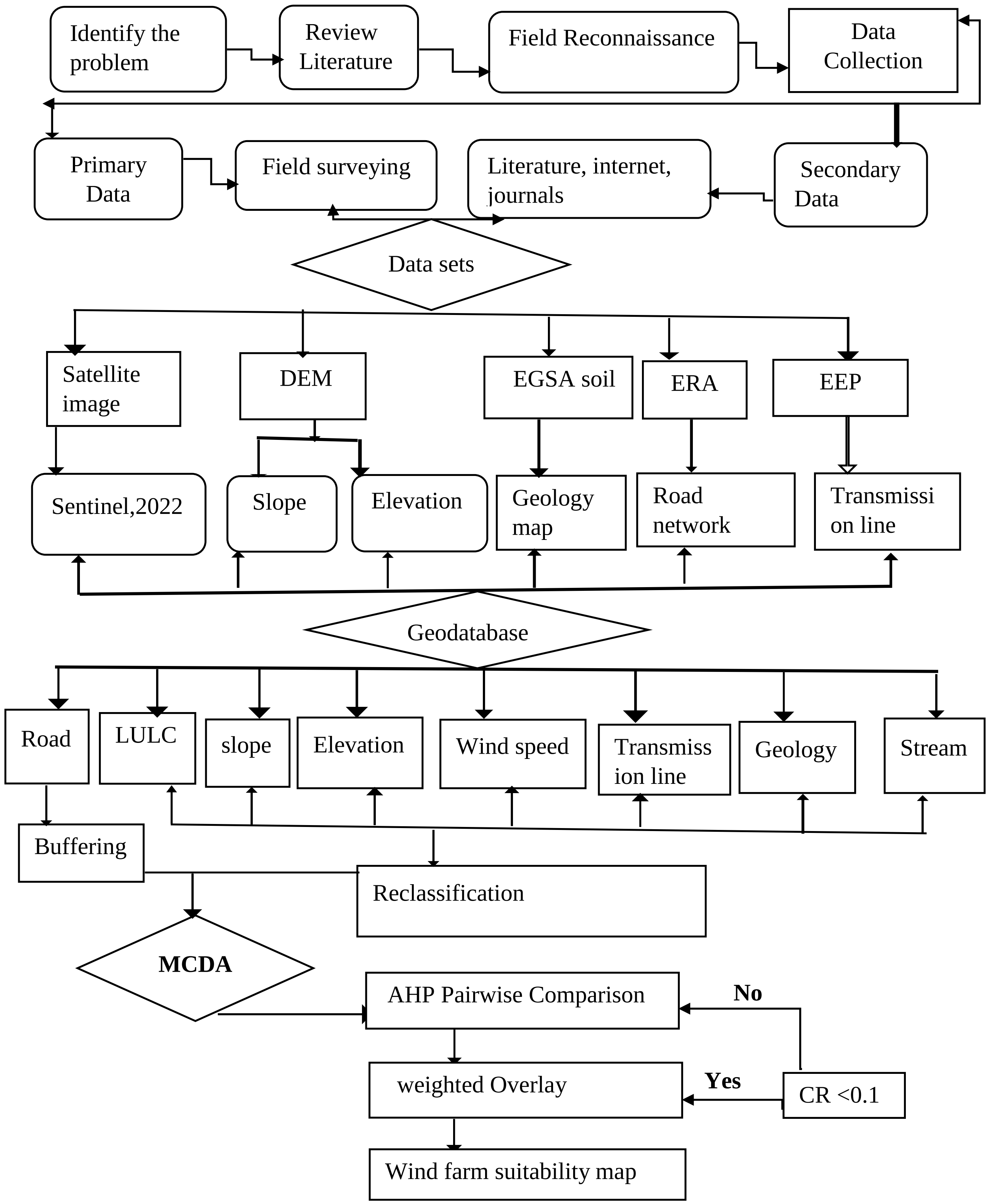


Figure 3.5: Methodological Work Flow

CHAPTER FOUR: RESULT AND DISCUSSION

This chapter discusses based on synthesized the literature reviews, expert opinions, and available data to achieve the objectives of this study. Relevant data analyses using the predefined methodology and Consecutive techniques of location allocation and spatial analysis are engaged. Descriptions of the discussed results in the form of information are briefly arranged. Discussions are provided to meet the purpose of study and objectives set briefly at the beginning of the study. The analyzed data was presented in the form of table maps and graphs to show the results first all criteria maps have been prepared based on methodology discussed in chapter three. For each suitability criterion, maps of suitability analysis for the development of wind farms were also produced, and the final composite map was constructed by weighted overlaying the individual maps. Reclassified criterion, standardization score, area coverage of suitability levels and weights of each factor were summarized using tables. Finally, the intentioned and refined greatest output of the research that is the most Optimum wind farm sites are distinguished as a candidate sites. These are candidate sites for wind farm service in study area can progressively support the Essential Communities.

4.1. Land use Land Cover Classification

To fulfill the overall objectives of the study LULC classification is the main criteria. In this study LULC were classified sentinel 2A image of 2022. This images were classified into five major classes. There are: bare land, forest land, farm land, water body and built-up area

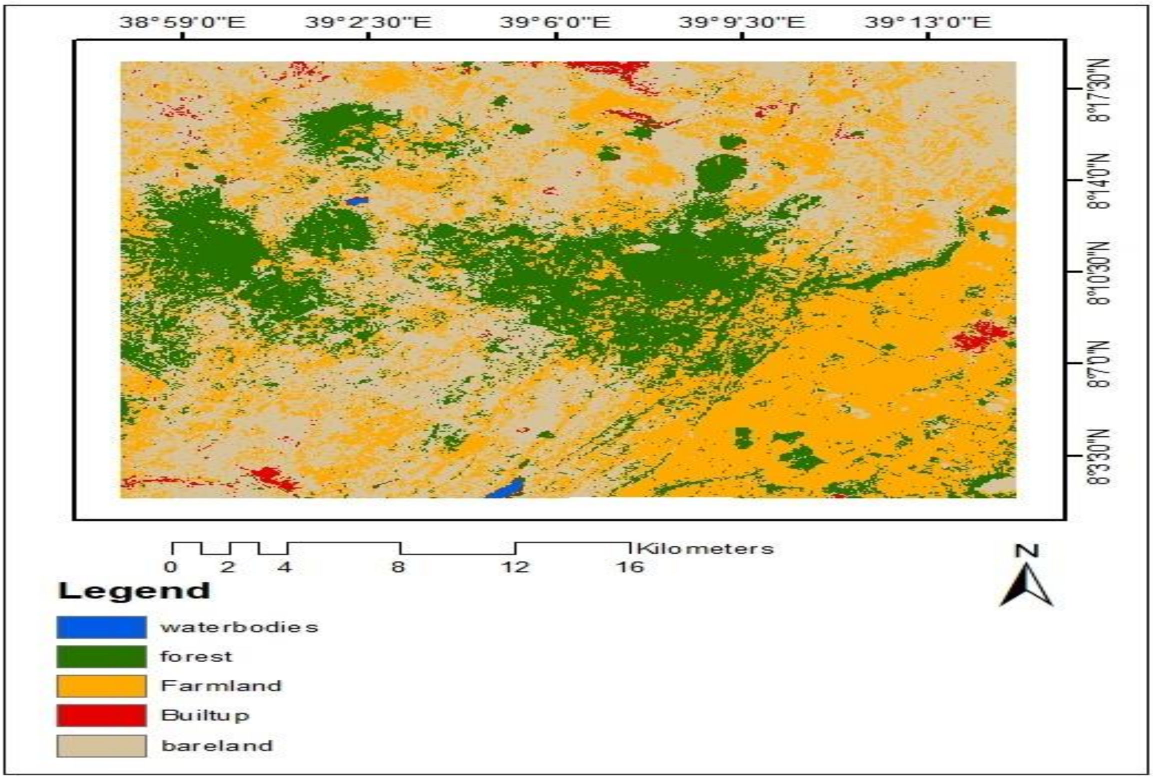


Figure 4.1: Land Use Land Cover Classification

4.2. Accuracy Assessment of the LULC Classification

Accuracy assessment was employed for determining whether the output map meets or does not meet level of acceptance. Sample points are selected by referring to the pan-sharpening Sentinel_2A image in ArcGIS to validate the accuracy of Supervised Classification methods, and then, converted this sample points to a raster format, which is considered as the ground truth samples. Error matrices are a common method of expressing classification accuracy, and were created to compare category by category basis, the reference data (ground truth) and the corresponding results of classification.

Based on formula in previous chapter equation (3.1) the results show producer Accuracy of image classification 88.1% indirectly it indicates errors of omission for a particular class. Using formula in equation (3.2). The Total User accuracy of classification calculated as 87.79% which is acceptable. In general, the overall classification accuracy of classified image was 95.29% and with Kappa Statistics K^= 0.929 calculated using equation 3.3 and 3.4 respectively. The details of confusion of error matrix discussed in table 4.1.

Table 4.1: Error matrix and accuracy assessment LULC of study area 2022

Classified Data	Reference Data						
	Forest land	Built-up	Water bodies	Bare land	Farm land	Total row	User Accuracy
Forest land	84.62	0	0	1.01	1	86.01	1.02
Built-up	0	71.66	0	0	0	71.66	1.00
waterbodies	1	0	70.3	16.29	0	87.59	1.25
Bare land	1.06	0.45	0	92.49	0	94	1.02
Farm land	0	0	0	0	89.03	89.03	1.00
Total column	86.68	72.11	70.3	109.79	90.03	428.29	
Producer Accuracy	1.02	1.01	1.00	1.19	1.01		

Overall Accuracy = 95.29 (%) Kappa Statistics K^= 0.929(92.9%)

Sources Own analysis& ERDAS IMAGINE v2015

4.3. The Dominant Factors for Wind Farm Development in the Study Area

The factors are important for wind farm development. In this study, the factors used for site selection process for wind farm development were selected based on different literature reviews and the prior knowledge of that particular area. Based on the existing situation and availability of data obtained; there was carried out eight factors to selected the suitable site for wind development for study area. There are: wind speed, LULC, distance from road, distance from transmission line, slope, geology, elevation and stream.

Wind speed: According to (Vanek and Albright, 2008), the availability of sufficient wind speed at the height where the turbine is to be installed determines the amount of wind power in a specific site. Because it determines the most feasible and profitable sites in the area for the site of a wind power project, wind power density is one of the most crucial factors (Baban and Perry, 2001). Wind speeds were the most crucial factor when selecting a location for a wind energy power plant because they are essential for the use of electricity generation (Okechukwu, 2019).

Land use and land cover: were both of the most important factors for investment projects. Wind energy should be put in place where they barely interfere with current land use. Land use has an impact on the decision to build a wind farm because there are some situations in which wind farms cannot be built even though there is sufficient wind speed. Examples of these situations include water bodies, built-up areas, and forest land sites that are not moderately suitable, while bare land and farmland are highly suitable (Okechukwu, 2019).

Slope: The steep slope of the land makes it challenging to access wind turbines for installation and maintenance. The permitted maximum slope threshold in literature ranges from 10% (Baban and Parry, 2001) to 30%. (Tegou et al., 2010). Even more so, Rodman and Meentemeyer (2006) prefer ridge crests and set the slope threshold at 40°, or around 84%.

Elevation: Wind turbines must be located in open areas and at higher elevations than the surrounding area in order to produce electricity effectively; ideally, elevations greater than 100 m (D. Sharping, &P. E. Baffoe, 2015). Wind power plants must be located in open areas and at higher elevations than the surrounding area in order to generate electricity efficiently; preferably, elevations more than 100 m (Okechukwu, 2019).

Distance from Transmission line: The distance from the electricity lines was determined using a distance function (multiple buffers). A wind turbine's production must be connected to the electrical grid. Sites close to existing power lines lower this cost because it can be highly expensive to build new transmission lines to deliver electricity where it is needed. Wind farms should be located closer to the electrical grid to reduce the expenses related to cabling and electricity losses over large transmission distances. However, there are significant differences in the determined maximum distance between wind turbines and the electrical grid from across literature (Tegou, Polatidis, and Haralambopoulos, 2010).

Distance from Road network: Because transporting larger turbines can be challenging and expensive, proximity to significant transportation infrastructure is a crucial stage in the development process. Making wind turbine transportation as effective as feasible can help reduce construction costs by reducing the distance between the potential wind farm site and main roadways (Effat, H. A.2014).

