ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

DEPARTMENT OF GEODESY AND GEOMATICS ENGINEERING

SOLAR PHOTOVOLTAIC POWER PLANT SITE SELECTION USING MULTI-CRITERIA APPROACH: CASE OF EAST SHOA ZONE, ETHIOPIA

Thesis Submitted to the school of Civil Engineering and Architecture in partial fulfillments of the requirements for the award of the degree of master of science in Geodesy and Geomatics Engineering.

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APPROVAL

The thesis paper attached here to, entitled “*Solar photovoltaic power plant site identification in East showa using multi-criteria approch*” prepared and Submitted by Debela Tadesse to the School of Civil Engineering and Architecture in partial fulfillments of the requirements for the award of the degree of master of science in Geodesy and Geometics Engineering.

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DECLARATION

The thesis paper attached here to, entitled "***Solar photovoltaic power plant site identification in East showa using multi-criteria approch***" prepared and Submitted by Debela Tadesse to the School of Civil Engineering and Architecture in partial fulfillments of the requirements for the award of the degree of master of science in Geodesy and Geometics Engineering authentic record of my own work under supervision of **Dr. Tilahun Erduno** (major advisor) and **Mr. Dejene Tessema**(co-advisor).

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CERTIFICATE

This is to certify that the above statement made by the author is correct and to the best of our knowledge and believe.

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ACRONYMS

PV	Photo Voltaic
UTM	Universal Transverse Mercator
CI	Consistency Index
RI	Random Index
CR	Consistency Ratio
DEM	Digital Elevation Model
NREL	National Renewable Energy Laboratory
ICS	Interconnected System
SCS	Self-Contained System
CSA	Central Statistical Agency
MCDA	Multi Criteria Decision Analysis
EIA	Energy Information Administration
GIS	Geographical Information System
AHP	Analytical Hierarchy Process
GHG	Green House Gas
EEPCO	Ethiopian Electric Power Corporation

ABSTRACT

Solar energy replacing conventional non-renewable energy has been widely implemented around the world. Before installing solar panels, assessing where solar panels should be placed can significantly benefit panel performance. The goal of this study was to identify and map the most suitable sites for solar power plant using multi criteria GIS modeling in East Shewa zone.

This study demonstrated the use of spatial analysis and GIS techniques for identifying potential solar panel installation sites at macro-scales. To achieve the stated objective, a suite of physical, Economic and Environmental factors were selected as criteria to model the most suitable location for solar power plant site. Water bodies, forest and urban land which extracted from classified land use land cover were used as a constraint for solar power plant site. Boolean overlay (applied for the three constraint factor) and weighted overlay of factors using AHP approach were used to model the final solar power plant in east shewa zone.

The final solar farm site suitability map reveals that the study area was divided in to five different classes. The area under more suitable, moderate suitable, suitable, less suitable and unsuitable (restricted area) stands at 1%, 27%, 44%, 11% and 17% respectively and the technical potential of more suitable area computed/assessed. In this study, the more suitable site were categorized in to six solar farm classes, and evaluated, prioritized and ranked depending on their estimated technical potential, size, distance from nearby the road and distance from nearby transmission line and the result showed that solar farm site 6 is the most suitable site and the estimated technical potential of the selected site 322.25 MW) while solar farm site 2 and solar farm site5,placed on the second and third rank with 309.38MW and 317.40MW respectively.

Key words: *Solar photovoltaic power plant, GIS, AHP, Technical potential, Solar panel and Multi-Criteria analysis.*

1. INTRODUCTION

1.1. Background of the study

Energy is a key element required for sustainable development and prosperity of a society (Amer, 2011). Nowadays, more than 80% of the global primary energy demand is based on fossil fuels. Clearly, fossil fuel resources are limited and will run out in the future. Global energy demand is projected to increase by 49% in the next 20 years and oil consumption is expected to grow from 86 million barrels per day in 2007 to 104 million barrels per day in 2030, has tremendous impact on the world economy, ecology and global climate (Brink & Marx , 2013).

The representatives of 195 countries in the 21st conference of the countries committed to climate change convention in Paris climate conference (COP21) in December 2015 reached a legal and binding agreement for determining the environmental situation of the earth. In this conference, development in the consumption of fossil fuels such as oil, biomass fuel and gas was considered to be the main reason for the emission of greenhouse gases and global warming. Based on the final COP21 statement, world's countries have committed themselves to maintain increase in the Earth's temperature to be lower than 2 ^{0}C.

The depletion of fossil fuels and the increasing awareness about environmental pollution have led to the use of renewable energy resources in the 21st century (Kang-et-al, 2012).

Renewable energy sources are clean sources and have a much lower environmental impact than other energy sources. Solar power generation has emerged as one of the most rapidly growing renewable sources in the world and has several advantages over other forms such as cleanest and silent source of energy.

In Ethiopia, almost 95 percent of electric energy is dependent on hydropower. The siltation of the reservoirs of the hydro power dam are losing their storage capacity resulting in reduced energy output. The other restriction of hydropower system is influenced by weather condition variability. In a time of low rain fall and drought, the amount of water availability during the summer season does not allow the reservoirs to be filled up to the required volume. The changes in water availability indicate the problem of electric energy supply. There is a need to supplement the power supply by alternative energy source, such as solar energy in order to guarantee the security of energy supply, the energy generation system has to be diversifies (EEPCO, 2006).

Site selection of solar power system is a difficulty, because the decision of power plant sites has a strong relationship with the plant's stability, efficiency and durability which should meet the technical requirement, economic requirement and environmental requirement (Yun-na & Luo-jie , 2013).

This paper use the combination of Analytic Hierarchy Process (AHP) with multi-criteria GIS modeling for the most appropriate solar farms site selection in East Shewa Zone.

This study develops a four-step framework; the map of unsuitable regions is extracted based on the defined constraints using Boolean overlay of constraints, factor map developed in order to identify the suitability of different regions of the study area using multi-criteria GIS modeling; the relative weights of defined criteria determined by applying analytical hierarchy process (AHP) technique. By overlaying these criteria layers, the final map of different regions of East shoa zone for development of solar photovoltaic (PV) power plant site obtained. In third step, assessment of technical potential of more suitable area is computed and lastly, the selected solar farm site is evaluated, prioritized and raked depending on determinant criteria/factors. Finally, based on the elsewhere scenario analysis was made, result obtained and presented in the form of maps and charts.

1.2. Statement of the problem

The rapid growth of business and population are putting more and more pressure on world power resources. The energy demand is likely to increase even faster, the proportion of energy supplied by electricity will also scale up with the same rate (William & Marry , 2004). The main source of energy, fossil fuel and biomass fuel that we use are believed to be running out rapidly. Moreover such kind of energy source can cause harm to our environment.

In Ethiopia, the electric power system is dependent on hydropower (EEPco, 2006). The siltation of the reservoirs, some of the hydro power dam are losing their storage capacity resulting in reduced energy output. The other restriction of hydropower system is influenced by weather condition variability. In a time of low rain fall and drought, the amount of water availability during the summer season does not allow the reservoirs to be filled up to the required volume. The changes in water availability indicate the problem of electric energy supply (EEPCO, 2006). Because of this, Biomass fuel is being consumed and the environment degraded at an unsustainable rate, the transformation from agriculture to industry is significantly constrained by current challenges in the power sector. While the vast potential of other forms of renewable energy (solar, wind, geothermal, etc.) remains virtually undeveloped. There is a need to supplement the power supply by alternative energy source, such as solar energy in order to guarantee the security of energy supply, the energy generation system has to be diversifies.

1. 3.Objectives of the study

The ***general objective*** of this study is to identify and map the most optimal location for the development of grid-connected solar photovoltaic power plant sites in East shoa zone using multi-criteria approach.

The ***Specific objectives*** of the study is to:

- Identify the constraint and factors necessary for solar photovoltaic power plant site selection.
- Develop constraint and factors map.
- Determine the technical potential/potential assessment of the identified suitable site.
- Evaluate the selected solar farm Sites to prioritize and rank the identified suitable sites according to their suitability.

1.4. Research questions

- What are the factors that are necessary in solar power plant suitable site selection?
- How suitable solar power plant site is identified and its map prepared?
- How does the technical potential of selected area computed?
- How does the final selected power plant site evaluated?

1.5. Significance of the study

There are numerous economic and environmental benefits associated with solar photovoltaic power plant. First, it can assist the diversification of current energy markets. In addition, it can reduce local and global greenhouse gas emissions and can supply specific needs for energy services, particularly in developing countries and rural areas. Furthermore, the result of the study should be used for future energy planners, policy makers, decision makers, NGOs and entrepreneurs.

1.6. Scope of the study

The study focuses mainly on suitable solar power plant siting in East Shewa Zone by incorporating economical, technical and environmental factors. This study develops a four-step frameworks. In the first step, the map of unsuitable regions is extracted based on the defined constraints using Boolean logic. In the next step, in order to identify the suitability of different regions of the study area, 10 defined criteria are identified. The relative weights of defined criteria also determined by applying analytical hierarchy process (AHP) technique. Next, by overlaying these criteria layers, the suitability of different regions of East shoa zone identified and mapped. It also focuses on evaluation of selected candidate sites to prioritize and rank the identified suitable sites according to their suitability and computation of technical potential of the solar farm sites. Engineering and design part of the construction are not included.

1.7. Organization of the paper

This thesis includes five chapters, the first chapter presents the introductory part which describe the background of the study, statement of the problem, objectives of the study, research questions, significance of the study, scope, limitation of the study and the organization of the thesis. The second chapter discusses the available literature related to the study, reviewed of related study to find the scientific support and theories behind the methodology. The third chapter presents the data collection, materials used, software used, the methods of data analysis. The fourth chapter spotlight on the result and discussion, building GIS based multi criteria analysis is the most important part of the whole study. In this chapter, the result is introduced and determination of criteria and computations of weight of factor are the important part of the study. Chapter five is the last chapter of this study, which concludes by summarizing the findings, contributions and limitations of this study and also forward the recommendations to improve the solar farm site selection in the future siting decisions.

1.8. Limitation of the study

This study had some limitations, including lack of appropriate financial support, the very critical and the principal was problem of obtaining the relevant data due to unavailability and lack willingness by few officers to provide relevant data was the major head ache; this reduce the accuracy of the work. However, formally and informally the author tried to collect the necessary data and other needed documents so as to complete the study and come up with the desired outcome.

CHAPTER TWO: LITERATURE REVIEW

2.1. Empirical Review

According to related forecast of International Energy Agency (IEA), by 2050, solar power generation will have accounted for 11% in global power supply, and then global photovoltaic power generation capacity will have approached 3,000GW, annual power output will have reached 4,500TWh, solar photovoltaic power generation capacity will have increased by nearly 100 times relative to that of 35GW in 2010. Here from it can be seen that photovoltaic power generation has very broad development outlook and room.

There are several studies performed recently about optimum solar power plant sitting and potential using application of Geographic Information System (GIS) across the world. Some of them are reviewed as following:

2.1.1. Optimal Site Selection for Solar PV Power Plant of Oman

Charabi & Gastli made a study of comparable nature in exploring the allocation of potential future PV sites in Oman (Charabi & Gastli , 2011). The analysis was carried out as a multi-criteria evaluation (MCE) that consisted of Boolean constraints as well as weighted factors. The criteria consisted of nine variables that fell into three distinct categories technical (Solar Radiation, Land Accessibility, Land use), economical (Grid proximity, Land slope, Load poles), and environmental (Sensitive areas, Hydrographic line, Sand/dust risk). They then input the factors into their model weighting them using a combination of algorithms from the ordered weighted averaging methodology and the analytical hierarchy process (AHP).

2.1.2. SESCI Photovoltaic Potential Mapping for Canada

Due to a lack of measured incoming solar radiation data in Canada, a photovoltaic potential map of the Thompson-Okanagan region was interpolated based on annual PV potential (kWh/yr) data released by the Solar Energy Society of Canada (SESCI) (Pelland et al, 2006). The SESCI study was performed to establish photovoltaic potential mapping of

Canada for Natural Resources of Canada (NRCAN) and was based on data retrieved from the Clouds and Earth's Radiant Energy System (CERES, 1974-1993). The CERES data gathered information from 144 major meteorological stations nationwide as well as an additional 8 stations based in Alaska, USA. This data was established in mean monthly and annual incoming global solar radiation values and calculated by SESCI to the annual photovoltaic potential for the PV mapping purposes. Pelland et al., Once the annual photovoltaic potential in kWh/year were calculated for the stations the PV maps were created using the interpolation method which was completed at a 95% confidence level and assigned PV potential values for 3500 municipalities nationwide. This thesis proposes the interpolation of the SESCI values to accurately model the photovoltaic potential in the study region (Pelland et al, 2006).

2.1.3. GIS based optimal site selection of PV site in Colorado

A similar case study was performed by Janke to determine the most optimal locations for wind and solar farms in the state of Colorado, USA. In this multi-criteria analysis Janke stated the MCA criterion as "wind speed and solar potential classes, land cover, population density, federal lands, and location of roads, transmission lines, and cities." Using these criteria a comprehensive analysis was made accounting for all the technical factors involved in site placement. Janke however, in contrast to the previously examined case studies, used a simplified weighting system assigning the most important factors (wind and solar potential) with a value of three down to the least important with a value of one (Janke, 2010).

2.1.4. Case Study of Spain

This thesis draws on methods used in previous case studies for the site selection of renewable energy farms. Carrion et al., carried out research to determine the most optimal sites in Spain for the allocation of a PV farm. The research describes the criterion required for locating the most optimal PV site as being within four distinct categories environment, Orography, location, and climate (Carrion-et-al, 2007). The four categories of criteria are further broken down in analysis to positive and negative indicators or restrictions within each factor. These indicators or restrictions are the specifics within each factor that influence and restrict the final outcome of the study. The initial three categories of criteria are environment, orography (slope, orientation), and location (highway access) were used in conjunction by Carrion et al. for determining preliminary location. The fourth criterion climate composed of the factors; global irradiance was used to maximize the energy output of the site. The factors that fell under the climate criteria were weighted highest in this analysis.

2.2. Conceptual Review

2.2.1. Basics of Renewable Energy

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

*Theoretical potentials***:** The highest level of potential is the theoretical potential. This potential only takes in to account restriction with respect to natural and climatic parameters**.**

*Geographical potential***:** Most renewable energy sources have geographical potentials. E.g. land use land cover that reduce the theoretical potential. The geographical potential is the theoretical potential limited by the resources at geographical locations that are suitable.

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

Economic potential: The economic potential is the technical potential at cost levels considered competitive. Economic potential is the proportion of the technical potential that can be utilized economically. It takes into account costs and other socioeconomic factors.

2.2.2. The Energy sector in Ethiopia

Access to energy is among the key elements for the economic and social developments of Ethiopia. The energy sector in Ethiopia can be generally categorized in to two major components: traditional and modern (traditional biomass usage and modern fuels i.e electricity and petroleum). As more than 80% of the country's population is engaged in the small-scale agricultural sector and live in rural areas, traditional energy sources represent the principal sources of Energy in Ethiopia.

Domestic energy requirements in rural and urban areas are mostly met from wood, animal dung and agricultural residues. At the national level it is estimated that biomass fuels meet 88 % of total energy consumed in the country. In urban areas access to petroleum fuels and electricity has enabled a significant proportion of the population there to employ these for cooking and other domestic energy requirements.

A survey by the Central Statistics Agency (CSA) in 2004 showed that about 71.1% of the total households use kerosene for lighting followed by firewood (15.7%) and electricity (12.9%). A higher proportion of urban residents use electricity (75.3%) for lighting, while the use of kerosene (80.1%) and firewood (18.5%) are predominant in rural areas. Major types of cooking fuel used by all households are firewood, leaves, dung cakes and kerosene. At the country level, about 81.4 % of the households use firewood, around 11.5 % cook with leaves and dung cakes and only 2.4 % use kerosene for cooking. The majority of rural households use firewood (84.4 %) and few of them (12.7 %) use leaves and dung cakes.

The use of modern source of cooking fuel such as butane gas, electricity and kerosene for cooking is uncommon in the rural areas (0.4 %). Use of kerosene is common in urban areas and stands at 13.8 % following firewood (65.4 %). Charcoal (7.7 %), electricity (2.4 %) and leaves (5.3 %) are also used by urban households. On the other hand, only 0.2 % of the households in rural areas are observed to use charcoal for cooking.

Currently, Hydropower is the main electric power supply in Ethiopia, EEPCO is the only electric utility enterprise in Ethiopia. The power system in Ethiopia is divided in to two systems, namely ICS (Interconnected system) and SCS (self-contained system). ICS is the most important power system in Ethiopia, which is a system dominated in hydropower. SCS is relatively independent, comprising small hydropower and diesel generators. Until the end of 2010, the total installed capacity of power system in Ethiopia was 2959.69MW, with total ICS installed capacity of 2,022.2MW and total SCS installed capacity of 37.49MW. Now, there are 141 sub stations in EEPCO, including 138 ICS substations, 10 hydropower substations, 3 diesel substations and 3 small SCS hydropower substations. The existing transmission line system is 10,397.42km in EEPCO at present. In which, ICS possesses 400KV line of 620.72KM single circuit power transmission and 65.98KM double circuit power transmission, 230KV line of 2842.53KM single transmission circuit power transmission and 443.77km double circuit transmission, 132kv line of 4,202.8km single circuit power transmission and 113.34km double circuit transmission, 66kv line of 1835.11km, and 45kv line 264.16km single circuit power and 9km double circuit power transmission. The remaining transmission line is possessed by SCS. According to the data provided by EEPCO, the total ICS installed capacity in 2010 was 2022.2MW In which there were 11 hydropower stations, with a total installed capacity of 1,842.6MW, accounting for 91.1% of the whole ICS, with 172.3MW in diesel generator accounting for 8.5% of the whole ICS, (Hydrochina-corporation, 2012).

The Government of Ethiopia (GoE), under its latest Growth and Transformation Plan (GTP), envisions transitioning from a developing country to a middle-income country by 2025. Ethiopia's ability to achieve this ambitious goal in such key sectors as agriculture and industry is significantly constrained by current challenges in the power sector. Although Ethiopia is endowed with abundant renewable energy resources and has a potential to generate over 60,000 megawatts (MW) of electric power from hydroelectric, wind, solar and geothermal sources, currently it only has approximately 2,300 MW of installed generation capacity to serve a population of over 95 million people. The targets for increasing generation capacity to 10,000 MW established under GTP I will be met by completion of two major hydro power plants in 2017 – 2018.

The current GTP II has a new target to increase generation capacity to over 17,000 MW by 2020, with an overall potential of 35,000 MW by 2037, which would help sustain Ethiopia's continued economic growth and enable it to become a regional renewable energy hub in East Africa.

The government is keen on exploiting the complementary between solar and hydro power. "Hydro power works best during the rainy season when reservoirs can be filled to utmost capacity, while solar power is, the opposite, working best during the dry season. So it can act as a plug against power shortage especially in the age of climate change,"

2.2.3. Solar Energy

Solar energy is another ancient energy resource which had been used through the history. One of the earliest developments on solar technology was made by Lavoisier who achieved to construct a 1700˚C solar furnace in the eighteenth century. Today, wide ranges of solar technologies are available such as solar thermal heating systems, solar PV systems, and solar buildings. Solar PV systems allow generating power via PV cells which take advantage of solar radiation.

Solar thermal heating systems, on the other hand, produce hot water and electricity by flat plate collectors or solar thermal electric plants (EIA, 2014.).