Stream network: River and stream data are collected from Topo sheets and evaluated on the most current version of Google Earth. Before selecting a suitable site, it is essential to identify the data streams as one of the factors. Because of the fact that we do not construct the wind farm on rivers or drainages (Ahmad,2021). Water bodies in the area should be made safe of wind turbine location (Haaren, 2011).

Geology(soil) types: The most significant aspect in determining whether a site is suitable for the development of wind farms is the soil. For the establishment of wind farms, soil types with high fertility, nutrient deficit, and high water holding capacity can be used. The FAO data source was used to identify the soil types in the research area. The case study area's soil types include Eutric Vertisols, which are located near water bodies, Vertic Cambisols, cmv, Luvic Phaeozems, which are located near lithic leptosols, and Vitric Andosols. Basalt mud.

4.4. Suitability analysis for Wind Farm Development

4.4.1. Suitability of Wind Speed Layer

The wind speed map of study is produced using the available (1 years) data. The wind speed of the study area is reclassified into five categories based on their speed. Consequently, wind speed 8.40-11.33 m/s, 7.47-8.40 m/s, 6.83-7.47m/s and4.78-6.09 m/s are considered very highly suitable, highly suitable, moderate suitable, and less suitable respectively. The average wind speed was reclassified using the opinions of past literatures and as per the nature of the study area.

Table 4.2: Reclassified Wind Speed and Area Coverage of Suitability Levels

Wind speed(m/s)	Standardization Score/Value	Level of suitability	Area in	
			(Ha.)	(%)
8.40-11.33 m/s	5	Very High Suitable	6437.174	6.80
7.47-8.40 m/s	4	Highly suitable	18080.85	19.11
6.83-7.47 m/s	3	Moderate suitable	26683.04	28.20
6.09-6.83 m/s	2	Suitable	28903.24	30.55
4.78-6.09 m/s	1	Less suitable	14508.77	15.33
		Total	94613.07	100

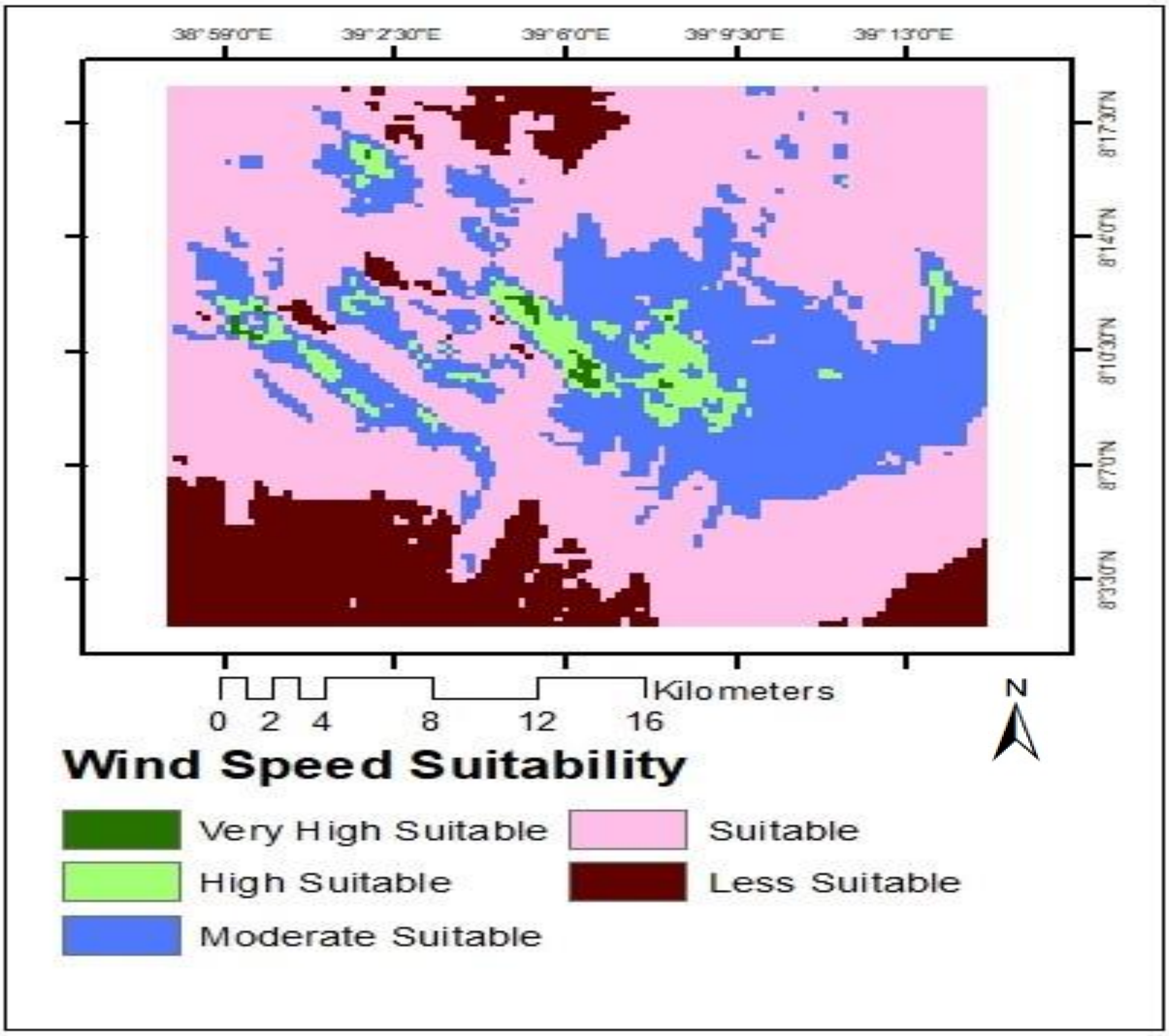


Figure 4.2: Wind Speed Suitability Map

4.4.2. Suitability of Land Use Land Cover Layer

The existing uses of the land should carefully be evaluated to determine how best the wind farm can integrate with the existing land uses. Accordingly, whether or not a wind farm project can be developed depends on having suitable land to install turbines. The relative costs of land must be considered while selecting sites for wind farm establishment. Accordingly, Ebisa,2016; Eyaye,2009) bare land considered as highly suitable, farm land moderately suitable, forest land is less suitable, built up area not suitable and lasses respectively while and built up area, forest land and water body are considered as least and water body is permanently not suitable land classes respectively

Table 4.3: Reclassified LULC and Area Coverage of Suitability Levels

LULC type	Standardization Score/Value	Level of suitability	Area in (Ha.)	Area in (%)
Bare land	5	High Suitable	37582.75	39.70
Farm Land	4	Moderately Suitable	36397.78	38.45
Forest land	3	Less Suitable	19495.25	20.59
Water body	2	Not Suitable	102.1268	0.11
Built up area	1	Permanently Not Suitable	1085.02	1.15
		Total	94662.93	100.00

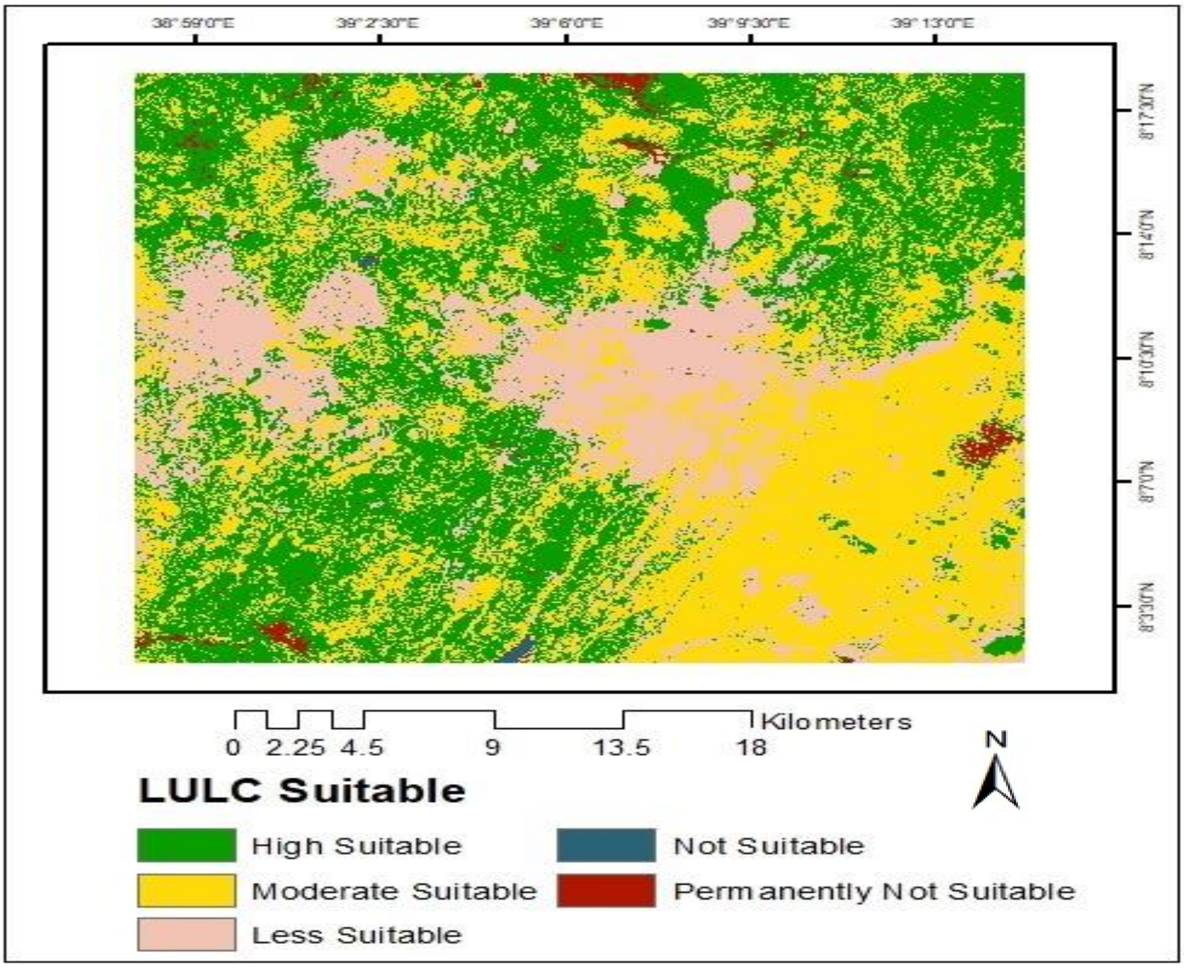


Figure 4.3: Land Use Land Cover Suitability Map

4.4.3. Suitability of Slope Layer

Slope reflects the terrain smoothness in the candidate region. A steeper terrain that is harder to install power facilities means there is a greater slope. Besides, unfavorable topography requires good performance of wind turbines with the high infrastructure cost. Therefore, it is advisable to select the sites with flat terrain. A lower slope corresponds to a higher score (Lijun Zheng,2020). Slope of the study area was calculated from DEM (12.5 resolution) and used in GIS environment as a thematic map. According (Dereje,2016). Finally, slopes were calculated and reclassified in to five slope classes: 0-5%, 5-10%, 10-15%, 15-25% and >25%.