A vast amount of research has been conducted about solar energy in recent years. The researches emphasize mostly on, feasibility, environmental impacts and economic aspects of solar energy systems. The study concluded that the grid connected PV systems can provide an important contribution to current energy system.

2.2.4. Solar Energy in Ethiopia

In the past, restricted by technology and cost, Ethiopia didn't input a lot in the development and utilization of solar energy resources, moreover, people didn't fully recognize the significance of solar energy as potential renewable resource for national energy supply. With the development of world solar energy utilization technologies and the expansion of related markets, the development and utilization of solar energy resources are more and more regarded by every country, and Ethiopia has also gradually recognized the significance of renewable energy resources inclusive of solar energy for national energy supply (Master plan R., 2012).

Solar radiation resource is influenced by solar elevation angle, altitude and surface layer weather conditions, etc. Ethiopia is in a low latitude region with approximately perpendicular incidence of sunshine so that, in general, it's very rich in solar radiation resource. However, solar radiation resources are distributed differently in different regions with the change of terrain height and weather conditions. To be exact, solar radiation resources are mainly distributed central region, northern highland, mid-south region and east Somali state plain region.

According to the solar and wind energy master plan of EFDRE 2012, northern region is under the influence of downward flows of northeast trade wind on the south side of subtropical anticyclone. In central region, it has dry air and few clouds, moreover, air with low water vapor content, so solar radiation is very strong there and forms ample solar energy resources.

Mid-south region has lower latitude, but it has rich precipitation, high water vapor content and large cloud amount, so its solar radiation is obviously weakened, forming relatively poor solar resources.

East Somali state plain region is near an ocean and has high water vapor content in air and large cloud amount, forming relatively weak radiation resources.

Under its ambitious Growth and Transformation Plan II (GTP II) for 2015-2020, it has plans to increase its electricity generation capacity from wind, Solar, geothermal and hydro energy, Ethiopian Government put forward a strategic plan of powerfully developing renewable energy resources in GTP.

At present, there hasn't been any large scale solar PV (photovoltaic) projects put into commercial operation in Ethiopia yet and Grid-connected solar PV power generation projects are still blank in Ethiopia.

2.2.5. Application of GIS for solar energy siting

A Geographic Information System (GIS) is the combination of hardware, software, data and expertise to use to create, modify, evaluate and analyze spatial information in a digital format. GIS are comprised of two components, spatial features and attributes. The spatial features are those elements that could be shown on a map. This would include roads, meteorological stations, and solar resource distributions. The attributes are the associated information such as land ownership, Temperature and solar radiation values. The combination of both computerized map and 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 solar 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, solar or solar- wind hybrid systems. According to the United Nation Environmental program, the sophisticated nature of the software requires that the GIS component of the project must be carefully factored in to the capacity building plans for developing countries in order for it to be used effectively. According to the National Renewable Energy Laboratory, the essential components of GIS can be divided in to five broad categories: data acquisition, data pre-processing, data management, manipulation and analysis and output generation. Data acquisition NREL gathers data from many sources including the US Geological survey, the National Climatic Data Center, foreign countries and commercial sources. The reliability of a new data source must be assessed before it can be confidentially used. If necessary data is not available in a digital format, information contained in paper format can be brought in to a digital format with manual data entry or digitizing. Datasets used by NREL includes Digital Elevation Model (DEM), detailed Hydrographic layers, Federal land ownership, federal facility location, and political features. Pre-Processing data from outside sources must be pre-processed to insure it will match other data formats at NREL. In particular, the units of measurement and the coordinates system must be consistent to ensure all data can be used together appropriately. Data Management; The database are defined with specific common fields in consistent formats. The data is generally organized by geographic extent, original source, and planned use. Manipulation and Analysis; the data can be manipulated using spatial overlays, extractions or complex combinations of spatial functions that allow exploration of the spatial relationships in the data. Output Generation; The output of the GIS can include statistical reports, charts, tables, on-screen displays, and high quality maps.

2.2.6. Multi Criteria Analysis

Determination of best suitable locations for solar photovoltaic power plants is a complex decision making problem, involving several, sometimes conflicting, criteria and multiple objectives. These complex problems require simultaneous evaluation of many criteria. For this purpose, Multi-Criteria Decision Making (MCDM) can assist decision makers in selecting the best alternative (Janke, 2010). Accordingly, many spatial planning or management problems can be solved by GIS-based Multi-Criteria Decision Analysis (MCDA) or in other words, spatial MCDA (Pohekar & Ramachandran, 2004). Most of the decision making procedures for site selection problems require simultaneous evaluation of multiple criteria which are used to assess the suitability degree of each alternative location. The Analytical Hierarchy Process AHP, which is a mathematic technique for multi-criteria decision making. The AHP, which is used as a decision analysis device, is a mathematical method developed in decision analysis and determines values for each criteria in pair wise comparisons and relies on the judgment of the experts to derive priority scales. It is the scales that measures intangibles in relative terms. The comparisons are made using a scale of absolute judgments that represents how much more one element dominates another with respect to a given attributes. The judgments may be inconsistent, and how much to measure inconsistency and improve the judgments when possible to obtain better consistency is a concern of the AHP (Saaty, 2008). The derived priority scales are synthesized by multiplying them by the priority of their parent nodes and adding for all such nodes. The AHP is very popular means to calculate the needed weighting factors by the help of preference matrix where all identified relevant criteria compared against each other.

2.2.7. AHP process description

Factors or criteria which are considered for a decision are compared against each other in a pair-wise comparison matrix which is a measure to express the relative preference among the criteria. Therefore numerical values expressing a judgment of the relative importance or preference of one criteria against another have to be assigned to each other, (Saaty, 2008) suggested a scale for comparison consisting of values ranging from 1 to 9 which describe the intensity of importance (preference). A value of 1 expresses "equal importance" and value of 9 is given for those factors having an "extreme importance" over another factors.

Table 2-1: Example scale for AHP evaluation scale

Numerical value of P_{ij} (intensity of importance)	**Description**
1	Equal importance of i and j
3	Moderate importance of i over j
5	Strong importance of i over j
7	Very strong importance of i over j
6	Extreme importance of i over j
2,4,6 & 8	Intermediate values reciprocal value inverse comparison

2.2.8. Overlay Analysis

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

Overlay analysis is one of the spatial GIS operations. Overlay analysis integrates spatial data with attribute data. (Attributes are information about each map feature.) Overlay analysis does this by combining information from one GIS layer with another GIS layer to derive or infer an attribute for one of the layers. At its simplest, overlay analysis can be a visual operation, but analytical operations require one or more data layers to be joined physically. Results of overlay analysis rely on the spatial accuracy of the GIS layers. If the layers don't line up well, then the attributes inferred by the overlay may be incorrect. That is, the results are only as good as the GIS data used for the analysis. Today, there are many types of GIS overlay. Vector and raster models both perform overlay, but their overlay functions differ considerably and thus will be discussed separately.

Vector (logical) overlay; Vector overlay predominantly overlays polygons in one layer over polygons in another layer, but it can also be used to overlay point or line features over polygon layers. Sometimes referred to as topological or logical overlay, it is conceptually and mathematically more demanding than raster overlay. There are three types of vector overlay operations.

Raster (arithmetic) overlay; Raster overlay superimposes at least two input raster layers to produce an output layer. Each cell in the output layer is calculated from the corresponding pixels in the input layers. To do this, the layers must line up perfectly; they must have the same pixel resolution and spatial extent.

Raster overlay, frequently called map algebra, is based on calculations which include arithmetic expressions and set and Boolean algebraic operators to process the input layers to create an output layer. The most common operators are addition, subtraction, multiplication, and division, but other popular operators include maximum, minimum, average, AND, OR, and NOT. In short, raster overlay simply uses arithmetic operators to compute the corresponding cells of two or more input layers together, uses Boolean algebra like AND or OR to find the pixels that fit a particular query statement, or executes statistical tests like correlation and regression on the input layers.

2.2.9. Weighted Overlay Analysis

To meet a specific objective, it is frequently the case that several criteria will need to be evaluated. Such a procedure is called Multi-Criteria Evaluation (Janke, 2010). A "Weighted Suitability Model" is developed using GIS techniques for proposing locations suitable based on the principle of Multi-Criteria Evaluation. Such models are used for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis. Additionally, the factors of the analysis may not be equally important. Each individual raster cell is reclassified into units of suitability and multiplied by a weight to assign relative importance to each and finally add them together for the final weight to obtain a suitability value for every location on the map.

2.2.10. Boolean Overlay

Boolean logic was introduced by the English Mathematician and logician, George Boole (Saaty, 2008). Boolean logic generally applies a binary condition to the inputs and evaluates to a binary condition for the input. The binary condition can be expressed in several ways: "1"and "0", "True and "false", "Yes" and "No", "On" and "Off", and so on. In logical Math tools, the False condition is represented with a value of 0, and the True condition as any value other than 0. The Boolean tools evaluate the inputs only as True or False conditions and return the result of the particular tools 1 or 0 (True or False) Boolean value. The combinatorial tools identify unique combination of input values based on logic of the particular tool and return different value for each combination. The relational tools compares the values of one input relative to one another and the result of the particular tool as 1 or 0 Boolean value.

2.2.11. Lesson learnt

Identifying areas suitable for solar photovoltaic power plant site is a component of sustainable energy planning, as it will determine the extent to which solar energy might be connected and developed as part of renewable energy strategy, taking in to account various environmental and technical limitations.

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

Review of literatures shows that models are often made up of a combination approaches such as the Boolean overlay and weighted overlay combination. Case studies of GIS based models for solar energy facility site selection literature used in the Canada, Spain, Oman and Colorado illustrates how GIS has been applied by planners and decision-makers in different geographic locations and contexts. A description of GIS based model is given, taking in to account in different assessment criteria used and approach taken in determining site suitability. These GIS based models were assessed on their strengths and weakness in locating suitable sites for energy development and to show the overall support GIS provides for decision making.

The main weakness or gaps of the reviewed study was the omission of certain important criteria such as sunshine duration and temperature, these criteria has great influence on final suitability because the sunshine duration is the climatological indicator of the area and the temperature has the inverse relationship with the solar panel performance.

In this study, criteria identification and selection addressed by considering the criteria used in the literature reviewed. An overview of most important criteria for the suitability assessment of solar farm site is provided in chapter three, while some relevant criteria can be more or less applied similarly worldwide, others vary due to national regulations and legislations. Issue related to multi criteria decision making analysis and weight derivation of factors tackled through the application of the Analytical Hierarchy Process (AHP).

CHAPTER THREE: MATERIALS AND METHODS

3.1. Research Strategy

The important steps used in methodology of this study are: (a) identifying and selection of the factors and constraint; Since site selection for solar farm establishment depends on various factors which are expected to affect the efficiency, durability and stability of the farm. (b) data and data source (c) data acquisition techniques (d) methods of data analysis so as to make thematic maps for the criteria that influence the site selection process, assessment of technical potential and evaluation of the selected solar farms. The step by step process followed for the present problem is as explained in the following sections.

3.2. Study area Description

The study was conducted in East Shewa zone, Oromia Regional State of Ethiopia. Geographically, it is situated from 38° 03′ to 40° 05′ E longitude and from 7° 04′ to 9° 10′ N latitude covering a total area of about 13766.5 km2 (Fig.3-1). The altitude of the study area ranges from 902 to 3101 m above sea level. East Shewa zone is characterized by semi-arid and sub-humid climate based on the moisture index classification of climate. Considering the long-term average seasonal (June - September) rainfall, the area receives 458 - 518 mm rain. Based on mean annual rainfall and temperature of the area, the major climatic classes of the zone are dry climate and tropical rainy climate. Dry climate includes the arid and semi-arid subdivision, while tropical rainy climate is characterized by tropical humid and sub-humid climate. Land use/ land cover patterns of the study area include water bodies, shrub lands, bare land, forest, grass land, settlement, rain-fed and irrigated farms. Among these, the rain-fed farm covers a large area.

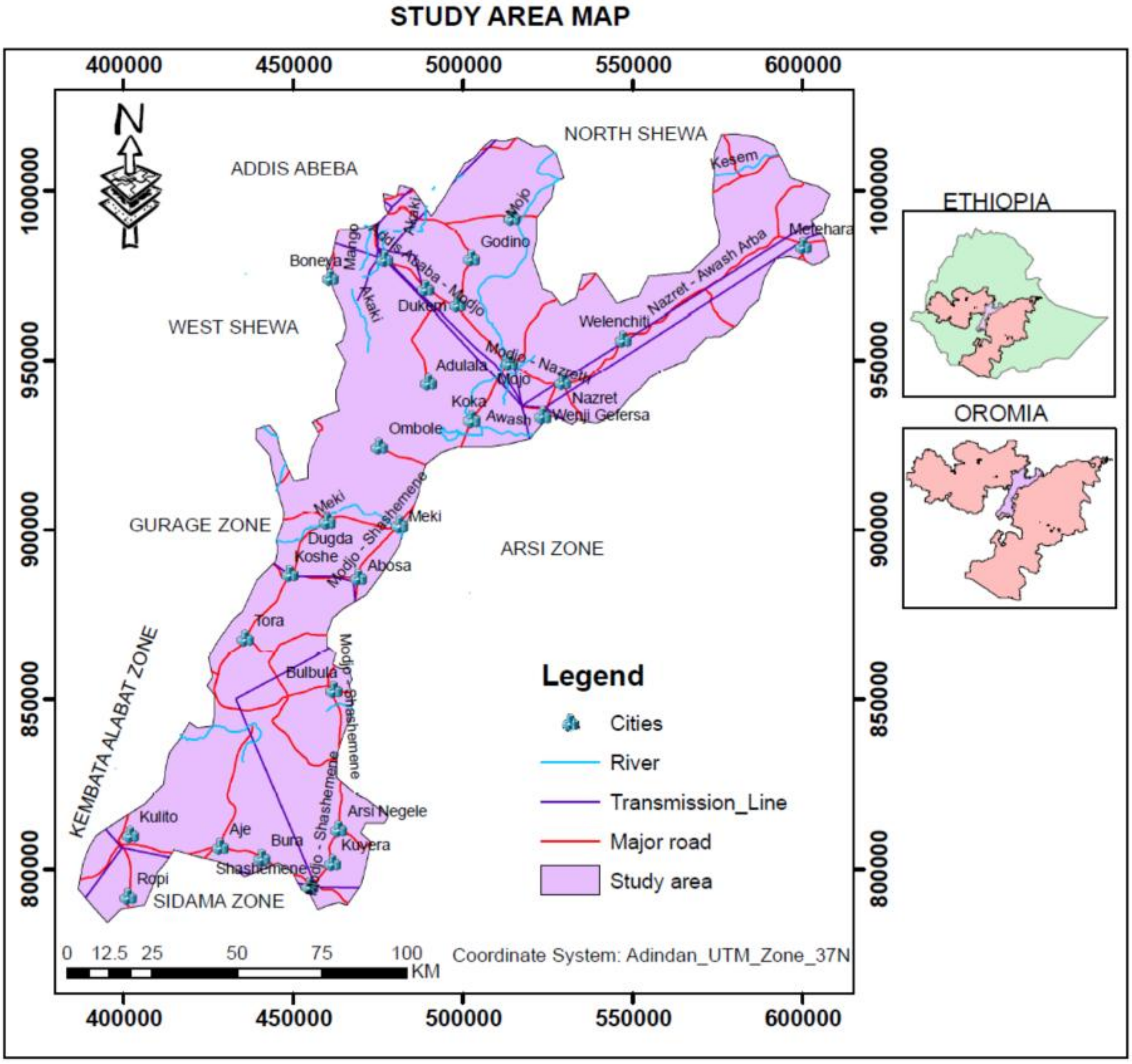

Fig.3-1.Location map of East showa zone.

3.2. Materials

The materials used in this study for data analysis include computer hardware and software. The hardware used in this study includes PC, printer, binder, and ring binder and color printer. The software for preparing and analysis of the data include MS word 2007 for editing purpose, MS excel 2007 to store attribute information collected from National Meteorology Agency and also used for simple calculation, Arc GIS 10.1 to create the geo database, data management and storage, performing spatial multi-criteria analysis, generating criteria maps and assigning weight for each criterion, overlaying and visualization of output data and suitability modeling.

Global Mapper 14.1 was used to show the terrain pattern of the study area, also used to geo-referencing and ERDAS imagine 2014 was used for image pre-processing and classification and to weigh each class of criteria were derived in IDRISI32 Software, a comprehensive geographic analysis and image processing system that has been developed by Clark Labs for Cartographic Technology and geographic analysis at Clark University, south Carolina, USA. The software has been used to perform multi-criteria decision analysis using the built-in support module and process using AHP methods.

3.3. Selection of Factors

Suitable site selection for solar farm establishment depends on various factors which are expected to affect the panel efficiency, durability and stability of the farm. Therefore, selection of factors will requires understanding of the relationship between factor and the solar farm in terms of environmental, economic, and technical concerns..

For energy generation efficiency (*technical factors*), incoming solar radiation is the most important consideration. Shadow effects due to slope were also taken into account. Since PV performance can be affected by the increasing temperature of PV cells, accessibility to water resources for cooling and cleaning was considered but with less relative importance. In addition, PV panel performance can be influenced by dust risk from adjacent roads. Distance to road network was determined by considering the road density of the area. Areas covered by sandy soil were avoided in the site selection process for reducing dust risk.

Economic factors were considered in the site selection process. For example, areas should be accessible to roads for the ease of construction. In addition, PV farm should be constructed close to electricity transmission lines to reduce energy loss and transmission costs.

From an *environmental perspective*, solar panels should avoid environmentally constraint areas. Solar panels should also be installed in locations that are difficult to be accessed by residents, or passersby to decrease the probability of vandalism or deliberate damage water bodies and forest land. Hence, in the present study, the following factors are identified and incorporated in the site selection process.

Slope: Gradient of land will affect the receiving radiation. The more flat, the more amount of radiation received (Charabi & Gastli , 2011).

Proximity to roads: In a terrain where other mode of transport cannot be built, road provide the most convenient means of transport and is the basic prerequisite for solar site selection. Proximity to roads minimizes cost in infrastructure construction and maintenance (Janke, 2010).

Proximity to Transmission Line: A PV power plant's distance from transmission lines is important for two reasons. Firstly, technical losses during the transmission are proportional to the length of the distribution line, secondly, the construction of new transmission lines can significantly increase the investment costs, because building new transmission line to move electric power to where it is needed can be very costly (Charabi & Gastli , 2011).

Solar Radiation Potential: For a PV development the primary interest is to have a high long term average daily, monthly and annual global solar radiation. The solar power plant in a given site depends on having sufficient solar potential available at which the PV module is to be installed (Miller & Lumby , 2012).

Elevation: Altitude is one of the major factors affecting the global solar radiation. The distance solar rays have to travel through the atmosphere is less at higher altitudes. Therefore there is less atmospheric absorption, and consequently, more solar radiation as the elevation increases (Sharma, 1990).

Land use/Land cover: The land use/land cover is considered as an environmental factor for site selection of solar farms. The suitability of an area for the siting of solar farms also depends on the prevalent land cover types. From a social acceptance point of view, some land cover type can be considered to be more preferable than others. Thus, Barren land, shrubs and grass land can generally be considered most suitable, since they need only minimal investment into land preparation or cleaning (Kahraman et al, 2009).

Seismic Intensity: Seismic effect like earthquake related with geological structure should be required for PV site analysis. The intensity of an earthquake is measured by Mercalli intensity value (MIV). The MIV quantifies the effects of an earthquake on the Earth's surface, humans, objects of nature, and man-made structures on a scale from I (not felt) to XII (total destruction) (USGS, 2014).

MIV from i to v (Not felt): The effect not felt.

MIV between v and vi (weak): Felt only by a few people at rest, especially on upper floors of buildings.

MIV between vi and vii (Light): Felt indoors by many, outdoors by few at a time.

MIV between vii and viii (Moderate): Feel by nearly everyone; many awakened. May overturn unstable objects.

MIV between viii and ix (Strong): Feel by all, some heavy structure should move; a few instances of fallen plaster may happen.

MIV between ix and x (V. Strong): Damage negligible in structure of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures.

MIV between x and xi (Severe): Damage slight in specially designed structures; considerable damage in ordinary substantial structure with partial collapse. Damage great in poorly built structures.

MIV between xi and xii (Extreme): Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Wind Speed: For PV power plant efficiency, wind speed is important for three reasons. Firstly, wind is the most important factor influencing the cell temperature, by increased wind velocity more heat can be removed from the PV cell surface (i.e. cooling purpose). Secondly, higher air velocity lowers the relative humidity of the atmospheric air in the surroundings which in turn leads to better efficiency. Thirdly, removes dust from PV panel, PV panel performance can be influenced by dust deposition and settlement on the surface of PV cells can drop the efficiency (Mani & Pillai, 2010).

These Criteria mentioned above will be very significant in the site selection of the identified land use and will act as key drivers in the selection of the geographic location. These criteria can be clustered into a single decision model and the outcome collectively reviewed.

Constrained Criteria

These criteria impose strong negative opportunities in the selection of areas for the identified land use. Consequently, they inform of us of where the particular land use under consideration should not be located. These criteria serve to limit or exclude areas from the final suitability. To decrease negative environmental impacts from large scale PV farms, constraints should be filtered out in site selection (Charabi & Gastli , 2011). Hence, the constraint criteria filtered from present study were water bodies, forest land, urban area and lava flow area are excluded from the study area.

Water bodies: Any type of water bodies, lakes, sea, rivers, wetlands and flood plains are to be protected to preserve the natural wealth (Miller & Lumby , 2012). Therefore, all the water bodies in the study area were excluded with a buffer length of 500m around each water bodies.

Forest: The clearing and use of large areas of land for solar power facilities can adversely affect native vegetation and wildlife in many ways. These area serve the protection of nature and wildlife and are therefore excluded from the study area or from solar energy development site with a buffer length of 500m each features (Charabi & Gastli , 2011).

Urban: urban development had to be excluded due to their non-suitability for an industrial-size PV installation and a buffer within that distance was set from cities (1000m from cities) (Janke, 2010).

3.4. Data and Data source

The data collection is the important step of the present research next to selection of factors. A number of data were chosen for modeling the suitability of solar farm location(s) based on selection of factors.

Collecting accurate and reliable data is the most determinant factor for any research as it determines the quality of the research. Accordingly, the necessary data were collected from the respective secondary and primary data sources. Climate data like sunshine duration, temperature, wind speed recorded at 14 station from 2005-2015 were collected from national meteorological agency and converted as an input data in GIS environment.

Seismic intensity map of east shewa from Geologic Survey of Ethiopia for mapping the intensity of earth quake found in the study area, The Digital Elevation Model (DEM) was obtained from Ethiopian Mapping Agency (EMA) used to derive slope and elevation pattern of the study area. Road networks were collected from Ethiopian Road Authority (ERA) and ready for use in the GIS environment, Power grid line map were obtained from Ethiopian electric power corporation. Global solar radiation was collected from Solar and Wind Energy Resource Assessment (SWERA) and converted as an input data to the GIS environment for analysis and Landsat image also collected from Ethiopian Mapping Agency (EMA) for preparation of land use land cover layer of the study area. In today's world of advanced technology where most remote sensing data are recorded in digital format, virtually all image interpretation and analysis involves some element of digital processing. Digital image processing may involve numerous procedures including formatting and correcting of the data, digital image were enhanced to facilitate better visual interpretation.

Supervised Classification: This paper identified and develops numerical descriptions of the spectral signatures of each land use/cover type of interest in the scene in ERDAS environment.

Classification accuracy assessment: Classification accuracy assessment is a general term for comparing the classification to geographical data that are assumed to be true to determine the accuracy of the classification process. Therefore a set of reference pixels were used. Reference pixels are random points on the classified image for which actual data are known.

Confusion matrix (Error Matrix): The most commonly used method of representing the degree of accuracy of a classification is to build a confusion (or error) matrix. This study selected a sample of pixels or random points and built a confusion matrix with 82.05% accuracy and the details were shown in appendix A.

The criteria selection started with comprehensive literature review and was narrowed down to those data believed as relevant and critical to the suitability of solar farm in the study area.

Table 3- 1.Summary of data and data source.

Data	Data Source
Landsat	Landsat 7 imagery_2015_ 30m*30
Average annually GSR	Monthly GSR obtained from SWERA.
Road	Main road of the area from ERA.
Sunshine Duration	Daily sunshine hour recorded at 14 meteorological station_2005-2015.
Transmission line	Grid line map of Ethiopia from EEPCO _ 2012.
DEM	USGS Aster DEM_ 30m*30m.
Seismic Intensity	Seismic intensity map from geological survey.
Average monthly Wind speed	Daily wind speed recorded at 14 meteorological station_2006-2015.
Average monthly temperature	Daily temperature recorded at 14 meteorological station_2005-2015.

3.5. Data acquisition techniques

The technique used to select suitable site for PV plant establishment involves GIS spatial overlay analysis of spatially referenced data. The accuracy and reliability of spatial data depends on; completeness over an area, date, scale and formats of different datasets being compatible, locational accuracy of field observations, accuracy of attribute data being entered.

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

The raw GIS data and the same formatting criteria was used for this study. In order to avoid error in the GIS analysis, all spatial data were projected to common projection system UTM_ Adindan_Zone_37N and converted into Raster format the same geo-database for analysis. Horizontal units were given in meters. Similarly, raster layers were standardized to a 30 x 30 meter resolution for all data. Spatial resolution, which is also called cell size, defines the quality of data represented on a map layer. The raster resolution chosen for this study was detailed enough to show sufficient information.

Table 3-2.Various criteria used and data formatting for the study.

Variable	Original File extension	Final data	Final projection for SA	Final resolution (meter x meter)
Elevation	TIFF	Continuous	UTM_Adindan_Zone_37N	30
Slope	TIFF	Continuous	UTM_Adindan_Zone_37N	30
Sunshine	Csv	Continuous	UTM_Adindan_Zone_37N	30
Temperature	Csv	Continuous	UTM_Adindan_Zone_37N	30
Transmission L.	Shp	Continuous	UTM_Adindan_Zone_37N	30
Road	Jpeg	Continuous	UTM_Adindan_Zone_37N	30
Solar Radiation	Csv	Continuous	UTM_Adindan_Zone_37N	30
L.use/L.cover	TIFF	Categorical	UTM_Adindan_Zone_37N	30
Seismic intensity	Shp	Categorical	UTM_Adindan_Zone_37N	30
Wind speed	Csv	Continuous	UTM_Adindan_Zone_37N	30

3.6. Methods of Data Analysis

Planning for solar energy usually entails the consideration of a number of interrelated factors. For studying such factors, the following materials acquired, collected, processed by adequate methods and a Spatial Multi-Criteria Evaluation model design by using GIS. The Data analysis of Solar PV siting involves numerous factors with complicated correlations. Therefore, GIS based multi-criteria spatial analysis techniques and Analytical Hierarchy Process (AHP) approach has been used to address the proposed study.

Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision maker towards a judicious choice. MCA is a device which enables people to make the most appropriate choice among many criteria and it is a widely used concept in GIS technology. Suitability is achieved by examining a number of individual criteria, assigning them relative levels of importance as a whole, and identify the most suitable location. By adopting this site suitability method, it is possible to systematically identify the criteria considered, clearly document the relative importance of one criterion over another, and analyze the net outcome using a Geographic Information System. By revising the relative importance to identified criteria based upon the particular land use under consideration, it is possible to generate “suitability maps” for each individual land use, and then generate a final composite land use that is based on a best possible collective suitability of multiple land uses. MCDA consists of a series of techniques such as weighted summation or concordance analysis that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by, for example, experts, interest groups and/or stakeholders according to their degree of suitability or importance for locating/sitting a particular facility/service (Pohekar & Ramachandran, 2004).

3.6.1. Spatial analysis

GIS spatial analysis is a powerful tool used for generation of factors and conversion from their sources (Pohekar & Ramachandran, 2004). The author have been used this operation to generate factor maps for the present study.

Generally, PV power plant site selection is the complex and tedious process that needs to consider many conflicting criteria. In this research, environmental, economic and technical related factors were used for factor map development. Moreover, urban area, forest land and water bodies, which are extracted from classified land use land cover was also considered as solar farm sitting constrains. All the factors and constrains were internally classified.

Multi criteria evaluation analyze suitability based on standard factors, constraints and weighted overlay. Constraints are based on the Boolean criteria (True/False) which limits the analysis to specific regions. Factors defines areas or alternatives according to continuous measure of suitability and factors weights was determined by Analytical

Hierarchy Process(AHP) and the final solar farm site is produced by integrating this two factor map and constrain map in to one by using suitability modeling.

Digitizing: This function of GIS converts the base map of the area into digital map to use in GIS environment. This is done by using on- screen digitizing by encoding the spatial coordinates of the features on the map. It was used to digitize boundaries and roads that exist in the study area.

Buffering: Buffering is a spatial analysis also called proximity analysis. It is used to generate areas of a given distance around the specified criteria used for solar site selection. The features that buffered include: urban land, water bodies, and forest area.

Reclassify: The reclassification tools reclassify or change cell values to alternative values and one value at a time or groups of values at once using alternative fields; based on a criteria, such as specified intervals (for example, group the values into 5 intervals); or by area (for example, group the values into 5 groups containing the same number of cells). The tools are designed to allow you to easily change many values on an input raster to desired, specified, or alternative values. In this study, all the factors were reclassified and assigned a "new values" denoting their relative levels of importance from 5 to 1 (more suitable to very less suitable) based on the reviewed literature.

3.6.2. Overlay

An overlay operation was performed to identify areas that fulfill all the site selection criteria and to show areas that do not meet these criteria. GIS can overlay different types of information that helps to understand the association between network analysis and specific geographic features. The final map is intersected from the factor map and constrain map by using overlay operation.

3.6.3. Weighted Overlay Analysis

Weighted overlay is an intersection of standardized and differently weighted layers in a suitability analysis. The weight quantify the relative importance of the suitability criteria considered. A "Weighted Suitability Model" is developed using GIS techniques for proposing locations suitable based on the principle of Multi-Criteria Evaluation. Such models are used for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis. Additionally, the factors of the analysis may not be equally important. Each individual raster cell is reclassified into units of suitability and multiplied by a weight to assign relative importance to each factor and finally add them together for the final weight to obtain a suitability value for every location on the map.

3.6.4. Boolean Overlay

In a raster GIS, this type of analysis is typically performed by creating a Boolean data layer (a layer which contains only 0 and 1, with 1 signifying areas where the criterion is satisfied, and 0 signifying areas where the condition is not satisfied) for each criterion. After all of the Boolean data layers have been prepared, a series of overlay steps is performed to produce a final result. Generally multiplication overlay is used; a Boolean image for one criterion overlays a second Boolean image representing the second criterion. Multiplication overlay produces an output pixel value of 1 only if both input pixel values are 1 (1 times 1 equals 1), i.e. if both criteria are satisfied. An output pixel value of 0 is produced if one or the other or both input pixels is 0 (1 times 0 equals 0, or 0 times 0 equals 0), i.e., if one/both criteria is/are not satisfied (Saaty, 2008).

3.6.5. Analytical Hierarchy Process (AHP)

Analytic Hierarchy Process (AHP) is one of the most commonly used MCDM tools. Pair wise comparisons are also used to determine the relative importance of each alternative in terms of each criterion.

In AHP, a matrix is generated as a result of pair-wise comparisons and criteria weights are reached as a result of these calculations. Also, it is possible to determine the consistency ratio (CR) of decisions in pair-wise comparison. CR reveals the random probability of values being obtained in a pair-wise comparison matrix.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1i} \\ a_{21} & a_{22} & \cdots & a_{2i} \\ \vdots & \vdots & \ddots & \vdots \\ a_{j1} & a_{j2} & \cdots & a_{ji} \end{bmatrix}$$ …………………..(3.1)

If n number criteria are determined for comparison, the specific procedures are as following for AHP performs:

To create (n x n) pair-wise comparison matrix for multiple factors, let Pij = extent to which we prefer factor i to factor j.

Then assume Pij=1/Pij. The possible assessment values of Pij in the pair-wise comparison matrix, along with their corresponding interpretations, are shown in Table3.3.

Table 3-3.AHP evaluation scale.

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very	Strongly	Moderately	Equal	Moderately	Strongly	Very	Extremely

Less important ***More important***

If CR ≤ 0.10, the degree of consistency is satisfactory. If CR > 0.10, there are serious inconsistencies (Saaty, 2008).

Therefore, GIS based multi-criteria spatial analysis techniques and Analytical Hierarchy Process (AHP) approach has been used to address the proposed study. The assessment procedure for solar farm siting presented as the following figure below. Multi criteria evaluation analyze suitability based on standard factors, constraints and weighted overlay. Constraints are based on the Boolean criteria (True/False) which limits the analysis to specific regions. Factors defines areas or alternatives according to continuous measure of suitability and factors weights was determined by Analytical Hierarchy Process (AHP).

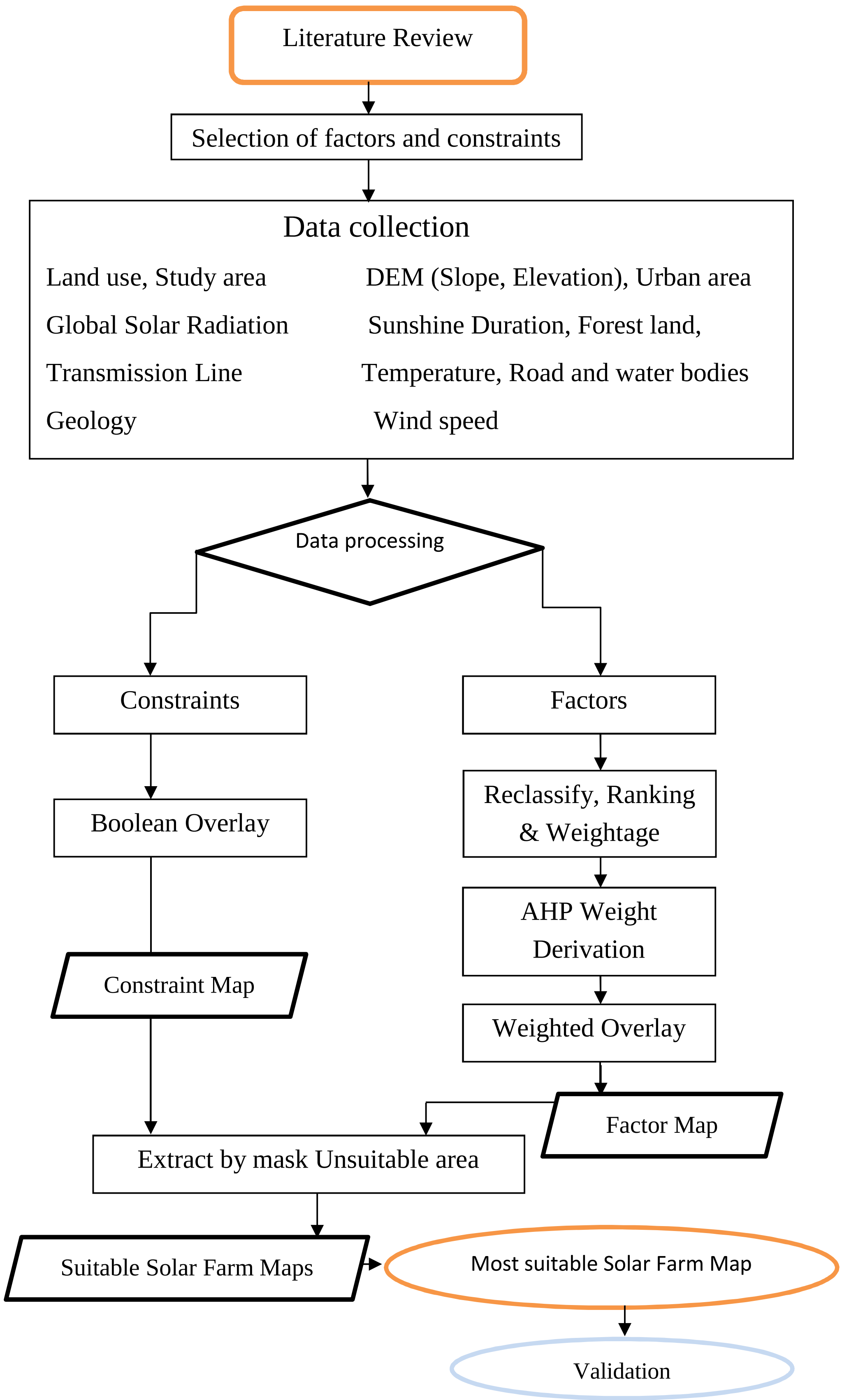

Fig.3-2.Technical scheme of the study

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0. Overview

The PV site suitability model and map product defines the areas of east shoa zone that satisfy the technical, economical, and environmental goals of this study. The weighted values of potential irradiance, Elevation, slope considerations, Temperature, sunshine duration and necessary existing infrastructure show areas with high potential. Weighted values produced based on this model were further broken down into five categories to facilitate a visual representation of the results. Because a cell size of 30mx30m was used for all processing, the resulting maps allow for a high definition visual map.

Solar farm site requires good connectivity and accessibility besides infrastructure development criteria. Sets of factors has been used to analyze the basic suitability of the area. This stage considers all the standard factors that normally determine the suitability of an area. The scale for weighing and ranking is 1 to 5, with 1 being assigned to the factor with lowest importance and vice versa.

4.1. Generation of factor and constraint maps

4.1.1. Constraint maps

In this study, the water bodies, urban area and forest land has been identified as constraint. Based on this, constraint map are created to determine the criteria that are constraints to the solar PV power plant site selection. It needs a sort of Boolean map, each pixel has a unique binary code value with zero (0) and ones (1). Pixels with values of zero represent the areas are restricted to be the optimal site and the other hand, pixel with the values of one (1) may be the optimal site (Charabi & Gastli , 2011).

Urban area

A map of the urban areas was created via isolating the developed area from the classified land cover map. This reclassified raster image was assigned values of 0 for urban area and a value of 1 for all other areas thus creating a Boolean constraint. In this study, urban development had to be excluded due to their non-suitability for an industrial-size PV installation and a buffer within that distance was set from cities (1000m from cities) (Janke, 2010).