Table 4.4: Reclassified Slope and Area Coverage of Suitability Levels

Slope(%)	Standardization Score/Value	Level of suitability	Area in	
			(Ha.)	(%)
0_5%	5	Very High Suitable	49233.13	52.19
5_10%	4	Highly suitable	30723.01	32.57
10_15%	3	Moderate suitable	9762.058	10.35
15_25%	2	Suitable	3619.525	3.84
>25%	1	Less suitable	993.6007	1.05
		Total	94331.32	100.00

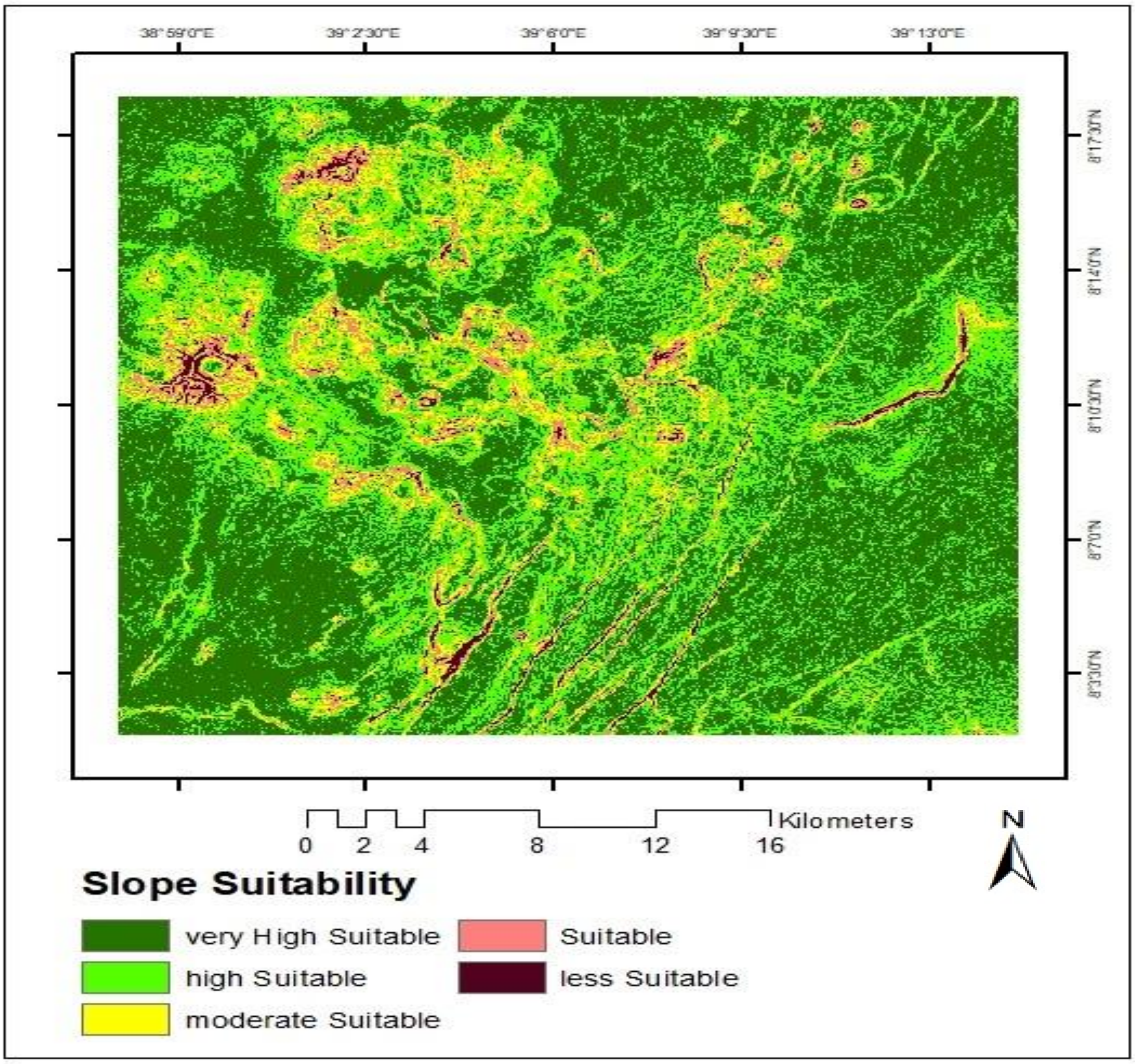


Figure 4.4: Slope Suitability Map

4.4.4. Suitability of Elevation Layer

High heights are desirable, according to the Wind Turbine Placement Analysis study by the Washington Department of National Resources. Classes are separated by natural breaks away from steep slopes and elevation change. In general, the location should be open and elevated above the surroundings. However, moderately sloping hills can actually increase wind speed at the top, contrasting to steep hills or cliffs that can produce turbulence and should be avoided. The elevation thematic layer in this study was created using a 12.5 resolution Digital Elevation Model (DEM). The thematic layer was reclassified in to five classes using arc GIS re classify tool. 1576 - 1700, 1700 – 1900, 1900 - 2100, 2100 – 2300, 2300 - 2509 (Dereje, 2016)

Table 4.5: Reclassified Distance Elevation and Coverage of Suitability Levels

Elevation(m)	Standardization Score/Value	Level of suitability	Area in (Ha.)	(%)
2300 - 2509	5	Very High Suitable	1051.22	1.11
2100 - 2300	4	Highly suitable	17282.5	18.25
1900 - 2100	3	Moderate suitable	15936.3	16.83
1700 - 1900	2	Suitable	43387.4	45.81
1576 - 1700	1	Less suitable	17051.1	18.00
		Total	94708.5	100.00

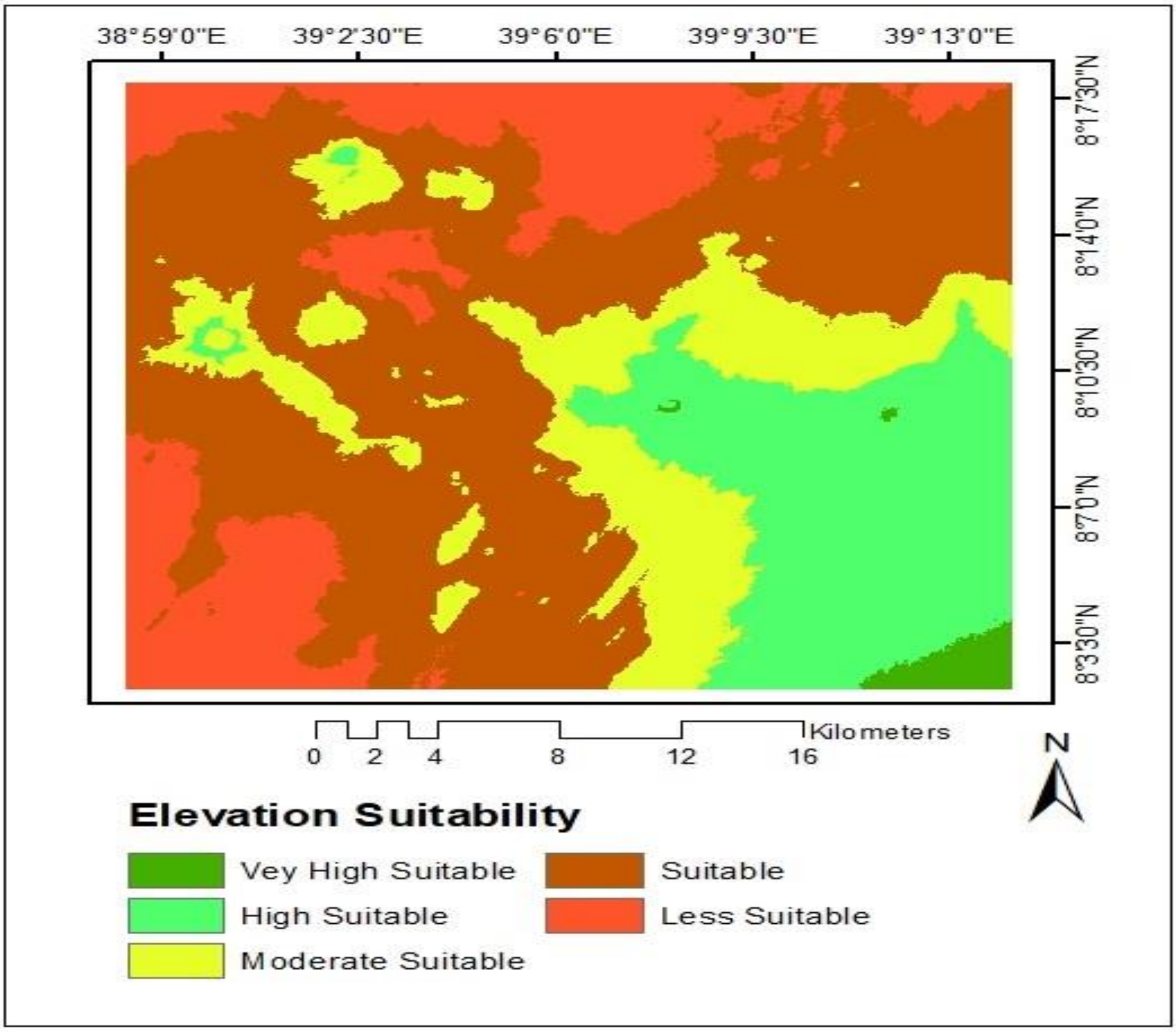


Figure 4.5: Elevation Suitability Map

4.4.5. Suitability of Transmission line layer

A wind turbine's production must be connected to the electrical grid. Wind farms should be located near to the electrical grid. However, there are significant variations in the literature on the maximum distance between wind turbines and the electrical grid. (Tegou, Polatidis, & Haralambopoulos, 2010). Set having a good wind energy resource will only be beneficial to wind farm developers if the energy generated by the project can be delivered to the purchaser in a cost-effective manner. As a result, areas which are near to the transmission line are classified as Very High suitable and which are far from the transmission line are classified as less suitable areas. According to (Dereje,2016). The transmission line is classified in to five classes, 0_100m,100_2500m,2500_5000m,5000_7500m and >7500m.

Table 4.6: Reclassified Distance from Transmission and Area Coverage of Suitability Levels

Distance from transmission line(m)	Standardization Score/Value	Level of suitability	Area in	
			(Ha.)	(%)
0_100m	5	Very High Suitable	566.674	0.60
100_2500m	4	Highly suitable	10835.7	11.45
2500_5000m	3	Moderate suitable	11626.8	12.29
5000_7500m	2	Suitable	10012.9	10.58
>7500m	1	Less suitable	61555.6	65.07
		Total	94597.7	100.00

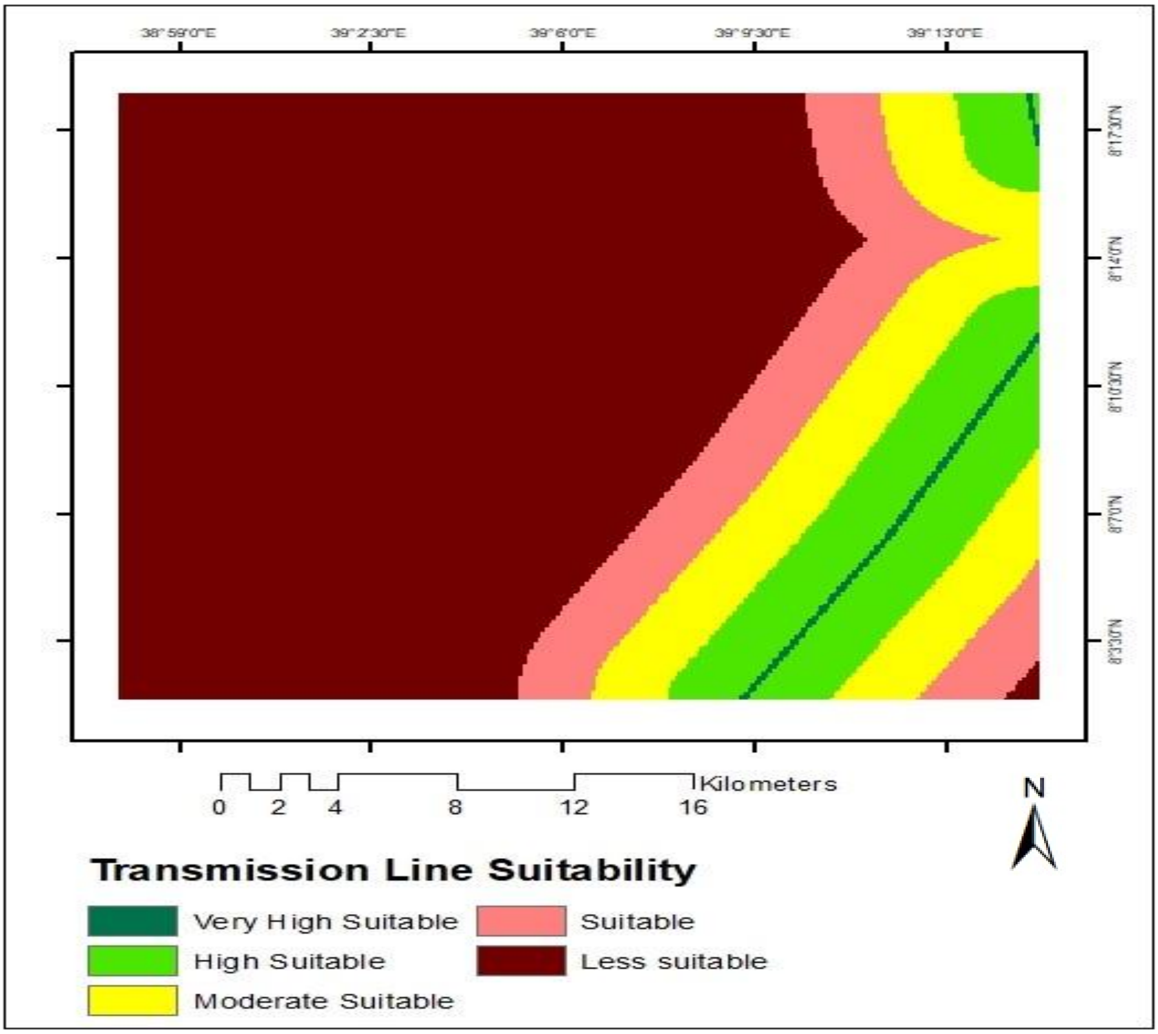


Figure 4.6: Transmission Line Suitability Map

4.4.6. Suitability of Distance from Road Network Layer

Making the transportation of wind turbines as effective as feasible can help reduce expenses by minimizing the distance between the potential wind farm site and major roads. In order to minimize soil sealing and reduce the expense of constructing new access roads, wind farm should be located as closely as possible to the existing road network (Windustry,2006) in the most wind farm sitting assessments, Locations very far from roadways are seen to be less suitable than those near roads. (Babban, S.M.J, & Parry.T, 2001, Dereje. A, 2016).

Distance from road network and reclassified in five classes,0_100m, 100_1000m,1000_2500m,2500_5000m,>5000m.

Table 4.7: Reclassified Distance from Road Network and Area Coverage of Suitability Levels

Distance from road network (m)	Standardization Score/Value	Level of suitability	Area in	
			(Ha.)	(%)
0_100m	5	Very High Suitable	2311.8	2.44
100_1000m	4	Highly suitable	18987	20.07
1000_2500m	3	Moderate suitable	24033	25.41
2500_5000m	2	Suitable	24206	25.59
>5000m	1	Less suitable	25062	26.49
		Total	94600	100.00

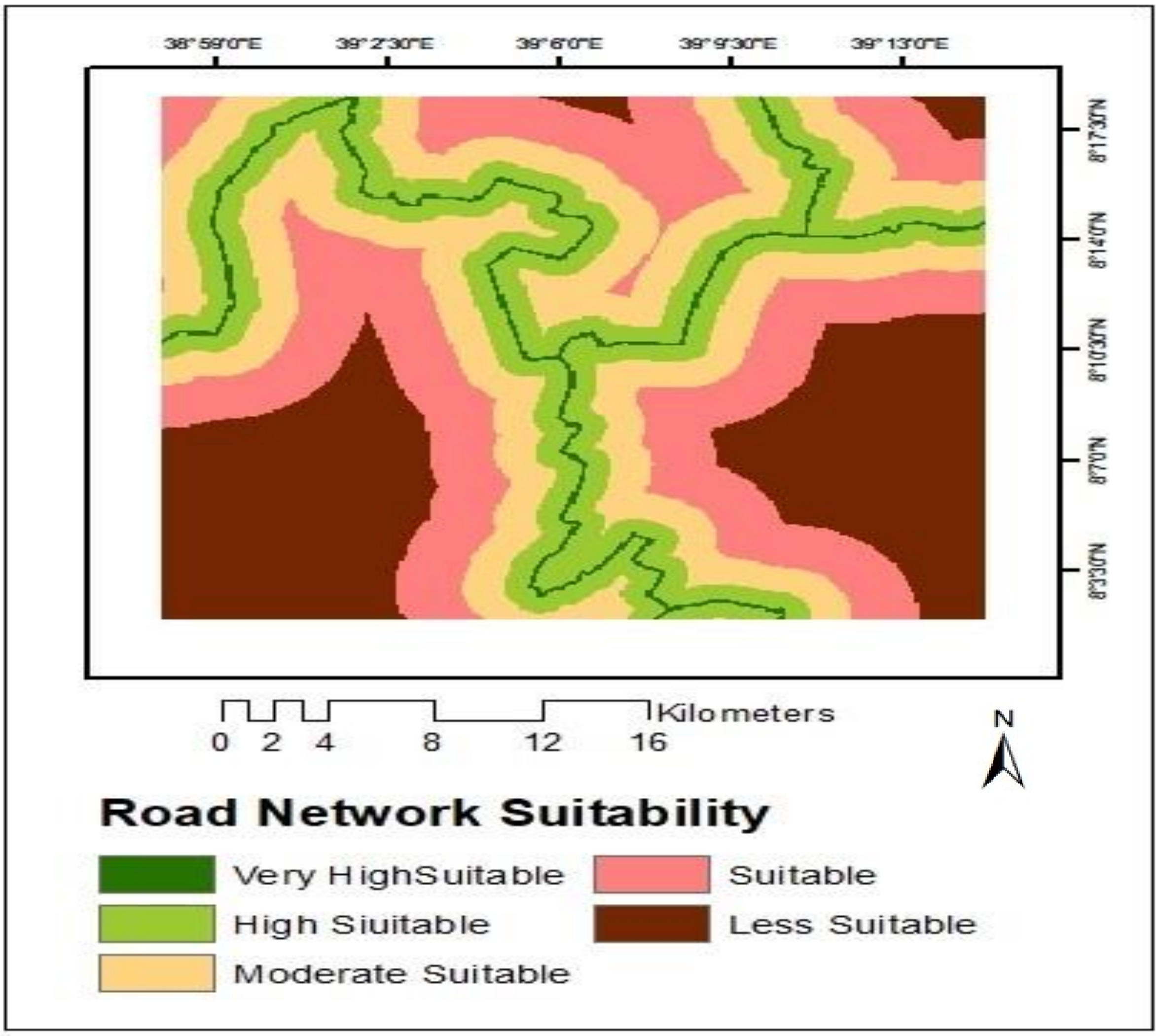


Figure 4.7: Road Network Suitability Map

4.4.7. Suitability of Geology (Soil) layer

The soil data (soil structure and stability) is one of a criterion, as building wind power plant foundations on weak soils will pave way for environmental problems like erosion in the study area. Therefore, the most suitable sites are located where there is strong geological structure which is better for wind turbines installation and to minimize soil erosion. There are various types of soil; this geology is classified in five classes this are, Mollic Andosols, loam, Vitric Andosols, Sandy loam, Luvic Phaeozems & lithic leptosols, Vertic Cambisols, cmv and Eutric Vertisols and water bodies; Very High Suitable, High Suitable, Moderate Suitable, Suitable and not suitable respectively. Soil data is from EGSA and classified according to study area soil types and classified as their suitable.

Table 4.8: Reclassified Geology and Area Coverage of Suitability Levels

Types of Geology layer	Standardization Score/Value	Level of suitability	Area in (Ha.)	(%)
Mollic Andosols, loam	5	Very high Suitable	50958.49	1.99
VitricAndosols,Sandy loam	4	Moderate Suitable	1762.49	21.86
Luvic Phaeozems & lithic leptosols	3	Suitable	19316	20.42
Vertic Cambisols, cmv	2	Less Suitable	20679.81	1.86
Eutric Vertisols and water bodies	1	Not Suitable	1883.146	53.87
		Total	94599.93	100.00

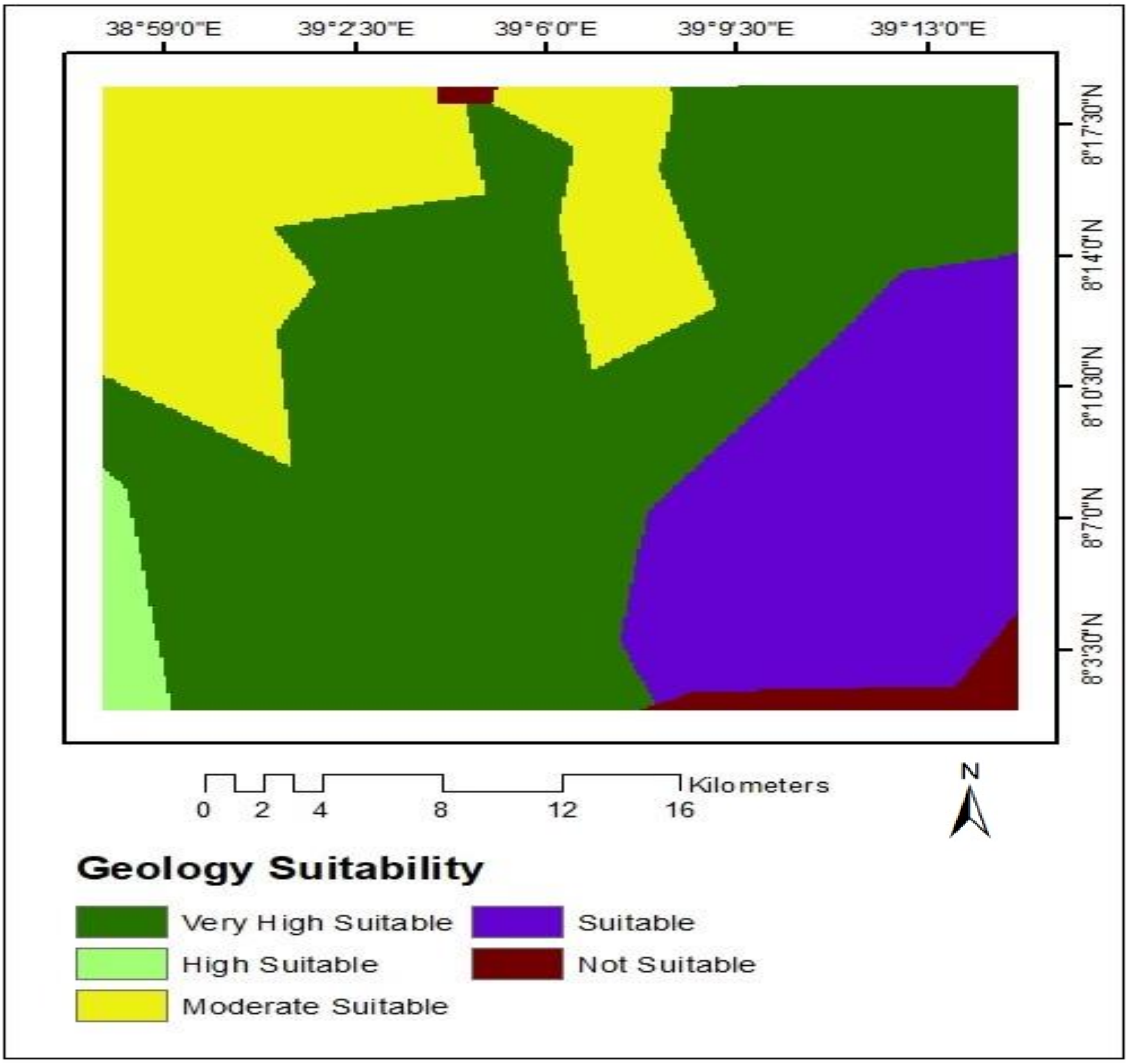


Figure 4.8: Geology Suitability Map

4.4.8. Suitability of Stream Network Layer

Any type of water bodies, rivers are to be protected to conserve the natural wealth. Rivers are dynamic systems that might lead to flooding and direction changes that could place a wind farm in danger. It is advisable for there to be as much distance as feasible. According (Bojan et al, 2016). In this study distance from river was reclassified in to five categories.