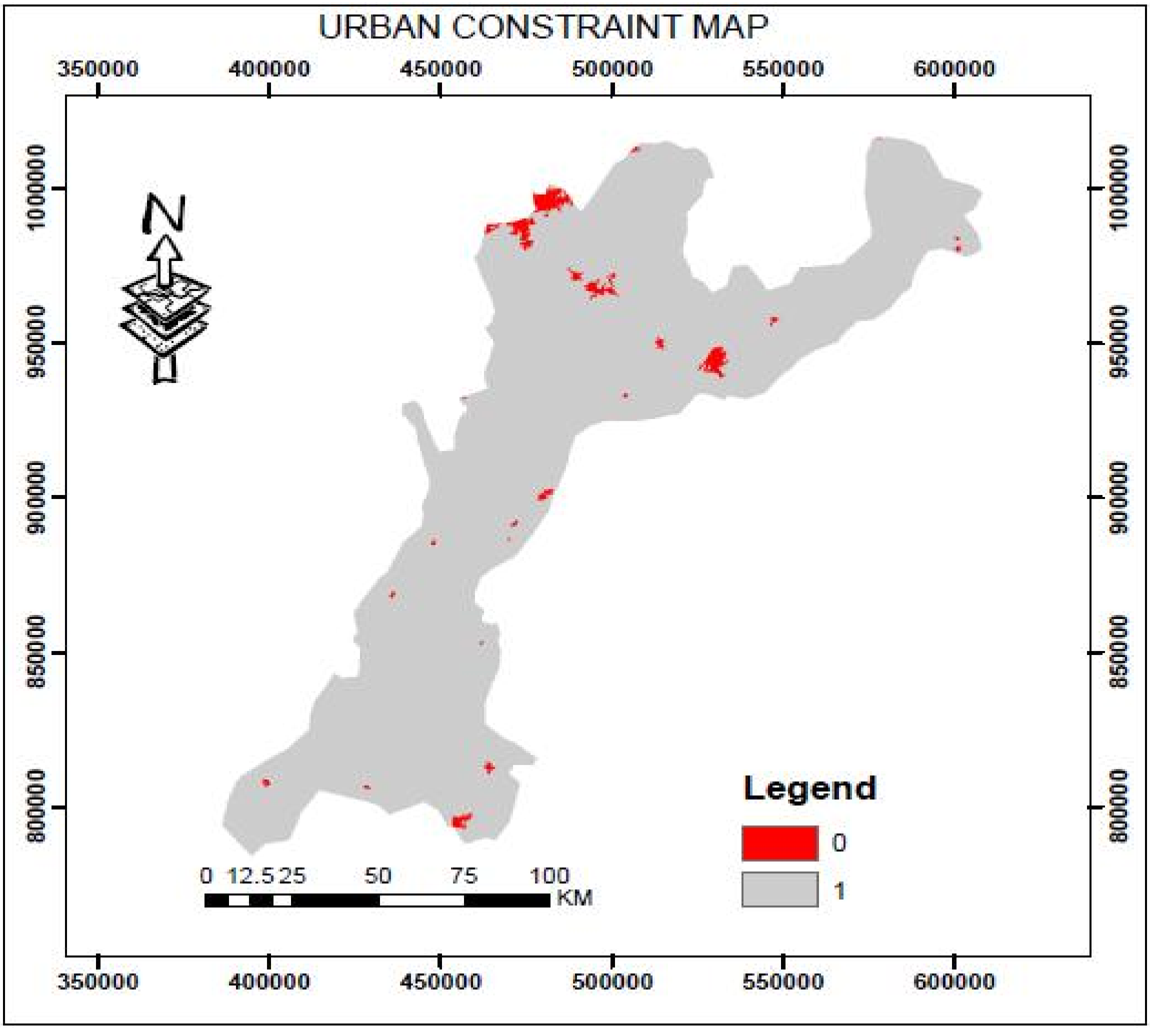

Fig.4-1.*Urban constraint layer of study area extracted from land use/land cover*.

From the figure above (figure 4-1), the spatial coverage of relative urban constraint computed from reclassified land use layer were 97%(13360.84Sq Km) of the total area were in the analysis whereas the rest 3% (405.2863Sq Km) of the total area is out of the analysis or excluded and the result of analysis of the thematic map generated were shown in figure 4-2.

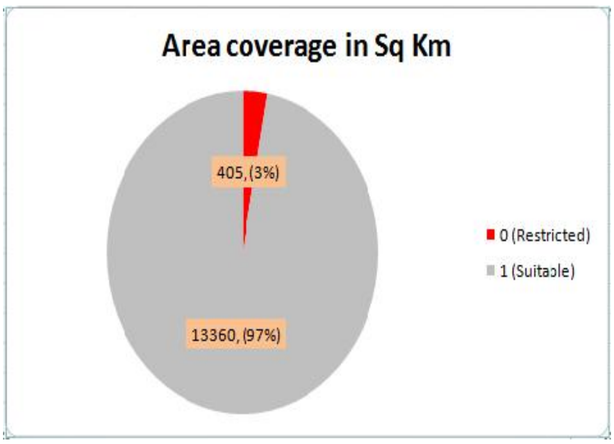

Fig.4-2.Spatial coverage of urban constraint layer extracted from land use layer.

Water body

Any type of water bodies, lakes, sea, rivers, wetlands and flood plains are to be protected to preserve the natural wealth (Miller & Lumby , 2012). In this study, water bodies considered as one of the constraint of PV development.

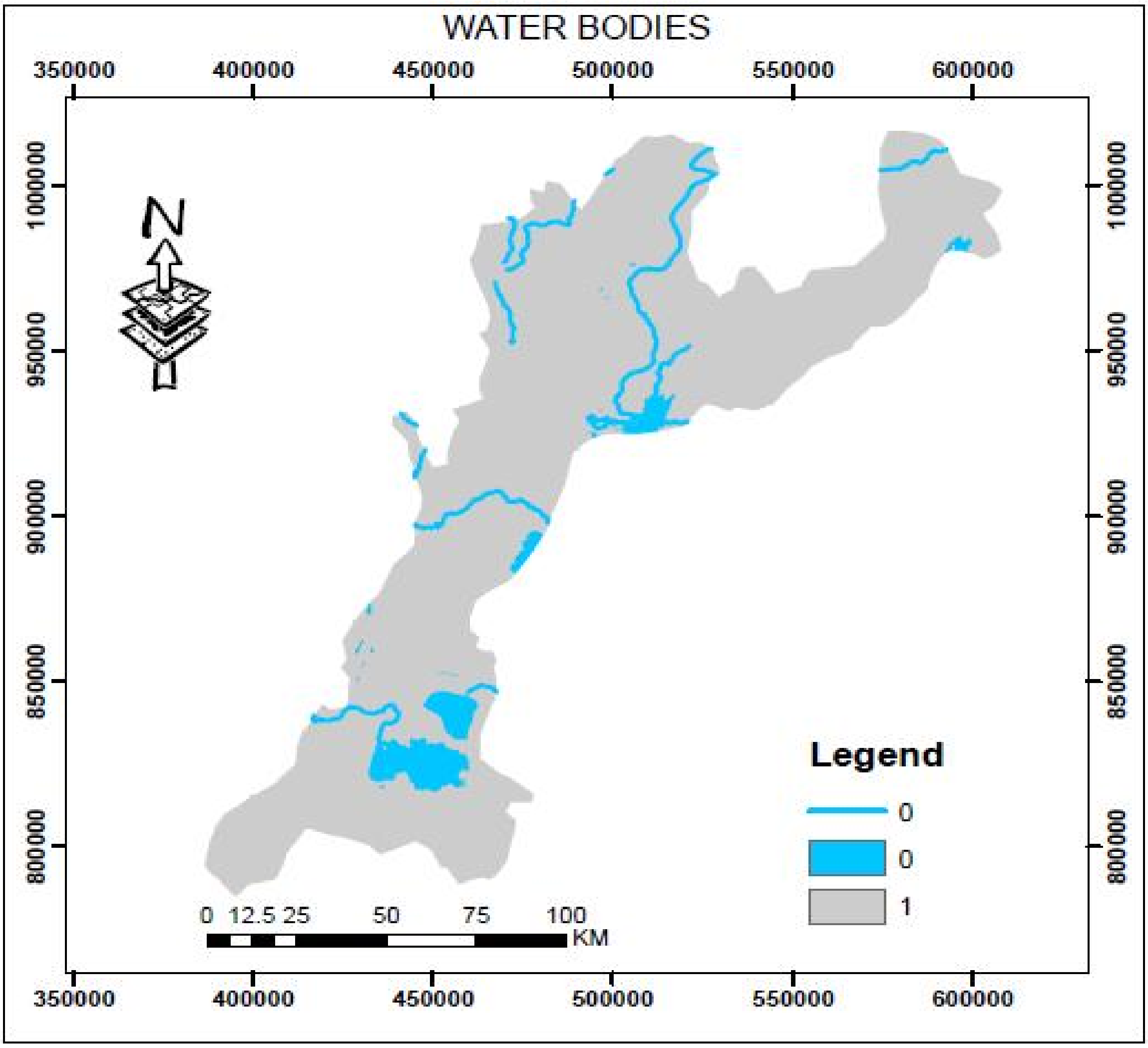

Fig.4-3.*Water bodies' constraint layer of study area extracted from land use/land cover.*

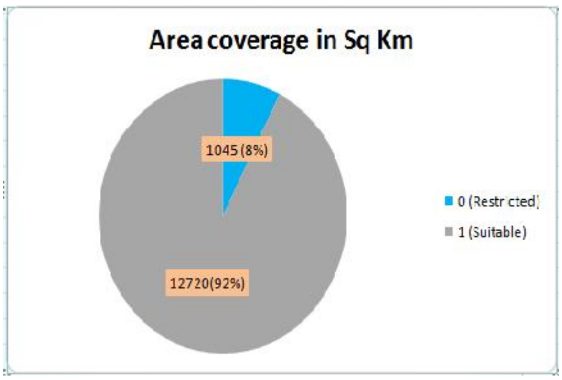

Fig.4-4.Spatial coverage of water bodies' constraint extracted from land cover layer.

All the water bodies in the study area were excluded with a buffer length of 500m around each water bodies. As it is shown in figure below, the excluded area 8% (1045.56 Sq Km) of the total area and the suitable area covers 92% (12720.57 Sq Km) of the total area of the study area were generated from reclassified land use/ land cover layer.

Forest land

Utility-scale solar energy environmental considerations include land disturbance/land use impacts; the clearing and use of large areas of land for solar power facilities can adversely affect native vegetation and wildlife in many ways. These area serve the protection of nature and wildlife and are therefore excluded from the study area or from solar energy development site with a buffer length of 500m each features (Charabi & Gastli , 2011).

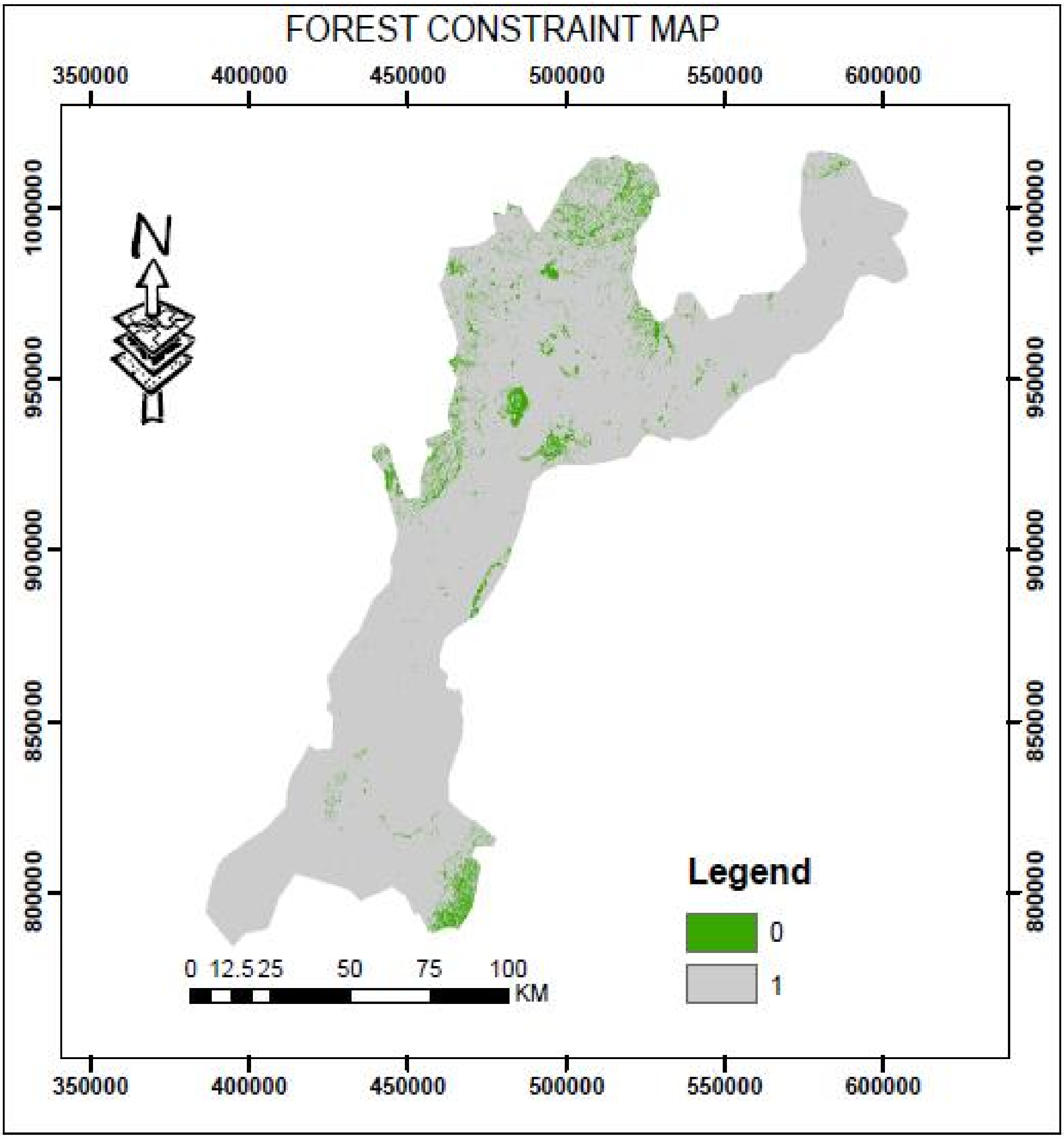

Fig.4-5.*Forest constraint layer of study area generated from land use/land cover.*

Accordingly, Spatial coverage of forest land constraint range computed from reclassified land use/land cover layer were 93% (12778.42 Sq Km)of the total area were in the analysis whereas the rest 7%(987.7158Sq Km) of the total area is excluded from the study area as it is shown in figure (4-6).

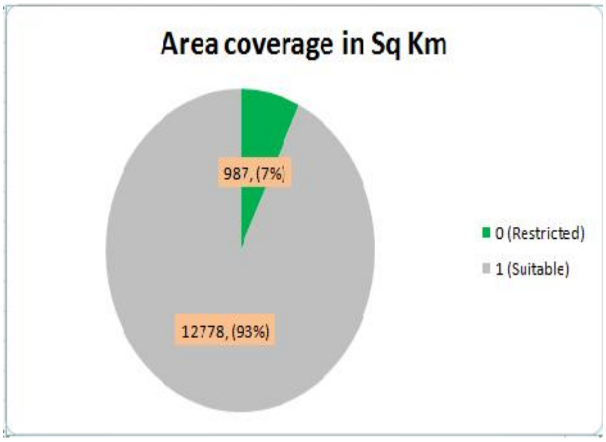

Fig.4-6.Spatial coverage of forest land constraint computed from land use layer.

4.1.2. Factor maps

A GIS system is capable of processing map related data which is the best alternative for decision making when solar farm planning is considered. The factor affecting the selection of Solar PV site are briefly discussed as follows. This factor map represent the criteria that will affect the optimal site selection.

Distance from the major Road

In a terrain where other mode of transport cannot be built, road provide the most convenient means of transport and is the basic prerequisite for solar site selection. Accessibility proves to be an important factor for potential solar power plant sites; most related site-suitability research incorporates proximity to roads (Janke, 2010).

Road accessibility is important during the whole life cycle of a solar plant, for example, accessibility would be important for construction and installation of the models, maintenance and dismantling at end of life. Its importance could also depend on the technology used; solar plants with tracking systems have typically higher maintenance requirements (Miller & Lumby , 2012). Compliance with local fire policies might also require easy accessibility (US EPA & NREL, 2013). Data for roads are obtained from the Ethiopian Road Authority, highways and significant roads were selected and extracted to a separate layer. A 100 meter buffer is created around the lines to avoid the slightly negative visual impacts, although this factor greatly depends on the location of the individual plant and to mitigate the risk of module efficiency decrease or damage from exposure to human impact, such as dust traffic (Miller & Lumby , 2012).

The vector file was rasterized and the Euclidean distance tool was applied to obtain potential areas ranging from favorable to less favorable. Distance less than 500m from road is highly suitable for solar power plant site, distance from 500m to 750m is moderate suitable, distance from 750m to 1000m is suitable, distance from 1000 to 1250m is less suitable and distance greater than 1200m is not suitable for Solar power plant site selection.

Table 4-1.*Weight assignment for different ranges of major roads (weight ∝ suitability).*

Road (R) in Meter	Weight assignment
100≤ R <500	5
500 ≤R<1000	4
1000 ≤R< 1500	3
1500 ≤R<2000	2
>2000	1

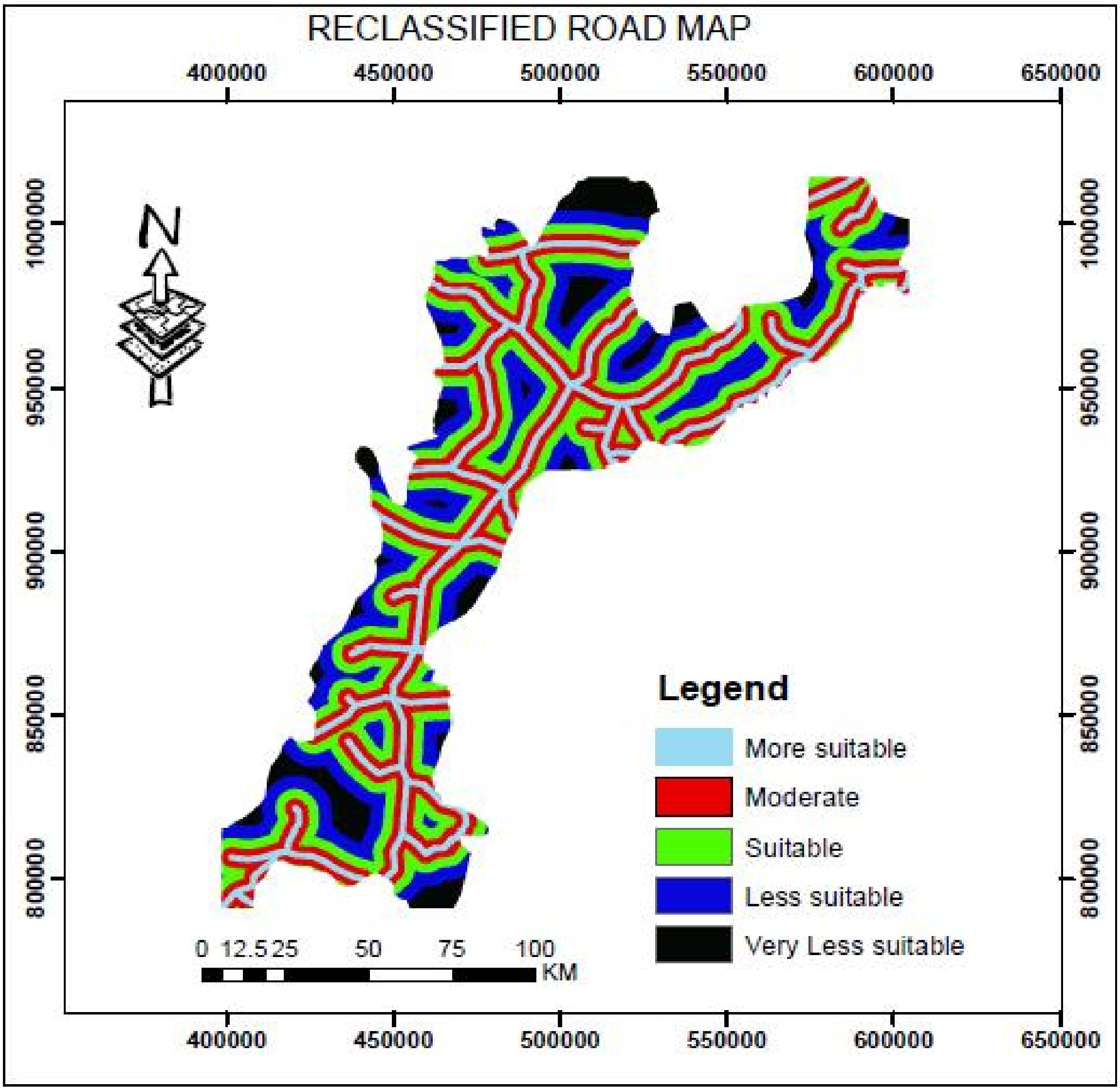

Fig.4-7. Road layer generated using new pixel value equal to estimated relative weight for roads.

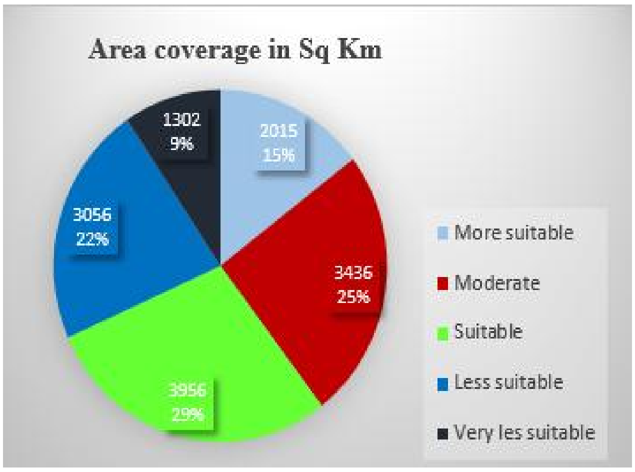

Fig.4-8.Spatial coverage of relative road range computed from reclassified road layer.

The spatial coverage of relative road range computed from reclassified road layer and the result of analysis of the thematic map generated were 2015.24Sq Km(15%) more suitable, 3436.53Sq Km (25%) moderate, 3956.389 Sq Km(29%) suitable, 3056.14Sq Km (22%) less suitable and 1302.21Sq Km (9%) very less suitable as shown in figure (4-8).

Distance to Transmission Line

A PV power plant's distance from transmission lines is important for two reasons. Firstly, technical losses during the transmission are proportional to the length of the distribution line, secondly, the construction of new transmission lines can significantly increase the investment costs, because building new transmission line to move electric power to where it is needed can be very costly (Charabi & Gastli , 2011). So, sites near existing power lines reduce expenses. In order to costs associated cabling and power losses over long distances, Solar power plant should be located in the proximity of the power grid. In this study, there are six transmission line (Adami tulu - Shashemene, Koka - Kaliti, Koka - Awash II, Melka Wakena - Koka, Awash - Nuraera and Koka - Awash 7 kilo) passing through the study area. Transmission line data alterations were executed in the same order as the roads, converted to raster files and classified to a range from more to less suitable distances with the help of the Euclidean distance tool. The value score increases with decreasing distance from the grid. Based on the spatial dimension and characteristics of the study area, area within the range of 0 to 1000m receive the highest value score of 5 and sites within the distance greater than 10,000m receive the lowest score of 1.

Table 4-2.Weight assignment for different ranges of transmission line (weight ∝ suitability).

Transmission line (Tr.) in Meter	Weight Assignment
<1000	5
1000 ≤R<3000	4
3000 ≤R< 6000	3
6000≤R<10,000	2
>10,000	1

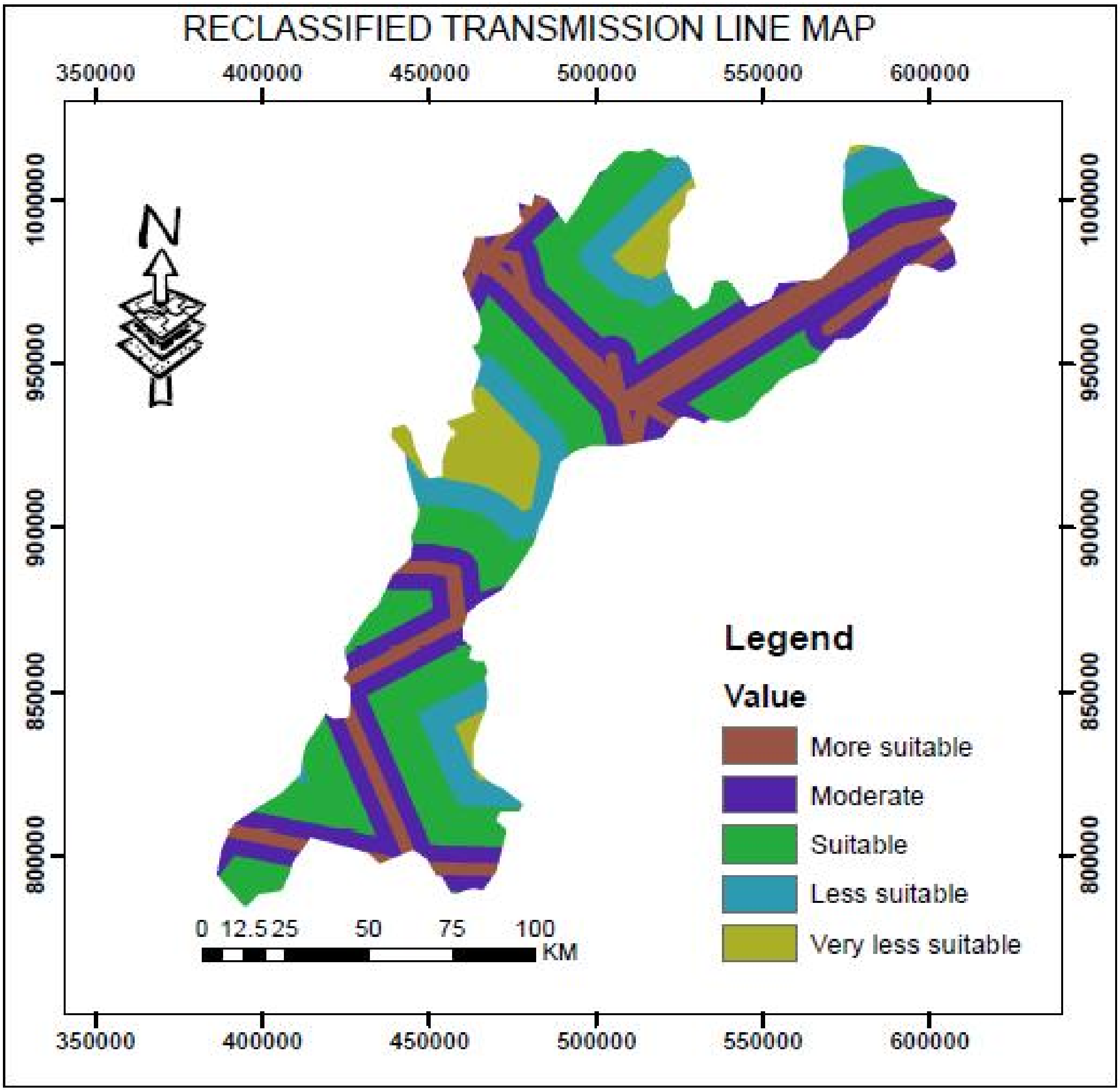

Fig.4-9.Transmission line layer generated using new pixel value equal to estimated weight.

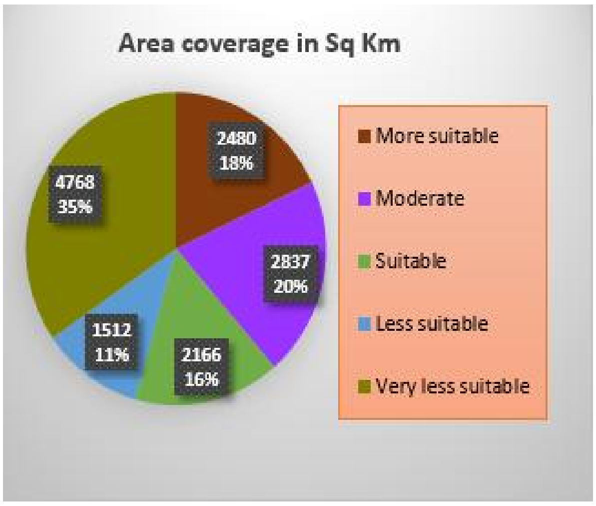

Fig.4-10.Spatial coverage of relative transmission line computed from reclassified transmission line layer.

From the above thematic map, the spatial coverage of relative transmission line range computed from reclassified layer and the result of analysis of the thematic map generated were 2480.398 Sq Km (18%) more suitable, 2837.755 Sq Km (20%) moderate, 2166.73 Sq Km (16%) suitable, 1512.84 Sq Km (11%) less suitable and 4768.78 Sq Km (35%) very less suitable were generated from the reclassified transmission line layer.

Solar Radiation Potential

Solar irradiation is a measure of the energy incident on a unit area of a surface in a given time period, usually a year (kWh/m2 year). Data for this criterion is taken from SWERA and is used to obtain information about the annual Global Horizontal Irradiation (GHI) in the east shewa zone.

For a PV development the primary interest is to have a high long term average daily, monthly and annual GSI (Miller & Lumby , 2012). For this study, the data was modified (re-projected) according to the specific state's coordinate system as stated in data acquisition technique. Insolation values were converted in to the surface by interpolation technique and reclassified into different annual solar irradiation categories.

The solar power plant in a given site depends on having sufficient solar potential available at which the PV module is to be installed. The solar radiation potential is the most important or critical factor because it provide information on the most feasible and profitable region in the area for siting solar power plant (Miller & Lumby , 2012). The solar radiation potential of the study area is between 1.88kW/m^2 to 3.9125kW/m^2 and this values were converted in to the surface by interpolation technique and reclassified into five different annual solar irradiation intervals or categories.

Table 4-3.Weight assignment for different ranges of solar intensity (weight ∝ suitability).

Solar Radiation Potential (KWh/m$^{2/}$)	**Weight Assignment**
2.650≤ SRP<3.9125	5
2.500 ≤SRP<2.650	4
2.250 ≤SRP< 2.500	3
2.000≤SRP<2.250	2
<2.000	1

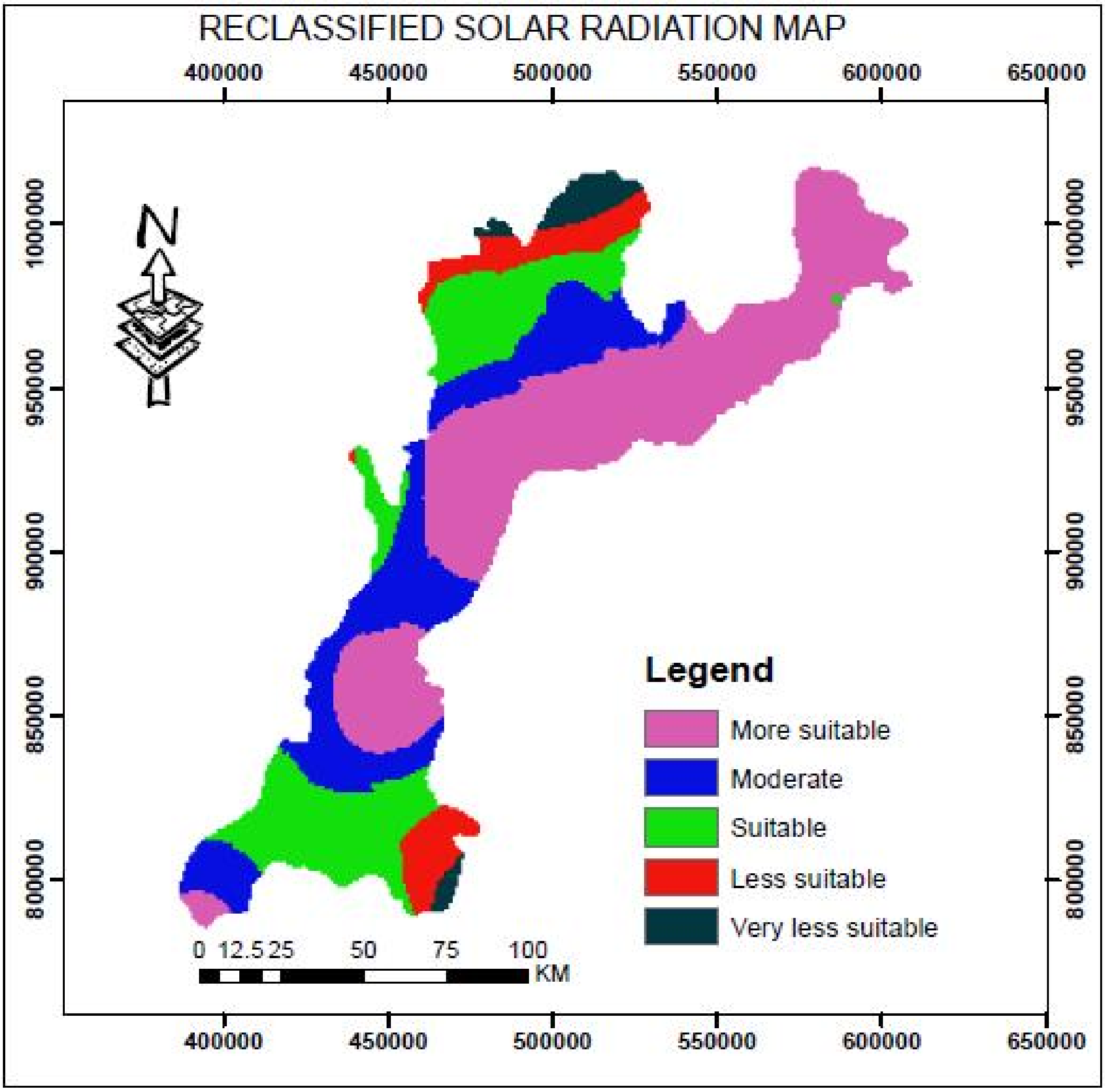

Fig.4-11.Solar intensity layer generated using new pixel value equal to estimated relative weight.

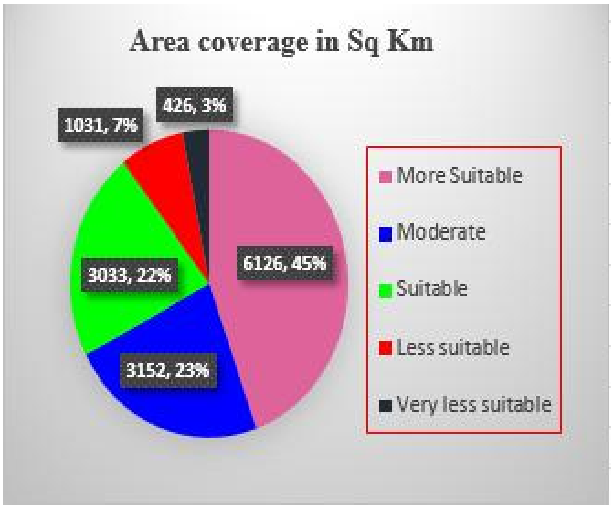

Fig.4-12.Spatial coverage of solar intensity computed from reclassified solar radiation intensity layer.

From the reclassified solar intensity, the spatial coverage of relative solar radiation intensity range computed from reclassified layer and the result of analysis of the thematic map generated were 6126 Sq Km (45%) more suitable, 3152 Sq Km (23%) moderate, 3033 Sq Km (22%) suitable, 3031 Sq Km (7%) less suitable and 426 Sq Km (3%) very less suitable were generated from the reclassified solar intensity layer.

Temperature

As temperature increases, again the band gap of the intrinsic semiconductor shrinks meaning more incident energy is absorbed because a greater percentage of the incident light has enough energy to raise charge carriers from the valence band to the conduction band. A larger photocurrent results; therefore, intrinsic semiconductor increases for a given insolation, and solar cells have a positive temperature coefficient (EIA, 2013). Temperature effects are the result of an inherent characteristic of crystalline silicon cell-based modules. They tend to produce higher voltage as the temperature drops and, conversely, to lose voltage in high temperatures.

The average annual temperature of this study area ranges between 15.3587°c to 22.141 °c and this values were converted in to the surface by interpolating from 14 different meteorological stations and this values were reclassified into five different annual temperature intervals or categories and details are described as table below.

Table 4-4.Weight assignment for different ranges of temperature (weight ∝ suitability).

Average annual Temperature (°c)	Weight Assignment
$15 \leq T < 20$	5
$20 \leq T < 25$	4
$25 \leq T < 30$	3
$30 \leq T < 35$	2
>35	1

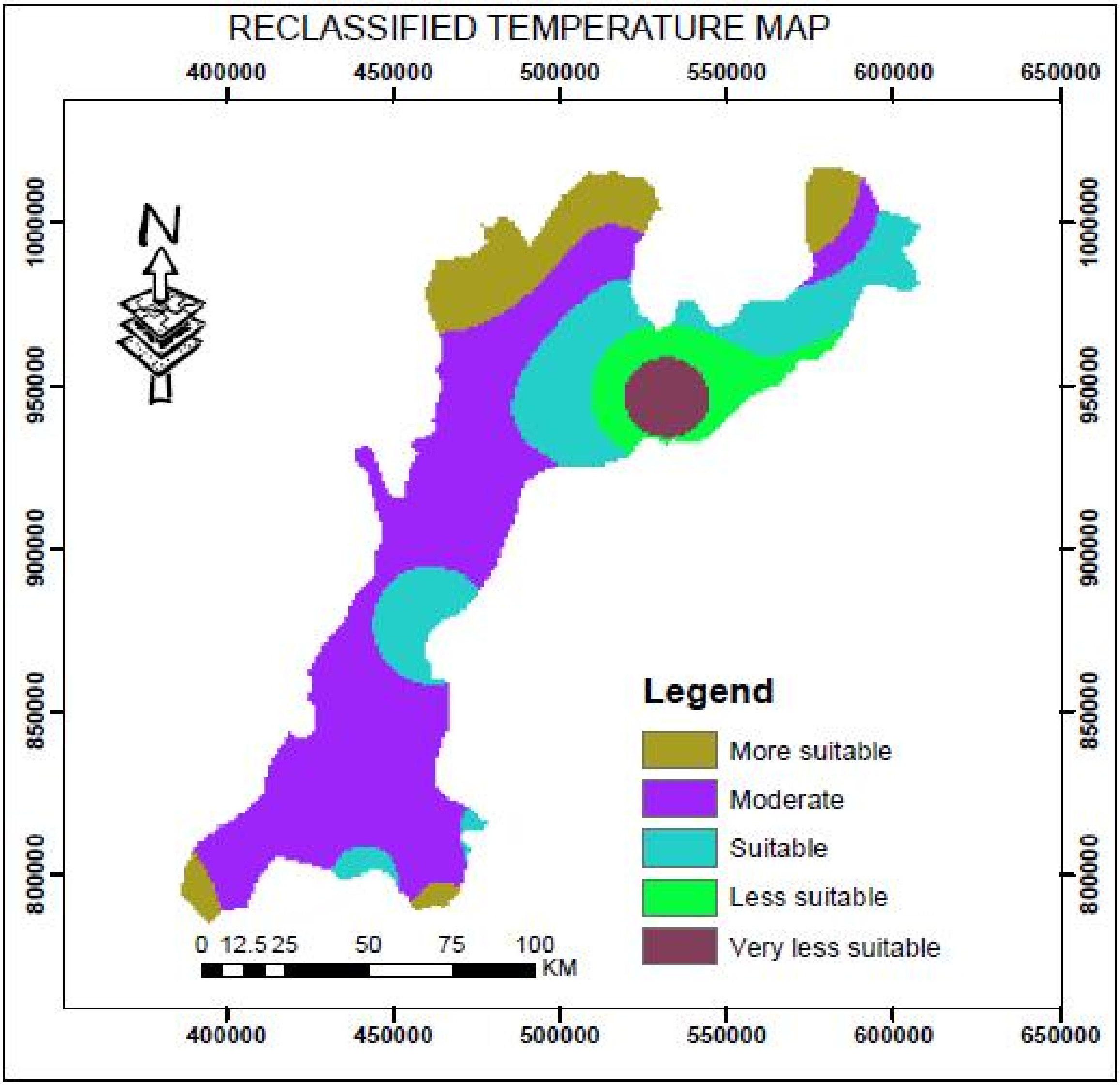

Fig.4-13.Temperature layer of study area generated equal to estimated relative weight.