Table 4.9: Reclassified Stream Network Layer and Area Coverage of Suitability Levels

Stream(m)	Standardization Score/Value	Level of suitability	Area in (Ha.)	Area in (%)
> 300	5	High Suitable	89491	94.60
200-300	4	Moderate Suitable	2512	2.65
100 -200	3	Suitable	1289	1.36
50 – 100	2	Less Suitable	521.3	0.55
0 – 50	1	Not Suitable	788.3	0.83
		Total	94601	100.00

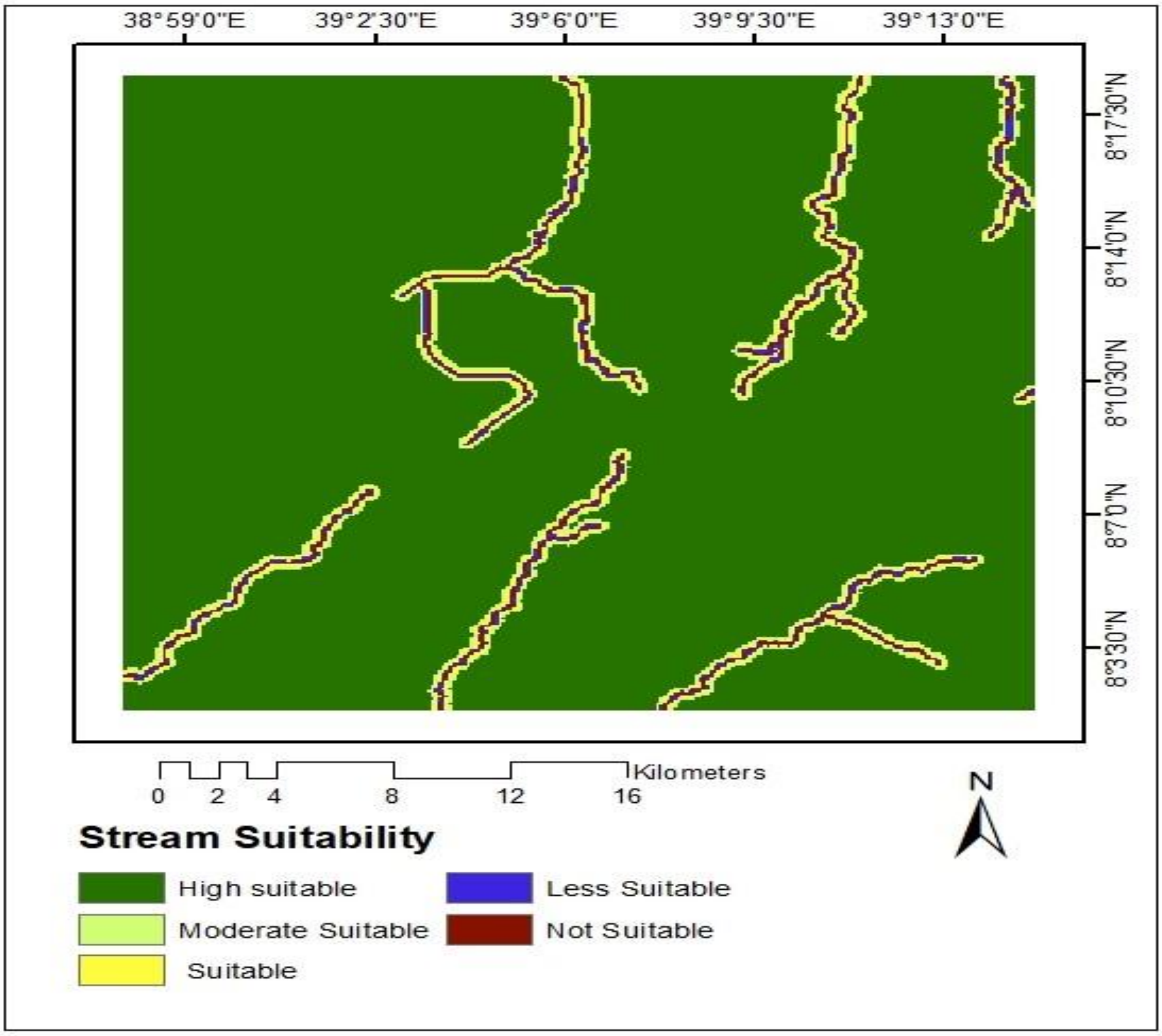


Figure 4.9: Stream Suitability Map

4.5. AHP Weight Derivation

A weight can be defined as a value assigned to an evaluation criterion which indicates its importance relative to other criteria under consideration (Sener et al., 2005). One of the components of GIS-Based MCDA methodology is assigning criteria weights for each factor maps. Assigning weights of importance to evaluation criteria accounts for the changes in the range of variation for each evaluation criterion and the different degrees of importance being attached to these ranges of variation (Malczewski, 2006). The purpose of weighting in site selection process is to express the importance or preference of each factor relative to other factor effect on site analysis. A number of parameter-weighting procedures based on the judgments of decision makers have been proposed in the multi-criteria decision literature. Accordingly, one of the most promising is pair-wise comparison developed in context of a decision-making process is known as the AHP.

AHP is a decision-making technique utilized for solving complex problems, with many parameters of interrelated objectives or concerned criteria. The importance level of each parameter is not equal; some parameters are dominant over others. Different weights can generate difference in the level of suitability (Andi et al., 2017). By comparing factors on a scale from 1 to 9, an analytical hierarchy process (AHP) pairwise comparison matrix was generated, and criteria weights were calculated for each factor. To express the importance or preference of each criterion to the other criterion for a suitable site analysis for wind farm development, the reclassified input datasets were assigned a weight value. As a result, shows wind speed with the weight of 22.93% has the highest priority, 13.85%,12.89%,11.86%,11.63%, 9.89%, 8.98%, and 7.97% was obtained as a weight value for the LULC, Elevation, Geology, Road network, Slope, Steam and Transmission line respectively with 0.036 of consistency ratio. Consistency ratio of 0.1 or less is acceptable to continue the AHP analysis (Saaty, 2008).

In this study, consistency ratio (CR) of conducted AHP comparisons has obtained 0.036, which is smaller than 0.1 therefore the comparisons can be acceptable. According to the findings of this study, AHP is a very useful tool for identifying factor weights and is more beneficial than alternative ways since the Consistency Ratio can be used to calculate and manage the inconsistency of the factor weight's pair-wise comparison matrix (CR). In various studies (Kumar and Shaikh, 2012; Bagheri et al., 2013; Romano et al., 2015; Pokhrel, 2019; this has been confirmed.

Table 4.10: AHP Weight Derivation Matrix for Wind Farm Suitability

	wind speed	Slope	LULC	Transmission line	Road network	stream	Elevation	Geology
wind speed	1							
Slope	0.5	1						
LULC	0.5	0.33	1					
Transmission line	0.25	0.25	0.5	1				
Road network	0.5	0.25	0.25	0.2	1			
Stream	0.5	0.33	0.5	0.33	0.25	1		
Elevation	0.5	0.14	0.33	0.25	0.5	0.16	1	
Geology	0.14	0.11	0.14	0.16	0.25	0.25	0.5	1

(sources AHP Extension in Arc GIS)

Table 4.11: Weights Comparison by AHP

s/n	Factors	weights comparison by AHP	Weight in (%)
1	Wind speed	0.229	22.93%
2	LULC	0.1385	13.85%
3	Elevation	0.1289	12.89%
4	Geology	0.1186	11.86%
5	Road network	0.1163	11.63%
6	Slope	0.0989	9.89%
7	Stream	0.8980	8.98%
8	Transmission line	0.0797	7.97%
Consistency ratio = 0.036, so it is Consistency is acceptable.			

4.6. Weighted linear combination (WLC)

Weighted Linear Combination is a type of MCDA method used in a GIS environment to assess an area's suitability for the development of wind farms. The method combines the reclassified maps to produce an overall suitability score and allows the responsible party to apply weights based on the relative importance of each suitability map (Malczewski, 2004). In this study, GIS based MCDA was employed. This methodology is best suited for wind farm development suitable site analysis accurately in time and cost-effective manner and hence it is used by many researchers.

However, the success of this method strongly depends on the selection of factor weights, as highly preferred factors would produce larger values in the raster output. This issue is critical, so expert's opinion is crucial in the defining scales applied to input layers and weights given to factors in the AHP process.

$$\boldsymbol{S} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} (\boldsymbol{wixi}) \text{..Equation (4.1).}$$

Where, **S** is the composite suitability score, Wi, is weights assigned to each factors

xi, is factor scores (normalized cell values),

4.7. Weighted Overlay Analysis

Weighted Overlay is defined as a technique use to integrate and combine different factor maps with common measurement scale values to produce one final integrated output. The Weighted Overlay Process allows us to set weights for as many different factors as we want to analyze. The weight establishes the relative importance of the factor under consideration. The sum of the weights must equal to 100 percent. Using the Weighted Overlay tool found under spatial analysis tools, the values of each dataset can be weighted and combined at one time (Giap et.al, 2003).

After weighting the factors, as regards the relative importance of each factor as well as suitability index, all the reclassified factors were overlaid in order to select suitable sites for wind farm development using the weighted overlay tool or a raster calculator in ArcGIS and the final wind farm development suitability map was prepared (Table 4.12). The reclassified results obtained above are all compare by pair-wise comparison to get percentages of each layers and combined through the weighted overlay toolset from spatial analyst tools.

Table 4.12: Suitable Area

score	suitability class	Area in (Ha)	Percentage %
5	very High Suitable	10725.02	11.4
4	Moderately suitable	14559.57	15.5
3	Less Suitable	53055.04	56.6
2	Permanently not suitable	14375.75	15.3
1	Restricted Area	1098.083	1.2
Total		93813.46	100.0