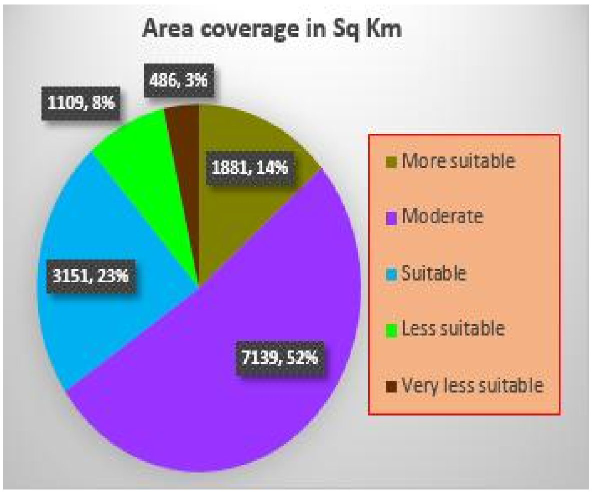

Fig.4-14.Spatial coverage of relative temperature computed from reclassified temperature layer.

From the analysis, the spatial coverage of relative temperature range were computed from reclassified temperature layer. Accordingly, the region was classified in to five classes and the result of generated thematic map layer were 1880.70 SqKm(14%) more suitable, 7139.50 SqKm (52%) moderate, 3150.67 Sq Km(23%) suitable, 1109.24 Sq Km (8%) less suitable and 486.40 Sq Km (3%) very less suitable as shown in figure (4-14).

Slope

Solar PV panels collect solar radiation directly from the sun, from the sky, and from sunlight reflected off the ground or area surrounding the PV panel. Orienting the PV panel in a direction and tilt to maximize its exposure to direct sunlight will optimize the collection efficiency. The panel will collect solar radiation most efficiently when the sun's rays are perpendicular to the panel's surface (Charabi & Gastli , 2011). Therefore gentle slope should be recommended for better potential of solar radiation. Slope of the study area was calculated from DEM (30m * 30m resolution) and used in GIS environment as a thematic map. Lastly, slope were classified in to five slope categories or classes as shown in table below.

Table 4-5.Weight assignment for different ranges of slope (weight ∝ suitability).

Slope(S) in degree	**Weight Assignment**
< 10	5
$10 < S < 20$	4
$20 < S < 30$	3
$30 < S < 40$	2
$S > 40$	1

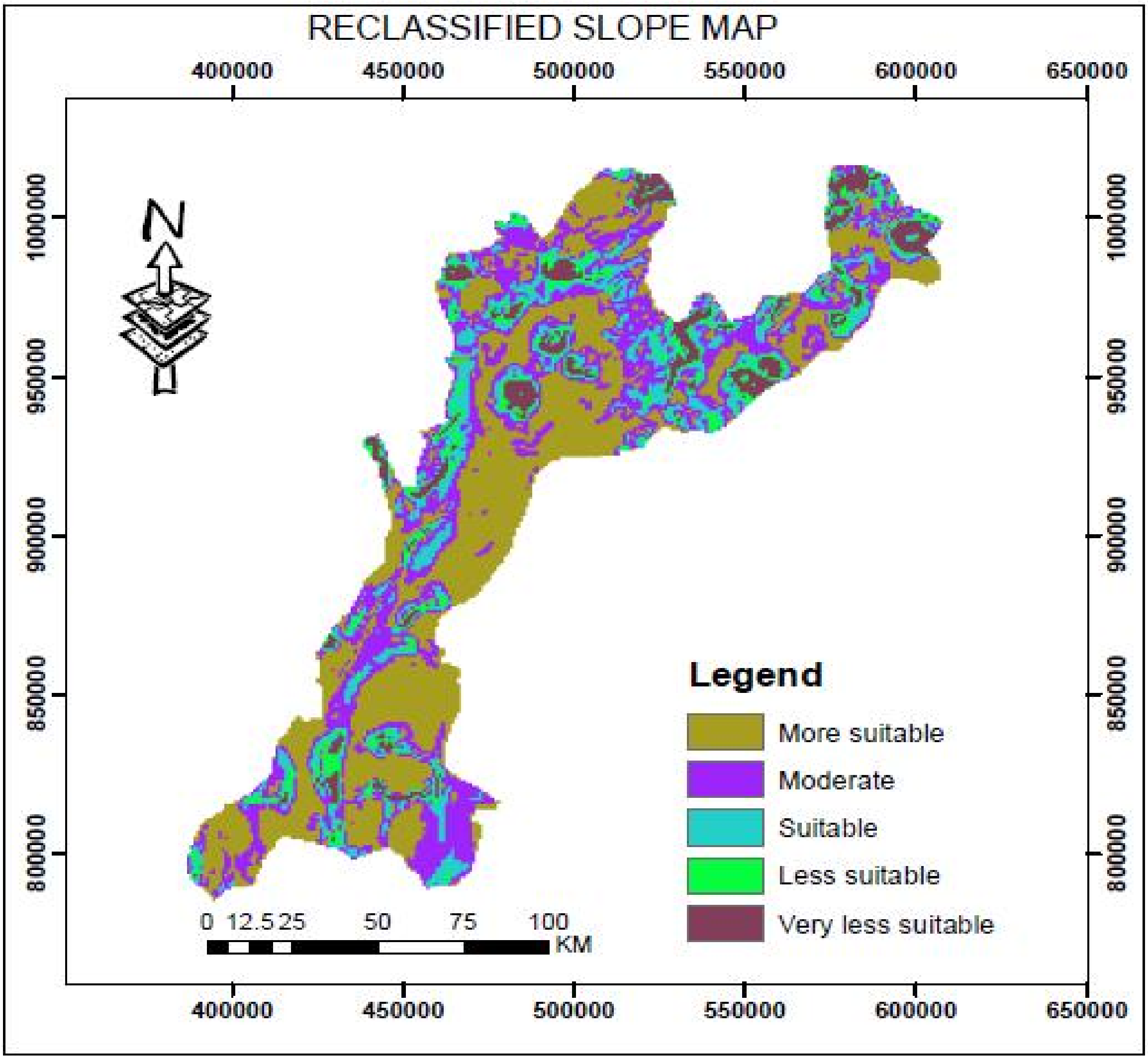

Fig.4-15.Slope layer generated using new pixel value equal to estimated weight for slope

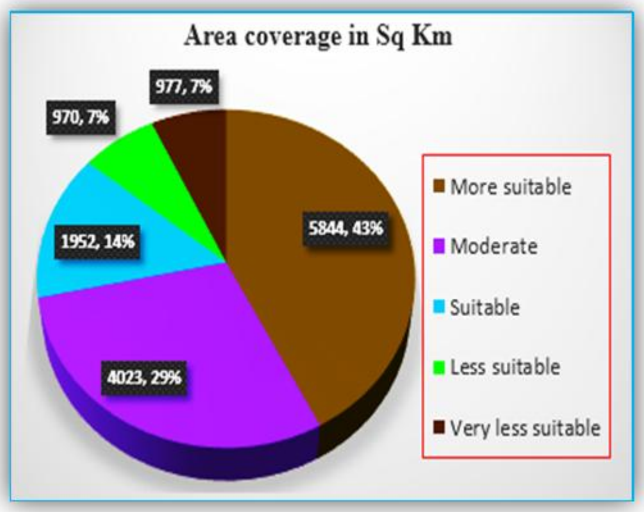

Fig.4-16.Spatial coverage of relative slope range computed from reclassified slope layer.

The spatial coverage of relative slope range were computed from the reclassified slope layer. Accordingly, the area with 5844.30 Sq Km(43%) more suitable, 4023.56 Sq Km (29%) moderate, 1951.70 Sq Km(14%) suitable, 970.10 Sq Km (7%) less suitable and 976.87 Sq Km (7%) were very less suitable.

Elevation

The distance solar rays have to travel through the atmosphere is less at higher altitudes. Therefore there is less atmospheric absorption, and consequently, more solar radiation as the elevation increases. Altitude is one of the major factors affecting the global solar radiation *(Sharma, 1990)*. The global solar radiation increases in altitude mainly due to decreasing amounts of air molecules, distance from the sun to earth and electromagnetic wavelength. In this study, the elevation of thematic layer derived from Digital Elevation Model and classified in to five different elevation ranges/ classes based on the estimated suitability level.

Table 4-6.Weight assignment for different ranges of elevation (weight ∝ suitability).

Elevation (E) in (m)	**Weight Assignment**
$2500 \leq E < 3101$	5
$2000 \leq E < 2500$	4
$1500 \leq E < 2000$	3
$1000 \leq E < 1500$	2
$902 \leq E < 1000$	1

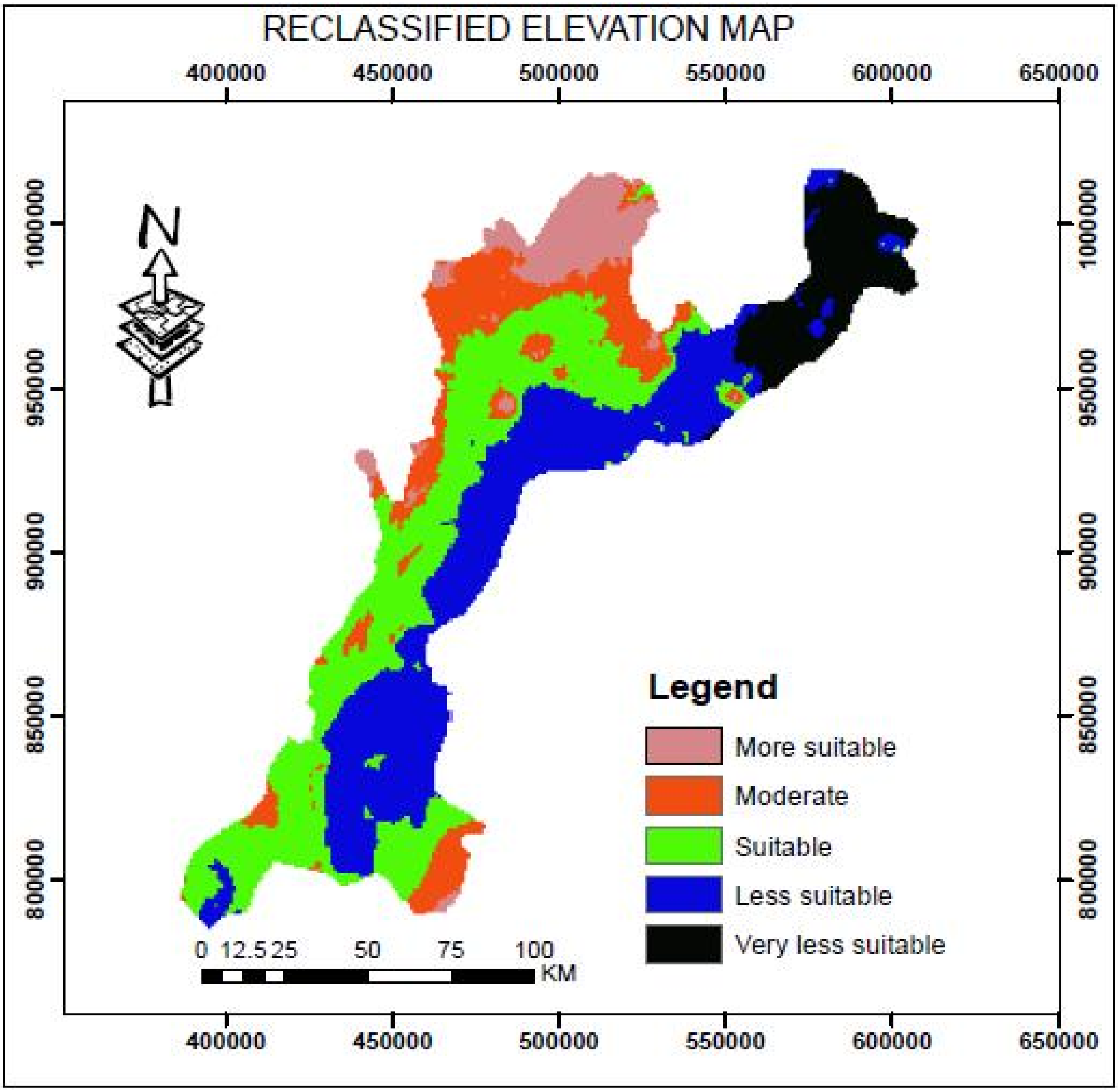

Fig.4-17.Elevation layer generated using new pixel value equal to estimated relative weight.

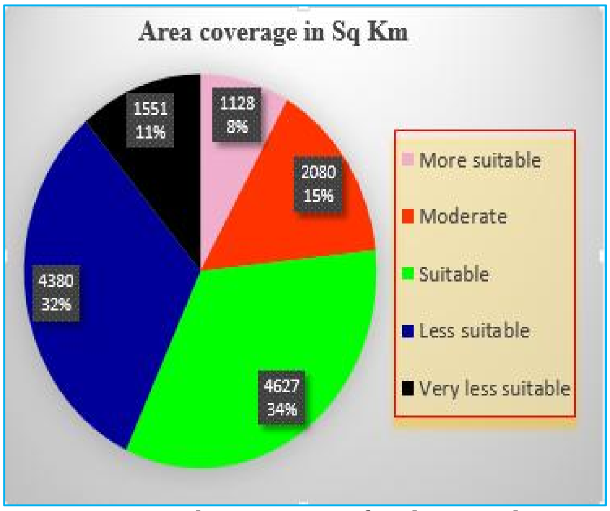

Fig.4-18.Spatial coverage of relative Elevation range computed from reclassified Elevation layer.

The spatial coverage of relative elevation range were computed from reclassified elevation layer. Accordingly, the region was reclassified in to five classes and the result of spatial coverage of each class shows 1127.56 Sq Km(8%) were more suitable,2080.34 Sq Km (15%) moderate, 4627.30 Sq Km(34%) suitable, 4380.40 Sq Km (32%) less suitable and 1550.90 Sq Km(11%) very less suitable as it is shown in figure (4-18).

Land use/cover

Land requirement is one of the most critical factors for the energy investment (Kahraman et al, 2009). The land use/land cover is considered as an environmental factor for site selection of solar farms. The suitability of an area for the siting of solar farms also depends on the prevalent land cover types. From a social acceptance point of view, some land cover type can be considered to be more preferable than others. Thus, Barren land, shrubs and grass land can generally be considered most suitable, since they need only minimal investment into land preparation or cleaning. High density urban development area and open water body were excluded, as PV deployment is not possible on these areas. In this study, land use/land cover were extracted from landsat_2015. Before reclassifying image, pre-processing(formatting and correcting of the data, digital image were enhanced to facilitate better visual interpretation), supervised classification (develops numerical descriptions of the spectral signatures of each land use/cover type of interest in the scene in ERDAS environment), classification accuracy assessment *(*a set of reference pixels were used and reference pixels are random points on the classified image for which actual data are known*)* and built a confusion matrix using ERDAS imagine software were applied and all land use/land cover layer were re-classified into five classes or categories. Hence the details of image classification was shown in detail under appendix A for more information.

*Table 4-7.Weight assignment for land use/land cover types based on estimated suitability level***.**

Land use/Land cover types	**Weight Assignment**
Barren land	5
Grass land	4
Open Shrubs	3
Closed Shrubs	2
Farm land	1

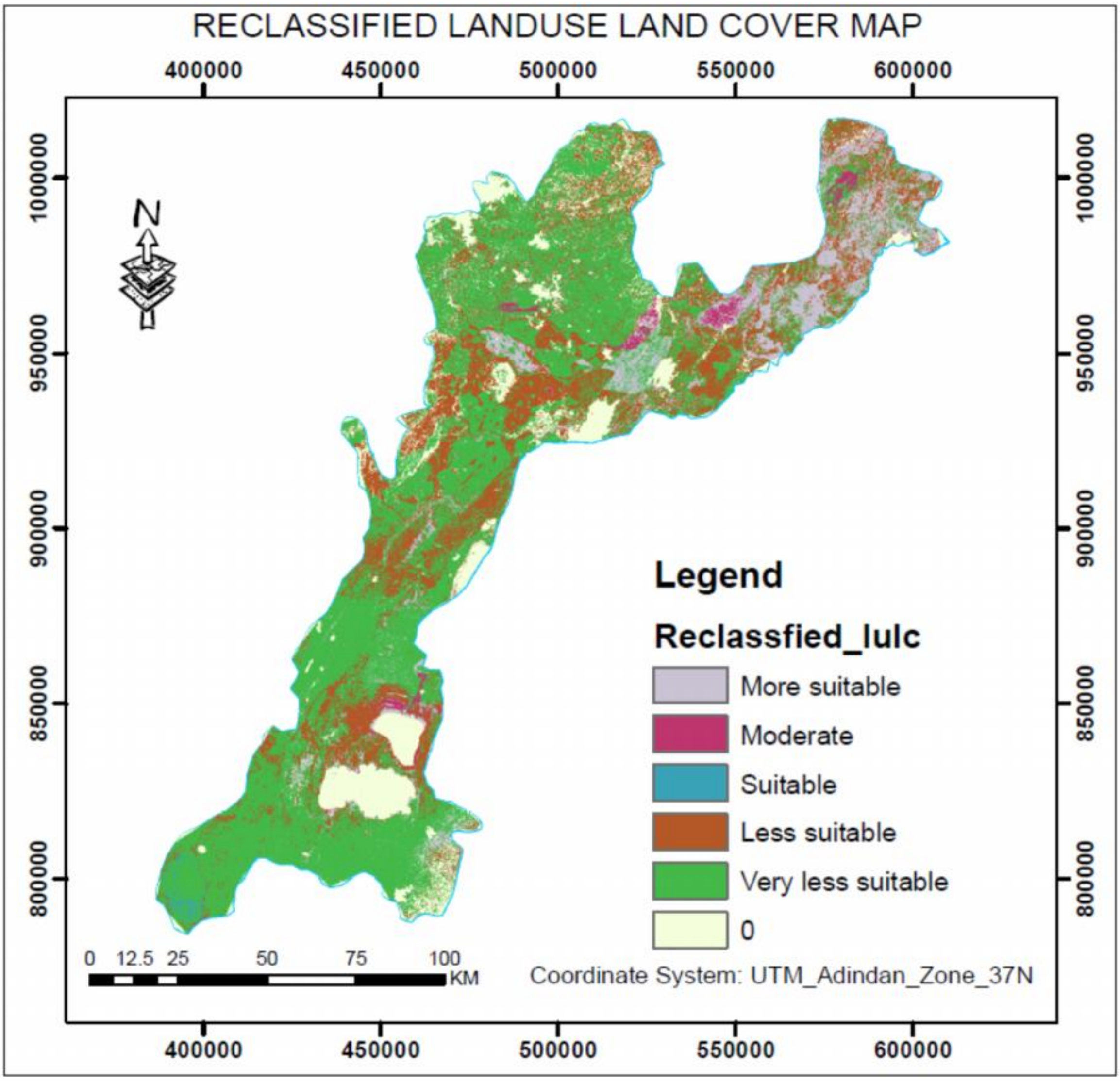

Fig.4-19.Land use/land cover layer generated using new pixel value equal to estimated weight.