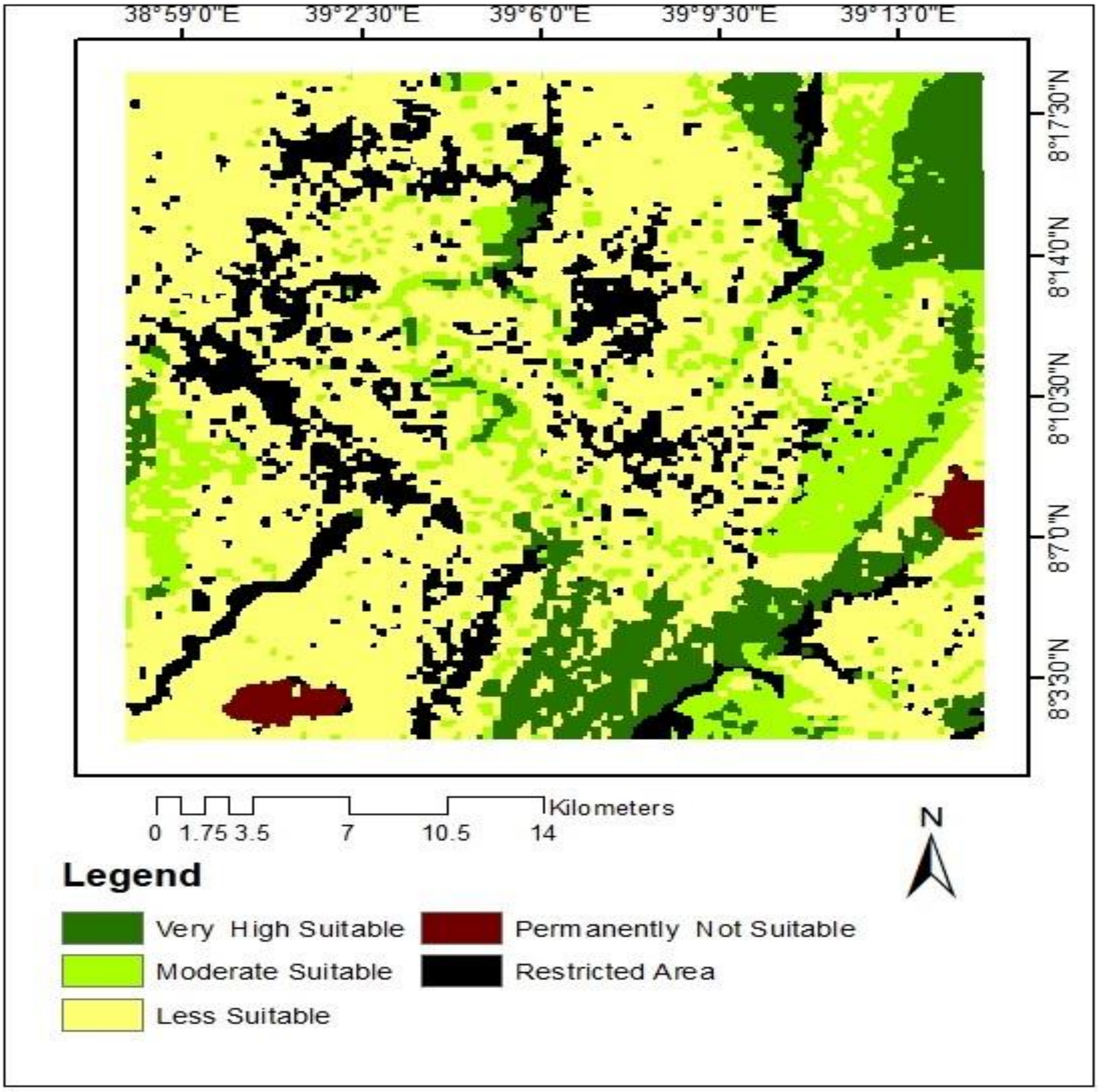


Figure 4.10: Suitability of Study Area Map

Table 4.13: Weighted Overlay Analysis by AHP

Weighted Overlay

Weighted overlay table

Raster	% Influence	Field	Scale Value
Transmission	8	SU_class	
		Very High Suitable	5
		High Suitable	4
		Moderate Suitable	3
		Suitable	2
		Less suitable	1
		NODATA	NODATA
Elevation	13	sut	
		Less Suitable	1
		Suitable	2
		Moderate Suitable	3
		High Suitable	4
		Very High Suitable	5
		NODATA	NODATA
Geology	11	Suitabilitya_index	
		Not Suitable	1
		Suitable	2
		Very High Suitable	5
		High Suitable	4
		Moderate Suitable	3
		NODATA	NODATA
LULC	14	suit	
		Not Suitable	2
		Less Suitable	3
		Permanently Not S	1
		High Suitable	5
		Moderately Suitabl	4
		NODATA	NODATA
Roadnetwork	12	su_index	
		Very HighSuitable	5
		High Siuitable	4
		Moderate Suitable	3
		Suitable	2
		Less Suitable	1
		NODATA	NODATA
Slope	10	sust	
		very High Suitable	5
		high Suitable	4
		moderate Suitable	3
		Suitable	2
		less Suitable	1
		NODATA	NODATA
wind_speed	23	suit	
		Less Suitable	1
		Moderate Suitable	2
		Suitable	3
		High Suitable	4
		Very High Suitable	5
		NODATA	NODATA
stream	9	Su_Index	

Sum of influence: 100

Set Equal Influence

Evaluation scale: 1 to 9 by 1

From To By

Table 4.14: Centroid of Most Suitable Location

OBJECTID *	Easting	Northing		Easting	Northing		Easting	Northing
1	507988.5	917995.6	14	525241	902611	27	518483.8	906470.1
2	519077.1	916748.4	15	508970	901812.8	28	504471.2	898365.6
3	520838.3	888092.1	16	524452	901330.8	29	512458.6	898765.8
4	510114.6	911094.1	17	496612	902242.8	30	511383.1	898640.8
5	525934.4	913880.7	18	523011	898083.2	31	512196.5	897813.4
6	506356.7	906690.4	19	497238	894708.1	32	514068.6	891813.7
7	509966.7	908550.6	20	518226	888567.5	33	497265.3	905728.8
8	511676.7	907187.9	21	526057	889163.3	34	507740.1	908844.4
9	526210.8	906389.4	22	512824	889136.9	35	504196.9	908617.8
10	508014.5	904182.3	23	518101	893244.5	36	511807.2	904827.1
11	513292.6	903732.8	24	510848	897085.8	37	512471	904162.3
12	525821.8	903868.9	25	521479	895250.8	38	520616.9	891982.3
13	509708.7	903268.8	26	520690	908469.6	39	518794.8	890333.4

4.8. Suitability Validation for Most Potential Proposed Site for Wind Farm

The proposed site for wind farm land layers were extracted from the proposed site with the final suitability map of this study to validate their suitability. The total area proposed for wind farm areas development is 93813.46hactar. The area which is very highly suitable is 11%, area which Moderately suitable is 16%, area which is less suitable is 57%, area which is permanently not suitable is 15%, and area which is restricted is 1.2%. Some of the most proposed site for wind farm are Adama, Hitosa, Tiyo, Dodota and Ziway dugda respectively.

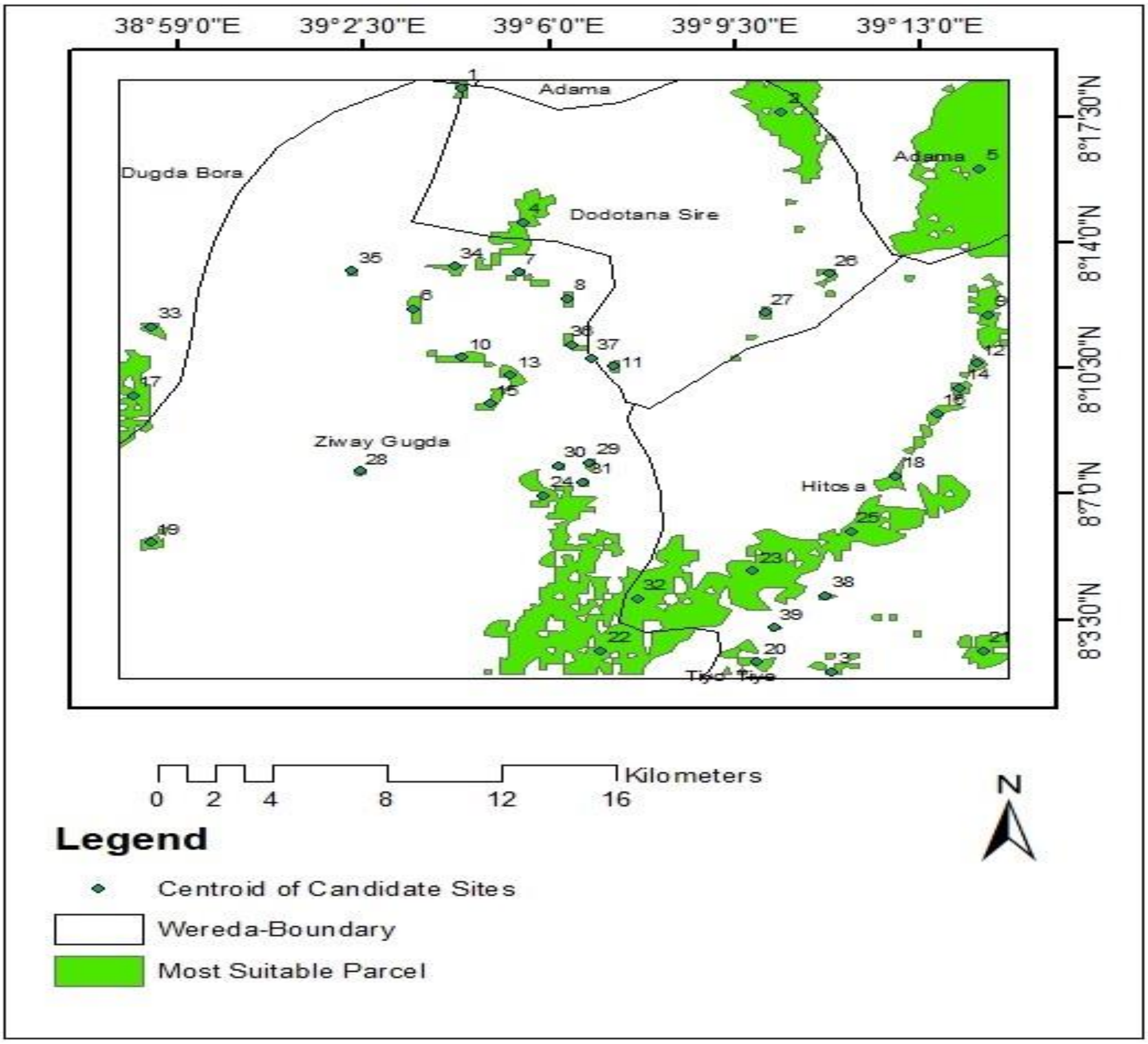


Figure 4.11: Centroid of Candidate Sites

Table 14.15: Centroid of Most Potential Site For Wind Farm

OBJECTID *	Most Potential site	Easting	Northing	Wereda/Area
1	Site_01	519077	916715	Adama
2	Site_02	525889	913870	Adama
3	Site_03	526036	889142	Hitosa
4	Site_04	512819	889145	Tiyo
5	Site_05	517651	892534	Hitosa

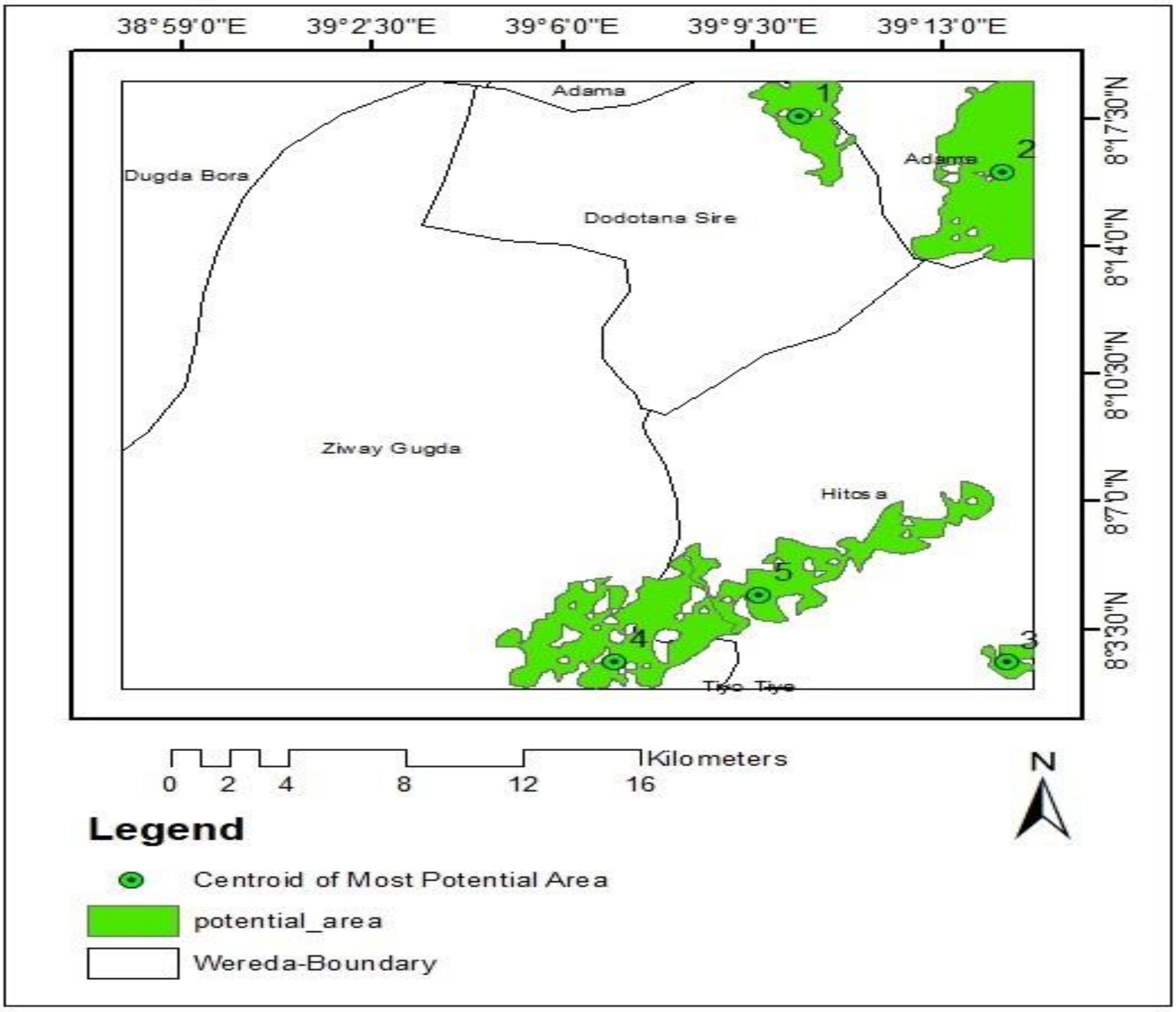


Figure 4.12: Most Potential Proposed Site for Wind Farm Map

As indicated in Figure (4.11) the less suitable sites have the highest area value followed by moderately suitable, permanently not suitable, very high most suitable, and restricted (area….) hectares respectively. As a result, the study area has enough space to accommodate the construction of a wind farm.

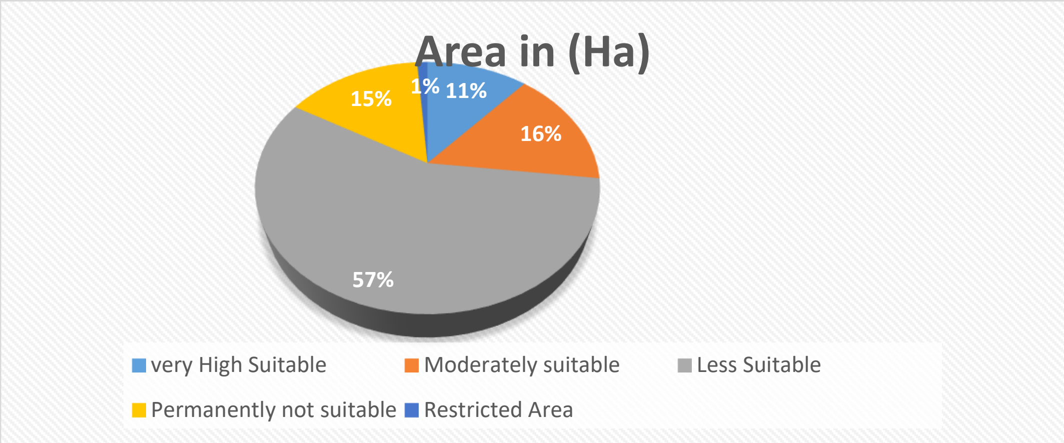


Figure 4.13: Most Proposed Potential Site in percentage

4.9. Discussion

In this study, the final result of the geospatial technologies method to analyzing wind farm suitable sites was developed through the identification and selection of wind farm influential variables, which are the primary determinant for selecting wind farm locations. Despite the fact that AHP and WLC have been used a lot to produce lands suitability maps in a variety of different contexts, there isn't a standardized way to decide how much weight to assign each criterion map (Malczewski,2004).In this study used the main factors (technical, socio-economic and environment) and eight site selection criteria (distance from transmission line, distance from road, stream, land use land cover, slope, geology(soil), elevation and wind speed to select and evaluate wind farm development site.

Vanek and Albright (2008) suggest that provision of appropriate wind speed at the height where the turbine is to be installed determines the amount of wind power at a particular site. Wind speed is the most significant factor among all other factors because it shows us where in the region a wind power project is most probably to be feasible and economical (Baban and Perry, 2001). Hence, in this research the weight obtained from AHP shows that weight of wind speed is 22.93%, greater than the weight of LULC 13.85%, Elevation12.89%, Geology11.86%, Road network11.63%, Slope 9.89%, stream 8.98% and Transmission line 7.97% as presented in (Table 4.11).

Moreover, the different influential factors identified for the analysis are not equally important to select potential wind farm areas. This difference can be managed by multi factor evaluation of weighted linear aggregation method for Weight calculation to give weight to each criterion to reflect their relative importance. This can be effective because it forces the decision maker/s to give thorough consideration to all elements of a decision problem and also by assigning quantitative weights it is possible to make important criteria have a greater impact on the outcome than other criteria.

The main strength of this study is the consideration of multiple criteria and uncertainty in the decision-making process by utilizing the AHP method. Thus, the results obtained and methodology adopted here may have implications for other regions, decision-makers and researchers understanding how can any problem associated with unanswered land use planning problem have been analyzed and assessed based on several geospatial parameters by utilizing GIS, RS and Google Earth technologies. The final suitability map has shown that in (figure4.10), this are classified in five suitability classes (unsuitable, less suitable, moderate suitable, highly suitable and very highly suitable) from all surface of study area, this suitability is described in hectares and percent (10725.02hac or11.4%) very High Suitable area, (14559.57hac or 15.5%) Moderately suitable, (53055.04hac or56.6%) Less Suitable, (14375.75hac or15.3%) Permanently not suitable and (1098.083or1.2%) Restricted Area shown in (table 4.12). The candidate sites identified are on a continuous dimensionless scale ranging from very highly suitable to restricted area. The Weighted Linear Combination (WLC) method, which was used to combine the constraints and factor maps in this study, has this as one of its characteristics. Finally, this thesis research study indirectly plays a key contribution for peoples who live in the villages. By selecting those responsible for choosing wind farm sites for relocation or development as well as by presenting the effectiveness of geospatial technology in the selection of wind farm development areas for the Oromia regional state and Ethiopia.

CHAPTER FIVE: CONCLUSIONS ANDRECOMMENDATIONS

Using geospatial technologies, the current study aimed to determine the best site for the establishment of wind farms. Additionally, identifying the main factors that affect wind farm development like technical consideration, socio-economic consideration and environmental consideration. Different Geospatial technologies with AHP MCA were used for developing the optimal wind farm. The study concludes with the following conclusion and recommendation.

5.1 Conclusion

The main objective of the study is to determine whether site in Between East shoa and Arsi Zone, Oromia, Ethiopia, is suitable for the development of wind farms applying geospatial technologies. The method was quite flexible in creation of the evaluation criteria, reclassified, assigning importance weights, standardization and map overlay suitability decisions could be made were determined based on the expert's opinion, relevant literature, and availability of data.

It provides visual intermediate and final results in the form of thematic maps that are comprehensive and useful for planning purposes. The rapid progress made in geospatial technologies augmented with MCA and analytical hierarchy process nowadays have been put forward with a series of functional capabilities and applications to solve conflicts and complexities in any geospatial decision making. Therefore, this study selects the suitability of site for wind farm sites in study area based on eight criteria that are classified under three types socio-economic, environmental and technical consideration. Performing proximity analysis and standardization for criteria in site selection process is the initial step for objective accomplishment. Spatial parameters upon which suitability decisions could be made were determined based on the expert's opinion, relevant literature, and availability of data. The method succeeds in mapping potential site for wind farm, while considering some factors such as land use land cover, elevation, slope, distance from transmission line, distance from road network, wind speed, geology and stream.

Site suitability analysis is a critical element in determining suitable areas for wind farm development. Proposing suitable sites for wind farm development using suitability analysis involves multi-criteria analysis steps. The result of this analysis revealed that for the selected parameters out of the total area of 93813.46 hectar found in study area, 10725.02, 14559.57, 53055.04, 14375.75 and 1098.083 are very High Suitable, Moderately suitable, Less

Suitable, Permanently not suitable and Restricted area respectively. Based on the output of this study, it was found that the study area has a potential for implementing wind farms to generate power. This will bring major advantages by alleviating incidents related to indoor pollution, and reducing burden on the country's economy by replacing imported fuel.

To counteract the subjectivity of analysis and to identify sustainable wind farm sites, it is significant to ensure and combine the recommendations of numerous academics that have studied proximity analysis for site selection criteria. Analytical Hierarchy Process (AHP) method based pairwise weight calculation is applicable to overcome the vagueness and uncertainty that originate from decision making during choosing the preference of criteria. For selecting a suitable wind farm site geospatial technology mainly GIS, RS and Google Earth are effective and efficient than the traditional approaches.

5.2 Recommendation

The study was an attempt to identify whether wind farm sites in the study area are suitable using geospatial technologies. The study shows that the use of a geospatial technologies for wind farm site suitability analysis is appropriate and a necessity in wind farm development planning.

Based on the result of the present study, the following recommendations are suggested for decision makers and future researchers;

- ✓ Wind speed and it is direction data are one of the crucial information needed for wind farm site selection but this information is poor in quality and distribution. Therefore, stakeholders should systematically acquire and analyze wind energy resource data at least for potential sites in the country.
- ✓ Land use land cover data is one of the crucial information needed for wind farm site selection but this information is poor in quality and distribution. Therefore, stakeholders, planners and government should systematically acquire and analyze land use land cover data at least for potential sites for wind fam in the country.
- ✓ 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.
- ✓ The present study considers main factors like; environmental, and economic for wind farm site standards and necessary documents for wind farm site selection. However, dependent factors including soil fertility, land value, and landscape characteristics

determine the selection of wind farm site and should be taken into consideration while evaluating candidates.

- ✓ As we have seen from this study, there are spots with high wind resource potential and suitable for wind farm development in study area. Therefore, the stakeholders who want to establish wind farm in Ethiopia should give attention to this area.
- ✓ 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.
- ✓ Generally, to selecting potential wind farm, in future the researchers, they should use geospatial technologies further investigated to use in different suitability assessment.

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APPENDICES

Appendix 1: Maximum and Minimum Temperature of Etaya

PARAMET	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
T2M_MAX	2003	26.95	28.05	28.7	27.92	28.3	28.02	23.8	22.62	23.37	25.19	25.51	23.66	28.7
T2M_MAX	2004	26.82	27.49	28.8	27.23	28.59	26.29	23.89	23.32	23.48	25.08	24.63	25.96	28.8
T2M_MAX	2005	27.55	29.49	27.85	28.56	24.13	24.81	23.27	22.97	25.52	25.3	25.85	25.86	29.49
T2M_MAX	2006	26.67	28.05	27.02	25.34	25.68	25.37	23.49	20.85	21.15	22.6	22.99	23.42	28.05
T2M_MAX	2007	25.66	26.26	29.41	27.1	26.9	25.16	22.26	21.04	21.53	22.14	23.14	23.91	29.41
T2M_MAX	2008	25.6	26.78	28.2	27.95	27.54	26.3	24.72	20.86	21.31	22.72	21.89	23.5	28.2
T2M_MAX	2009	25.38	26.44	29.05	26.53	27.81	28.65	23.21	22.12	21.8	21.94	23.93	23.87	29.05
T2M_MAX	2010	26.13	27.52	24.5	25.53	24.98	24.47	22.01	21.03	21.61	21.44	23.33	24.48	27.52
T2M_MAX	2011	25.99	27.08	28.08	28.27	26.97	25.42	24.92	22.99	24.36	24.98	25.17	25.07	28.27
T2M_MAX	2012	26.08	28.28	28.84	25.6	26.65	27.84	22.48	21.26	20.76	22.36	24.22	24.9	28.84
T2M_MAX	2013	27.05	28.03	28.81	25.48	26.08	24.98	21.94	20.43	21.07	21.42	22.09	23.06	28.81
T2M_MAX	2014	25.49	26.36	27.69	27.22	26.31	26.74	25.31	21.34	21.44	21.28	22.67	23.07	27.69

PARAMET	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
T2M_MIN	2003	3.73	7.28	8.16	8.08	7.21	11.12	10.34	10.33	10.05	5.71	6.22	3.44	3.44
T2M_MIN	2004	6.2	6.96	5.51	10.51	10.63	10.33	10.27	9.52	8.97	5.34	4.96	3.94	3.94
T2M_MIN	2005	2.79	4.29	8.52	9.2	9.51	10.35	9.88	9.27	9.56	6.43	4.51	3.33	2.79
T2M_MIN	2006	5.68	7.1	8.72	7.78	10.54	9.65	10.66	9.73	9.08	7.03	4.95	5.56	4.95
T2M_MIN	2007	4.36	7.83	8.01	9.26	9.33	9.48	10.08	10.18	9.44	5.38	3.75	3.03	3.03
T2M_MIN	2008	5.03	4.54	4.97	8.15	10.37	10.19	9.63	9.93	9.33	5.83	3.15	3.78	3.15
T2M_MIN	2009	4.47	6.99	8.44	9.58	10.26	10.58	10.27	8.85	9.08	5.44	4.4	7.07	4.4
T2M_MIN	2010	4.83	8.69	6.55	8.17	11.33	10.23	9.76	10.34	9.27	6.39	4.98	3.56	3.56
T2M_MIN	2011	4.94	5.16	7.33	8.12	10.44	10.4	10.39	9.45	10.33	6	5.95	2.83	2.83
T2M_MIN	2012	5.3	6.03	6.41	9.58	10.28	11.22	9.42	10.19	9.26	5.34	5.41	5.81	5.3
T2M_MIN	2013	5.8	6.8	9.96	10.28	10.87	10.18	10.58	9.73	9.41	6.33	4.62	3.8	3.8
T2M_MIN	2014	5.12	7.65	8.78	9.27	11.3	10.16	10.17	10.03	9.73	6.29	5.42	4.65	4.65