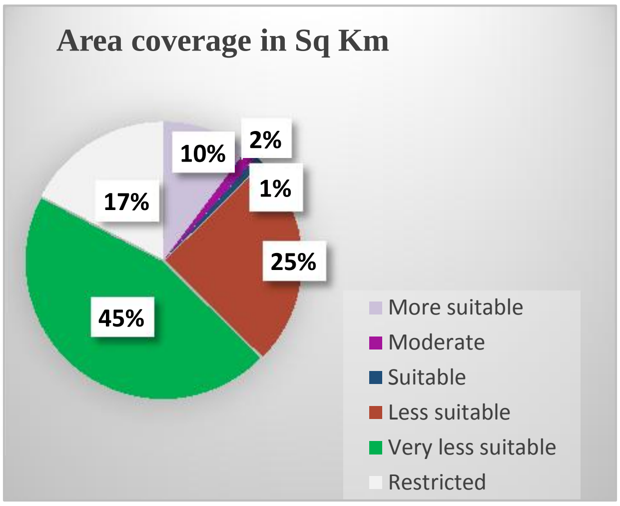

Fig.4-20.Spatial coverage of land use/land cover computed from reclassified land use/land cover layer.

From the figure (4-19) above, the spatial coverage of relative land use land cover were computed from reclassified land use/ land cover layer. Accordingly, the region was reclassified in to five classes and the result of spatial coverage of each class shows 3219Km^2(23%) were more suitable, 709Km^2 (5%) moderate, 126Km^2(1%) suitable, 133Km^2 (1%) less suitable and 7955Km^2 (57%) very less suitable.

Sunshine Hour

Sunshine duration or sunshine hours is a climatological indicator, measuring duration of sunshine in a given period for a given location on earth (typically, expressed as an average of several years). It is a measure of cloudiness of a location (Wikipedia, 2016). Bright sunshine hours at a given location vary significantly due to atmospheric components and it is measured by sunshine recorders. It has been shown that, among the atmospheric and meteorological parameters that affect the amount of global solar radiation reaching a horizontal location, the greatest influence is exerted by sunshine hours (Udo, 2002).

It is a general indicator of cloudiness of a location, and thus differs from insolation, which measures the total energy delivered by sunlight over a given period. Sunshine duration is usually expressed in hours per year, or in (average) hours per day. The first measure indicates the general sunniness of a location compared with other places, while the latter allows for comparison of sunshine in various seasons in the same location.

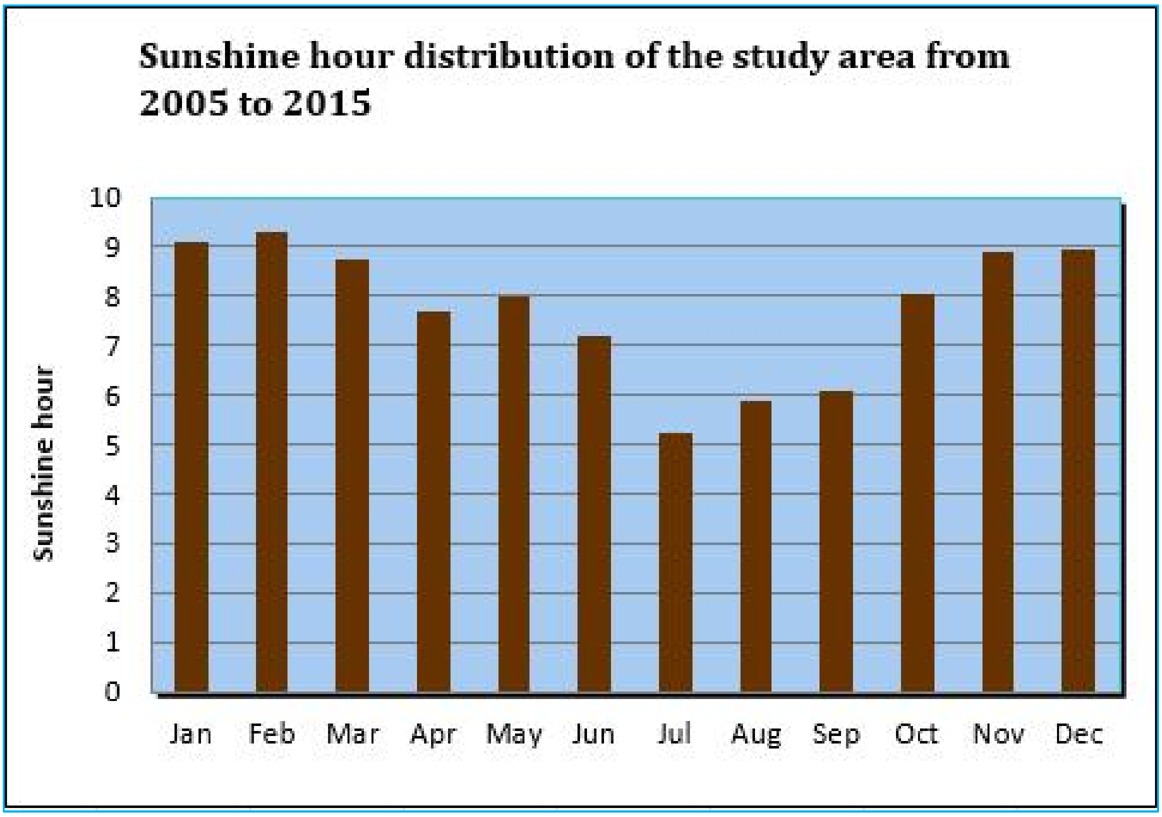

Fig.4-21.Average monthly sunshine duration recorded at 14 metrological station_2005-2015.

Table 4-8.Weight assignment for different ranges of sunshine duration in the study area.

Sunshine Duration	Weight Assignment
8 ≤ SH ≤ 9	5
7.5≤ SH ≤ 8	4
7 ≤ SH ≤ 7.5	3
6.5 ≤ SH ≤ 7	2
6 ≤ SH ≤ 6.5	1

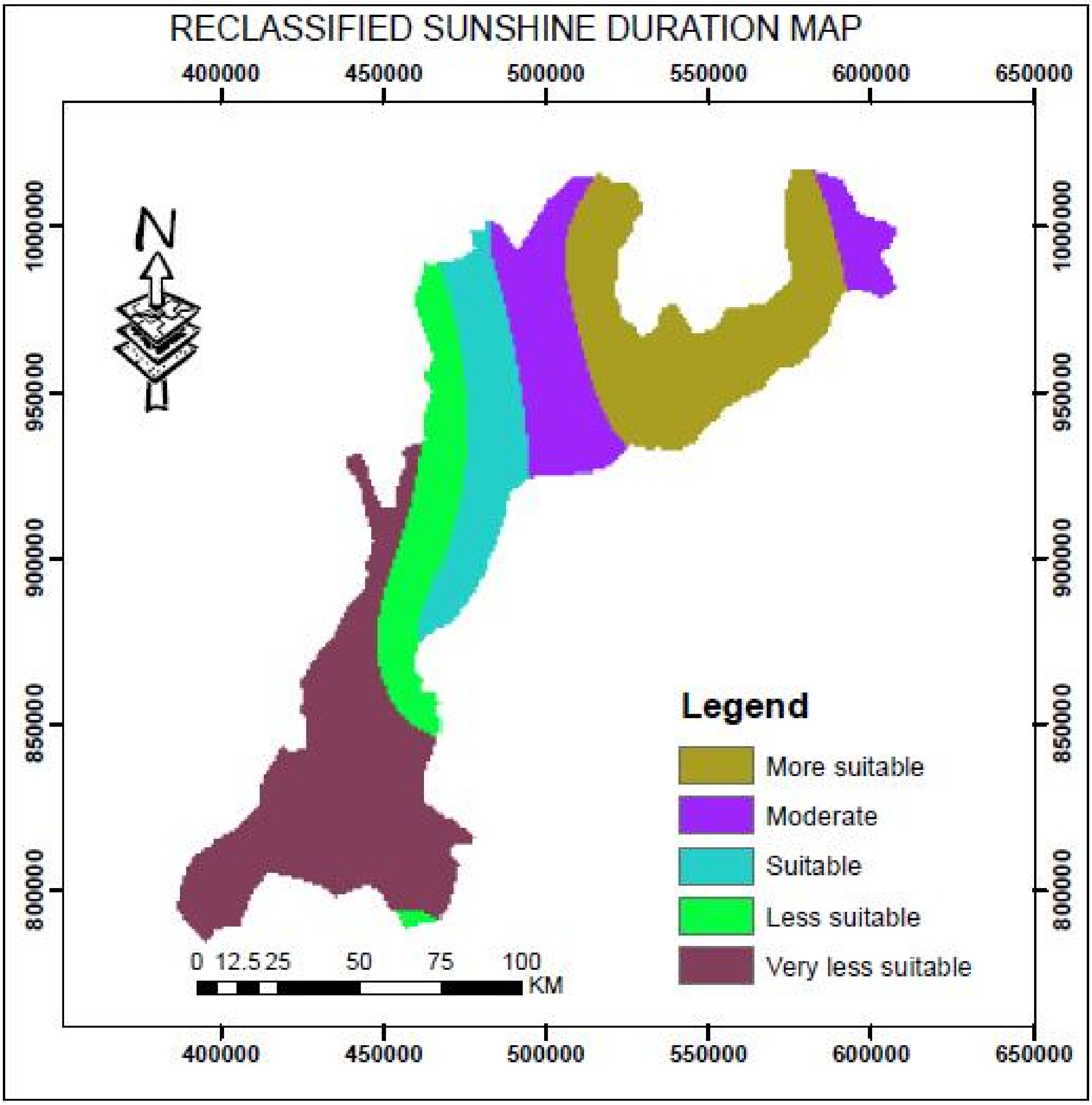

Fig.4-22.Sunshine hour layer generated using new pixel value equal to estimated relative weight.

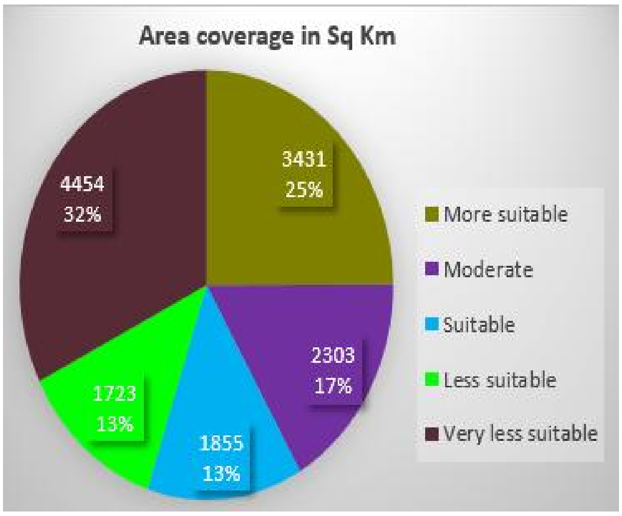

Fig.4-23.Spatial coverage of relative sunshine duration computed from reclassified sunshine duration layer.

The sunshine hour was reclassified in to five different categories or classes and it has been shown that the spatial coverage of relative sunshine duration range were computed from reclassified sunshine hour layer. Accordingly, the result of spatial coverage of each class shows 3431.30 Sq Km(25%) as more suitable, 2302.70 Sq Km (17%) moderate, 1855.40 Sq Km(13%) suitable, 1823.10 Sq Km (13%) less suitable and 4453.70 Sq Km (32%) of the total area were considered as very less suitable.

Wind Speed

For PV power plant efficiency, wind speed is important for three reasons. Firstly, wind is the most important factor influencing the cell temperature, by increased wind velocity more heat can be removed from the PV cell surface (i.e. cooling purpose). Secondly, higher air velocity lowers the relative humidity of the atmospheric air in the surroundings which in turn leads to better efficiency. Thirdly, removes dust from PV panel, PV panel performance can be influenced by dust deposition and settlement on the surface of PV cells can drop the efficiency (Mani & Pillai, 2010). Moreover, solar farm site with higher wind speed including gust is also not recommended, because wind gusts can have physical impacts on solar PV systems. Therefore, to minimize such problems, it must not be sited at very low and high wind speed (US EPA & NREL, 2013). Accordingly, the wind speed of the present study ranges from 2.74 m/s to 8.63m/s and classified in to five different wind speed ranges/ classes based on the estimated suitability level as shown in table below. Therefore the average of the maximum and minimum wind speed value should be the best site.

Table 4-9.Weight assignment for different ranges of wind speed in the study area.

Wind speed(m/s)	Weight Assignment
$3 \leq Ws \leq 3.5$	2
$3.5 \leq Ws \leq 4$	4
$4 \leq Ws \leq 4.5$	5
$4.5 \leq Ws \leq 5$	3
$Ws \leq 3$ & $Ws \geq 5$	1

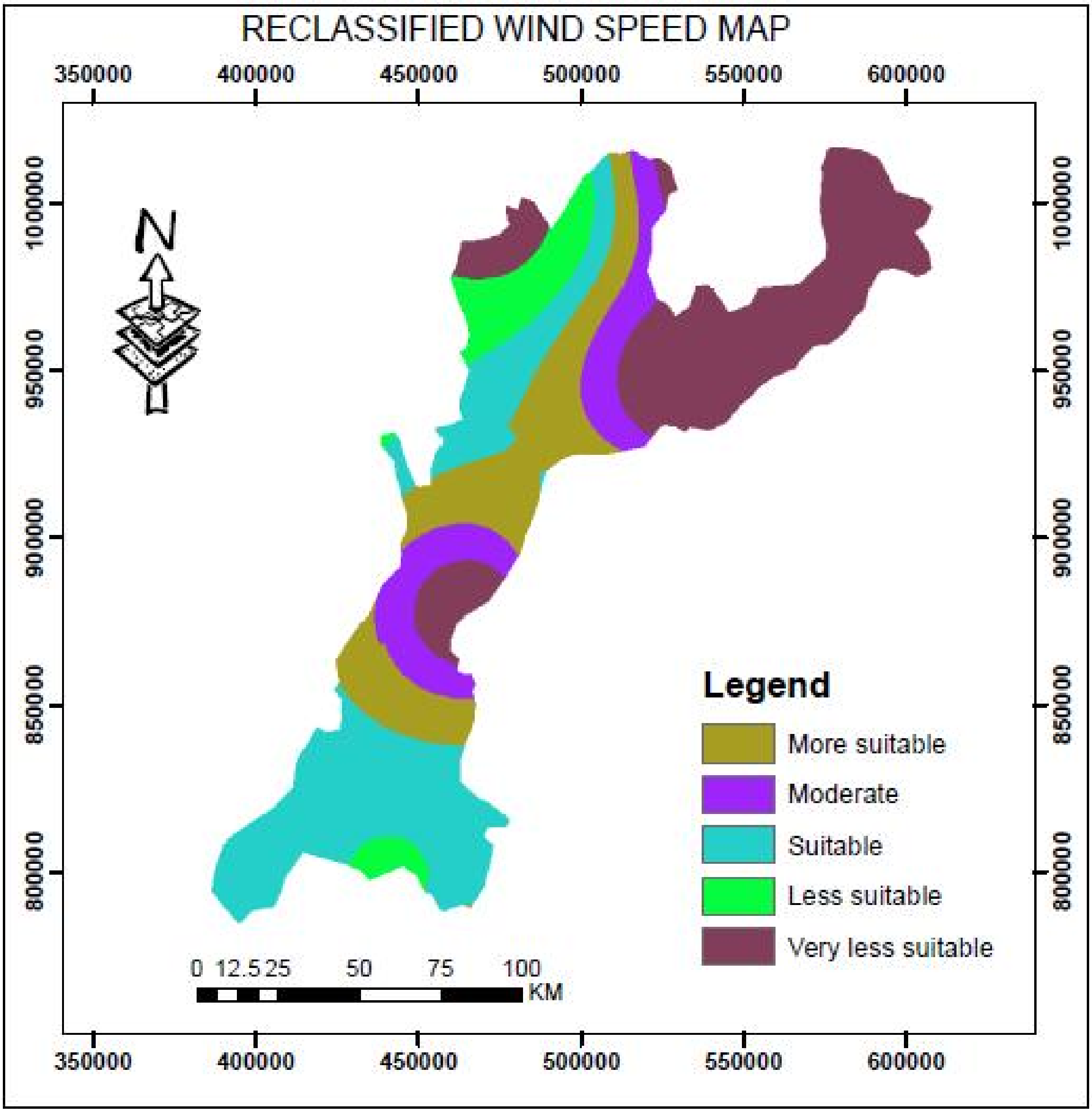

Fig.4-24.wind speed layer generated using new pixel value equal to estimated relative weight.

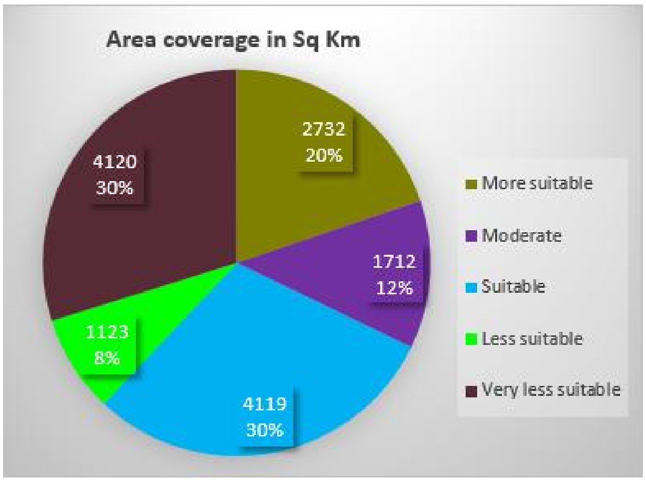

Fig.4-25.Spatial coverage of relative wind speed range computed from reclassified wind speed layer.

From the above thematic map, the spatial coverage of relative wind speed range were generated/computed from reclassified wind speed layer. Based on the generated thematic map, the result of the analysis obtained shows that, 2732.62 Sq Km(20%) were more suitable, 1711.80 Sq Km (12%) moderate, 4118.91 Sq Km(30%) suitable, 1123.20 Sq Km (8%) less suitable and 4120.202 Sq Km (30%) very less suitable.