Appendix 2: Maximum and Minimum Temperature of Ogolcha

PARAMET	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
T2M_MAX	2003	30.75	32.25	32.14	31.83	32.81	32.06	26.69	26.05	27.35	29.51	29.87	29.74	32.81
T2M_MAX	2004	30.65	30.7	32.18	31.34	32.64	30.16	27.11	26.1	28.12	28.21	29.08	28.96	32.64
T2M_MAX	2005	30.95	33.51	32.51	32.65	28.92	29.31	26.3	25.92	28.49	28.48	28.8	28.98	33.51
T2M_MAX	2006	30.81	31	30.26	29.48	29.97	29.11	25.46	24.16	24.5	26.04	26.51	27.22	31
T2M_MAX	2007	29.5	30.11	32.48	31.08	30.99	28.68	25.75	23.65	24.3	25.49	26.76	27.48	32.48
T2M_MAX	2008	29.7	30.25	32.06	32.71	31.25	29.01	27.2	23.73	24.62	26.4	25.25	27.8	32.71
T2M_MAX	2009	28.48	31.69	33.37	31.45	32.15	31.99	26.07	24.76	26.23	26.44	27.93	28.15	33.37
T2M_MAX	2010	30.32	31.02	29.94	31.83	31.15	28.51	24.87	24.25	23.9	25.89	27.12	28.49	31.83
T2M_MAX	2011	29.58	31.26	31.54	32.28	30.62	28.21	27.48	25.41	27.82	29.33	28.64	28.07	32.28
T2M_MAX	2012	29.65	31.3	32.48	29.85	31.2	30.87	25.77	23.76	24.36	25.99	28.38	28.4	32.48
T2M_MAX	2013	31.34	31.62	32.12	30.25	29.47	26.68	24.06	23.65	24.8	24.99	26.03	26.87	32.12
T2M_MAX	2014	29.77	30.97	32.38	30.54	30.23	30.09	27.3	24.32	24.76	25.47	26.53	26.48	32.38

PARAME	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
T2M_MI	2003	7.86	11.86	13.35	12.73	12.58	14.34	12.76	13.78	14.12	10.08	10.76	7.15	7.15
T2M_MI	2004	10.63	11.12	10.08	15.37	14.83	14.36	13.81	13.3	13.85	8.83	9.57	8.23	8.23
T2M_MI	2005	6.71	8.72	12.66	13.11	14.65	14.31	13.02	13.4	13.28	9.83	8.36	7.88	6.71
T2M_MI	2006	10.28	10.8	11.47	12.16	14.07	14.19	13.48	12.9	13.16	10.15	8.65	9.51	8.65
T2M_MI	2007	8.59	11.61	12.21	13.18	13.14	13.62	13.04	13.77	12.23	8.58	6.89	7.4	6.89
T2M_MI	2008	9.35	9.13	9.08	11.69	15.46	14.2	12.37	13.76	12.73	9.3	6.44	7.12	6.44
T2M_MI	2009	7.89	10.7	13.58	13.88	14.68	14.92	13.55	13.34	12.79	9.19	8.19	11.25	7.89
T2M_MI	2010	9.42	13.08	10.97	12.6	15.85	13.97	13.69	13.15	12.8	10.06	8.63	6.54	6.54
T2M_MI	2011	8.61	9.51	11.48	12.33	15.13	14.19	14.03	12.27	13.98	9.86	9.55	7.12	7.12
T2M_MI	2012	8.05	10.16	10.73	14	14.51	13.65	12.66	13.12	12.95	8.49	9.47	9.98	8.05
T2M_MI	2013	9.31	11.37	14.62	15	14.24	14.04	12.8	12.7	13.35	9.52	8.77	7.36	7.36
T2M_MI	2014	9.51	12.23	13.12	13.45	14.89	14.07	13.33	13.41	13.24	9.71	9.71	8.02	8.02

Appendix 3: Maximum and Minimum Temperature of AlemTena

PARAME	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
T2M_MA	2003	28.43	30.15	29.89	30.41	32	31.05	26.83	25.49	26.33	28.06	27.7	26.13	32
T2M_MA	2004	28.9	29.2	30.15	28.47	31.69	29.23	26.32	26.05	27.01	26.68	27.44	27.24	31.69
T2M_MA	2005	28.3	32.77	32.15	30.87	27.4	29.26	26.66	25.8	26.74	27.51	27.31	26.98	32.77
T2M_MA	2006	28.16	29.07	28.04	27.86	28.91	29.34	26.04	23.78	24.25	25.54	25.04	25.85	29.34
T2M_MA	2007	27.23	27.92	30.99	28.62	29.83	27.89	25.23	23.69	24.62	23.9	24.77	24.83	30.99
T2M_MA	2008	26.76	28.6	31.8	30.14	29.58	28.94	27.47	23.45	23.71	25.46	23.5	25.21	31.8
T2M_MA	2009	26.53	29.2	31.19	29.72	30.67	31.45	26.27	24.62	25.69	25.91	25.9	25.77	31.45
T2M_MA	2010	27.51	29.31	27.57	28.55	28.19	28.26	25.33	23.64	23.3	24.61	25.37	25.57	29.31
T2M_MA	2011	27.93	28.87	29.74	29.94	28.74	28.12	27.19	25.2	27.48	28.03	26.92	26.88	29.94
T2M_MA	2012	27.36	29.94	30.25	29.24	30.14	31	25.39	23.9	23.45	24.82	26.32	26.33	31
T2M_MA	2013	30.59	29.51	30.59	29.62	27.87	27.35	24.37	23.08	24.26	24.4	23.92	25.19	30.59
T2M_MA	2014	27.41	28.22	29.38	29.26	28.16	29.4	27.03	24.19	23.69	23.89	25.26	24.84	29.4

PARAME	YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
T2M_MI	2003	3.81	8.67	10.12	10.11	9.94	12.22	11.5	12.01	11.26	7.89	7.38	3.86	3.81
T2M_MI	2004	7.99	8.3	6.08	12.46	12.26	13.08	12.09	11.53	11.39	6.34	6.52	4.58	4.58
T2M_MI	2005	2.8	5.72	9.8	9.94	12.45	12.21	11.79	10.31	11.71	7.51	4.95	4.72	2.8
T2M_MI	2006	7	8.36	7.84	10.18	11.4	11.93	11.46	11.6	10.52	7.93	5.8	6.69	5.8
T2M_MI	2007	5.6	9.34	9.2	9.32	10.71	12.66	11.5	11.97	10.45	6.05	4.37	4.16	4.16
T2M_MI	2008	5.79	5.94	5.8	8.8	13.01	11.83	10.94	11.02	10.42	7.06	3.99	4.35	3.99
T2M_MI	2009	5.4	8.12	10.66	11.62	11.61	13.45	12.01	11.5	10.47	6.6	5.71	8.33	5.4
T2M_MI	2010	5.8	9.9	7.26	11.66	13.61	12.28	12.43	11.87	11.13	7.42	5.72	4.72	4.72
T2M_MI	2011	5.81	5.94	8.06	9.07	12.26	12.33	12.08	10.87	11.28	7.26	7.37	4.05	4.05
T2M_MI	2012	6.4	6.94	7.58	11.05	12.12	12.73	11.16	11.29	11.33	6.19	6.87	6.96	6.19
T2M_MI	2013	6.37	8.2	11.87	11.89	13.02	12.28	10.55	11.12	11.64	7.37	5.21	4.72	4.72
T2M_MI	2014	6.88	8.47	11.09	11.65	12.63	11.99	11.23	11.48	11.4	7.65	6.7	5.73	5.73

Appendix 4: Total Monthly Rainfall of Ogolcho

		Ogolcho monthly total rainfall											
year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2003	6.1	58.1	90.8	86.5	33.4	94.6	176.6	95.8	91.5	3.4	0.2	38.5	775.5
2004	32.5	0	49.1	125.2	9.5	76.5	68.6	71.3	121.7	16.6	0	0	571
2005	42	6.4	55.4	103.9	42.9	35.1	67	55.4	101.51	13.4495	4	0	527.06
2006	0.9	22.7	49.3	113.1	55.0521	47.8	162.235	26.5	13.2	44.6	0	0	535.387
2007	0.5	13.5	51.3	47.9	107	184	132.3	112.5	124.2	46.3	0	0.6	820.1
2008	6.8	0	16.2	155.8	215.8	83.38	301.8	193.2	67.02	201	17.7	0	1258.7
2009	38.9	2.77	22.9	53.88	37.43	69.17	121.44	48	43.3	58.7	24.2	105.7	626.401
2010	4.6	99.8	136.6	86.2	240.6	99.7	159.4	84	116	0	1.3	0	1028.2
2011	13.8	14.6	84.3	0	0	39.8	172	101.5	133.8	0	38.3	0	598.1
2012	0	0	13.5	63.7	25	55.1	323.4	223	170.7	4	0	0	878.4
2013	0	0	96.5	68.4	66.3	65	149.2	90.1	81.4	80.7	1.8	0	699.4
2014	0	23.5	53.7	50.2	59.4	9.3	86.7	88.5	86.4	91.2	0.3	0	549.2

Appendix v: Total Monthly Rainfall of Etaya

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2003	78.5	56	63.2	101.7	24.9	130.6	278.2	309.7	304.8	4	0	38.8	1390.4
2004	42.4	0.8	74.5	236	7.1	91	223.3	126.4	179.1	109.9	11.1	5	1106.6
2005	63.6	55.1	67.5	156.2	140	90.5	142.8	84.7	28.3	17	38.2	0	883.9
2006	0	10.1	39.4	135.3	36.2	159.8	172	119.2	82.2	10.4	0	33	797.6
2007	24.2	27.5	87.7	60.9	131.7	237.7	346.9	110.1	114.6	56.1	4.2	0	1201.6
2008	13.3	0	0	69	81.2	139.5	394.5	311.7	124.9	110.4	109.8	0	1354.3
2009	22.2	0	7.3	31.2	1.8	81	212.4	174.9	72.3	55.7	1.2	6.4	666.4
2010	0	47	82.8	48.2	169.9	139.9	581	184.2	265.8	0	2.7	4.5	1526
2011	0	11	25.1	20.3	155.6	142.5	118.2	166.6	123.2	0.8	20	0	783.3
2012	0	0	81	112.7	88	85.1	248.3	155.2	178.8	17.3	5.3	1.2	972.9
2013	9.2	0	77.2	22.1	157.7	90.6	238.6	127.1	63	60	17.1	0	862.6
2014	0	10.3	35.4	16.3	82.9	40.4	160.1	170.4	132.1	82.2	0	0	730.1

Appendix 5: Total Monthly Rainfall of AlemTena

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2003	19	16.7	116.3	54	29.4	84.6	392.5	105.4	96.5	0	0	21.7	936.1
2004	89.4	0	58.4	174.3	0	78.8	122.9	145	110.6	40.5	0	2.5	822.4
2005	32.7	1.2	100.9	130.7	80.4	55.1	103.6	237	136	12.5	5.5	0	895.6
2006	1.2	64.9	147.9	46.4	48.9	55.3	167	124.5	69.4	27.7	0	15.4	768.6
2007	10.1	32.96	29.88	47.8	101.5	136.7	146.6	153.1	116.4	5.2	0	0	780.24
2008	0	0	0	36	90.1	162.8	239.6	212.7	140.3	27.7	48.4	0	957.6
2009	120.9	0	19.6	28.8	55.57	61.3	147.6	85.36	64.91	80.4	4.12	77.27	745.83
2010	0	55.4	134.9	58.7	95.8	81.6	185.5	144.7	64	0	16.2	2.57	839.37
2011	0.11	0.23	1.57	1.59	2.86	2.92	3.42	3.28	2.07	0.3	0.73	0.02	1.6
2012	0.01	0	0.39	3.41	0.83	2.14	7.87	7.91	4.29	0.21	0	0.26	2.29
2013	0.47	0.05	2.34	4.69	2.86	3.96	7.14	5.98	4.05	2.08	1.29	0	2.93
2014	0.05	1.01	1.51	2.32	3.19	2.73	5.34	5.29	4.59	2.74	0.57	0.32	2.48
2011	0	5.27	42.19	15.82	79.1	84.38	94.92	105.47	47.46	0	15.82	0	490.43
2012	0	0	5.27	89.65	15.82	58.01	247.85	237.3	131.84	0	0	0	785.74
2013	10.55	0	73.83	131.84	73.83	116.02	232.03	168.75	105.47	58.01	31.64	0	1002
2014	0	15.82	36.91	47.46	79.1	73.83	174.02	179.3	137.11	79.1	10.55	0	833.2