Seismic Intensity

The Mercalli intensity value is a seismic scale used for measuring the intensity of an earthquake and it measures the effects of an earthquake, and is distinct from the moment magnitude usually reported for an earthquake (sometimes misreported as the Richter magnitude), which is a measure of the energy released. The intensity of an earthquake is not entirely determined by its magnitude. It is not based on first physical principles, but is, instead, empirically based on observed effects (USGS, 2014).

The Mercalli value (MV) quantifies the effects of an earthquake on the Earth's surface, humans, objects of nature, and man-made structures on a scale from I (not felt) to XII (total destruction) (USGS,201), Values depend upon the distance from the earthquake, with the highest intensities being around the epicentral area. In Ethiopia, the Mercalli value ranges from V (weak) to VIII (Moderate). In this study, the study area lies on MV of 7 and 8. Accordingly, weights were assigned for different ranges of seismic intensity as shown in table below.

Table 4-10.Weight assignment for different ranges of seismic intensity(weight ∝ suitability).

Seismic Intensity	Weight Assignment
SI ≤ 7.5	5
7.5≤ SI ≤ 7.6	4
7.6 ≤ SI ≤ 7.7	3
7.7 ≤ SI ≤ 7.8	2
7.8 ≤ SI <8	1

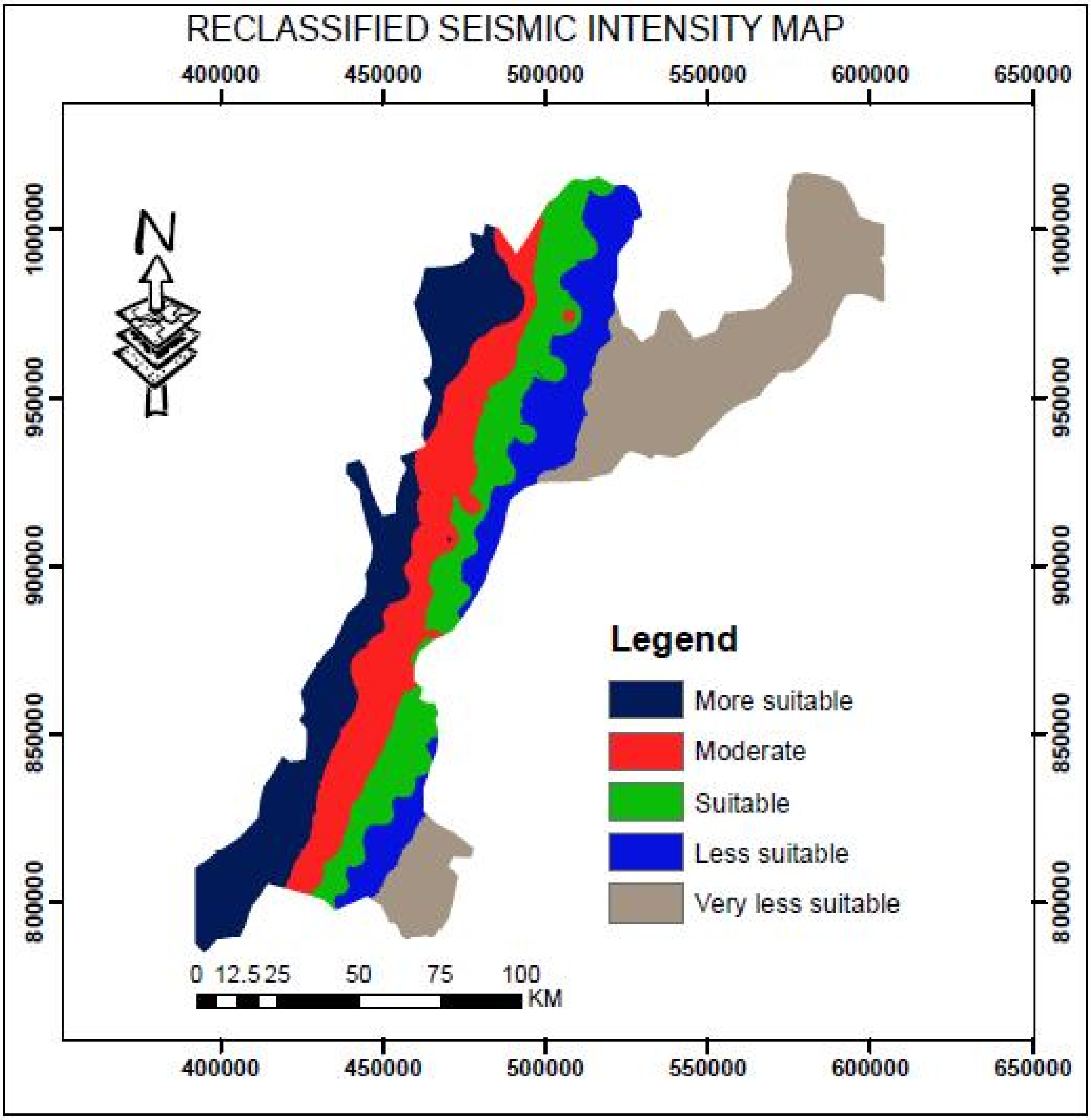

Fig.4-26.Seismic intensity layer generated using new pixel value equal to estimated relative weight.

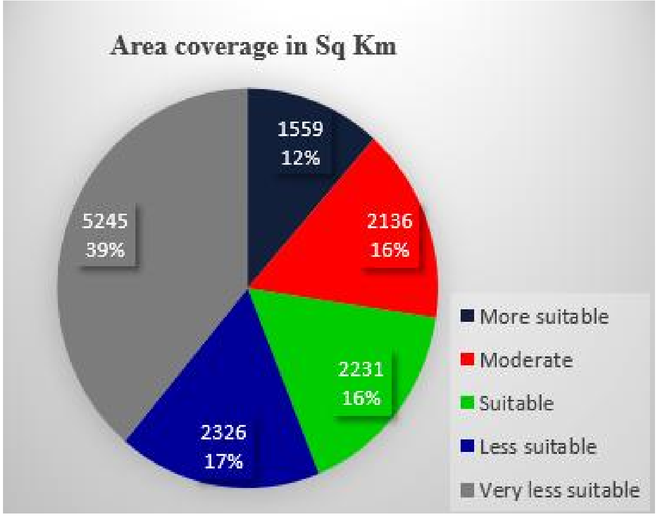

Fig.4-27.Spatial coverage of relative seismic intensity range computed from reclassified seismic intensity layer.

The spatial coverage of relative seismic intensity range were generated/computed from reclassified seismic intensity layer. Based on the generated thematic map, the result of the analysis obtained shows that, 1558.92 Sq Km(12%) were more suitable,2135.70SqKm(16%) moderate, 2231.51 Sq Km(16%) suitable, 2325.77 Sq Km (17%) less suitable and 5244.78 Sq Km (39%) very less suitable as shown in figure (4-27).

4.2. Determination of Weights using AHP

The pair wise comparison matrix used for the present study was developed based on the review of relevant literature. The decision making process in the multiple criteria problems is subjective process depending on the decision maker vision. For each factor, the attributes were standardized by transforming the original value to a suitability value (Saaty, 2008). The higher value is more favorable and vice versa. Areas with high suitability will have a higher score. To make comparisons, we need a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared. Table below exhibits the scale.

Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).

Table4-11Pair wise comparison matrix of the factors using AHP approach.

	SR	SH	LULC.	TRL	RD	SLP	TMP	SI	ELV	WS
SR	1									
SH	1/3	1								
LULC	1/3	1/3	1							
TRL	1/3	1/2	1/3	1						
RD	1/3	1/3	1/3	1	1					
SLP	1/5	1/5	1/3	1/3	1/3	1				
TMP	1/5	1/7	1/5	1/5	1/5	1/3	1			
SI	1/7	1/7	1/5	1/5	1/5	1/3	1/2	1		
ELV	1/7	1/9	1/7	1/5	1/5	1/5	1/3	1/3	1	
WS	1/9	1/9	1/7	1/7	1/7	1/7	1/5	1/3	1/3	1

Where, SR = Solar Radiation, SH = Sunshine Hour, LULC = Land use Land cover, TRL=Transmission Line, RD= Road, SLP=Slope, TMP= Temperature, SI= Seismic Intensity, ELV=Elevation and WS= Wind Speed

The consistency ratio (CR) indicates the probability that the matrix rating were randomly generated. As a general rule, a consistency ratio greater than 0.10 should be re-calculated. The result of the calculated CR= 0.07, which indicates a reasonable level of consistency in the pair-wise comparisons.

4.3. Overlay Analysis

The overlay analysis task can be divided in to two parts. In the first part, factors were overlaid using different weights (weights overlay of factors using AHP). In a second process, unsuitable areas were excluded with a means of Boolean overly (i.e. Boolean overlay of constraint factors).

4.4. Boolean overlay of constraints

The Boolean overlay of constraints, the three Boolean constraint layers incorporating water bodies, forest land and built up or urban areas were employed. By performing the Boolean overlay operations, the resulting raster of Boolean overlay operation is presented as follows.

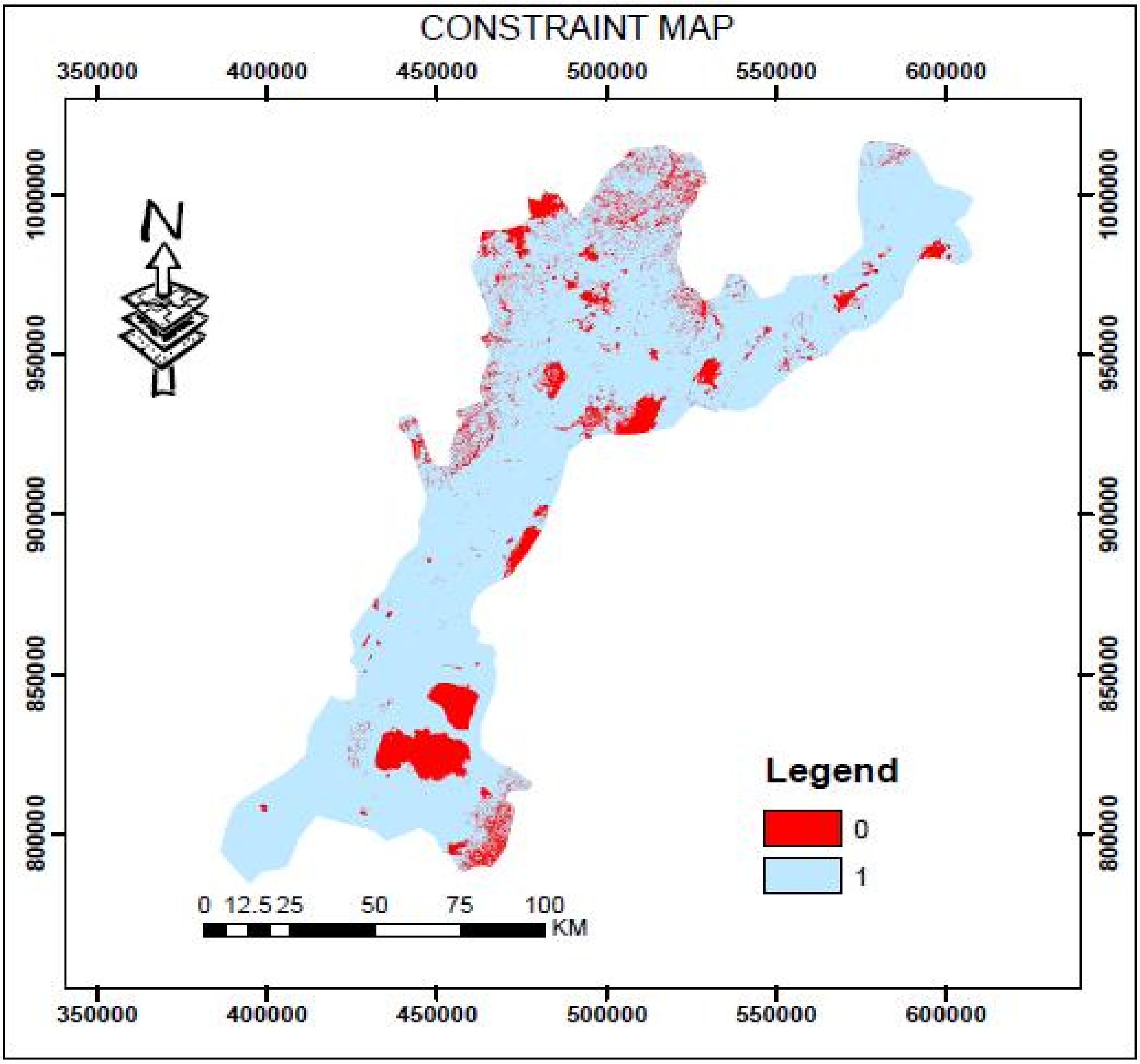

Fig.4-29.The constraints layer generated using Boolean overlay of constraints.

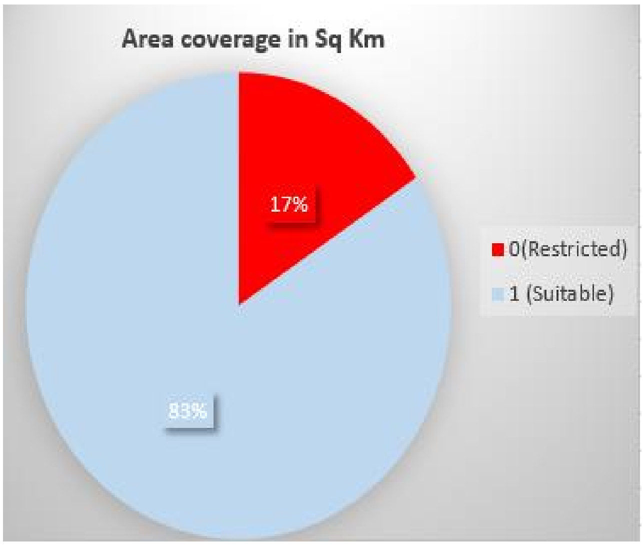

Fig.4-30.Spatial coverage of relative restricted area computed from land use/cover layer.

Based on Boolean overlay of constraint, constraint maps are generated to determine the criteria that are constraints to the solar PV power plant site selection. Pixels with values of zero represent the areas are restricted to be the optimal site. The spatial coverage of relative constraint layer were computed from Boolean overlay. Accordingly, the result of spatial coverage of each class shows 2168.56 Sq Km(17.56%) as constraint area whereas 11597.57 Sq Km(83%) of the total area were in the analysis.

4.5.2. Weighted Overlay of Factors

In this study, weighted overlay analysis were applied using Arc GIS software in order to obtain the suitable solar power plant site. The weighting and rating scheme was carefully designed through a comprehensive literature review of related researches, factors weight and suitability scores were summarized as table below.

Table 4-11.Weight derivation and score of factors using AHP approach.

Factors	Weight derived using AHP	% Weight
Solar Radiation	0.2655	26.55
Sunshine hour	0.2118	21.18
Land u/Land cover	0.1516	15.16
Transmission line	0.1046	10.46
Road	0.1017	10.17
Slope	0.0694	6.94
Temperature	0.0355	3.55
Seismic intensity	0.0264	2.64
Elevation	0.0198	1.98
Wind speed	0.0135	1.35

4.5. Solar Power plant factor Map

The analysis of the weight assignment shows that radiation potential and sunshine duration are more influential than the other factors as described in (Table 4-9), as they are very important to locate the best site. Weighted overlay of factors analysis result showed different ranges of suitability levels. These are less suitable, suitable, moderately suitable and more suitable.

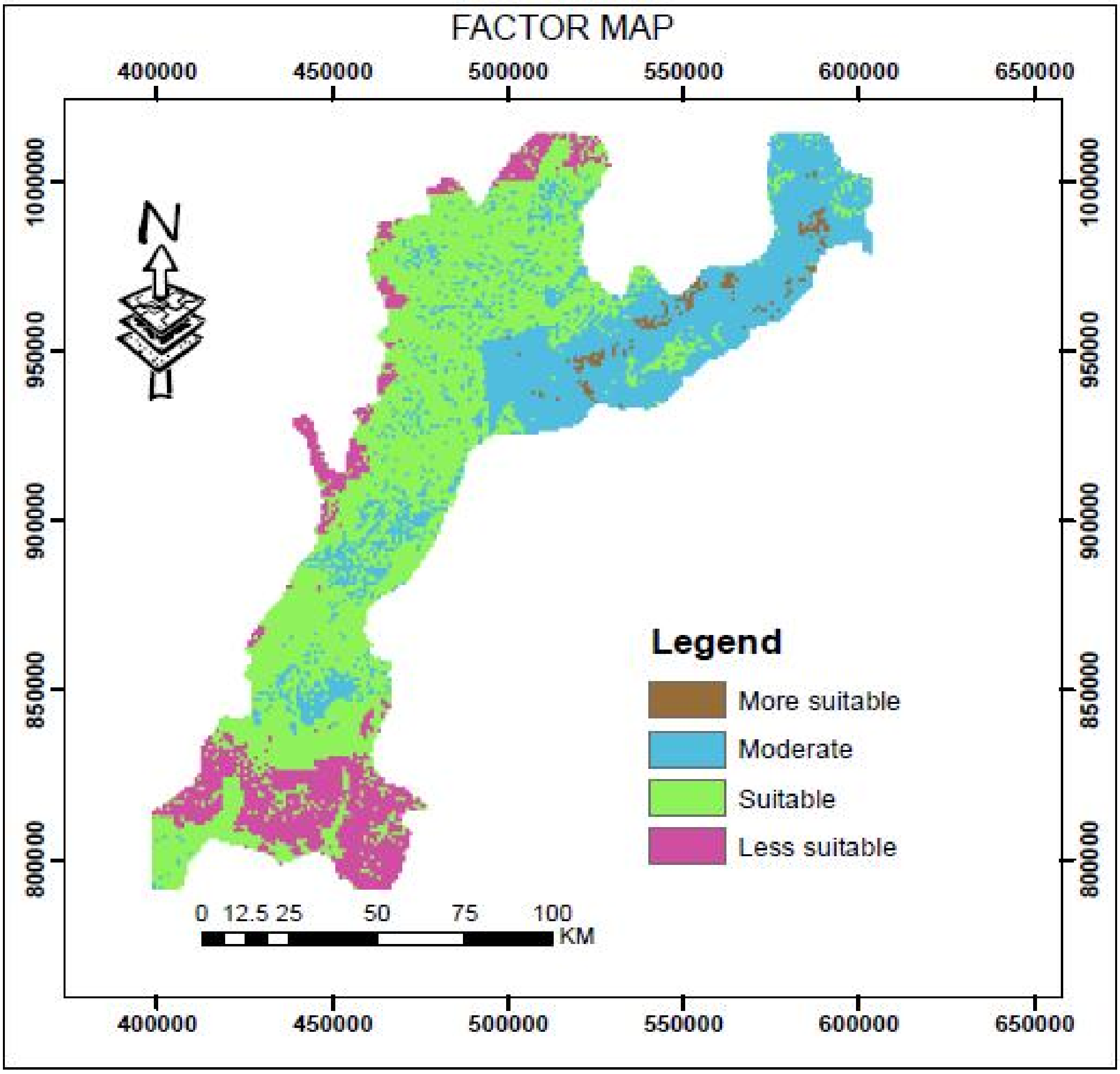

Fig.4-31. suitability of factors computed/generated using overlay of factors layer

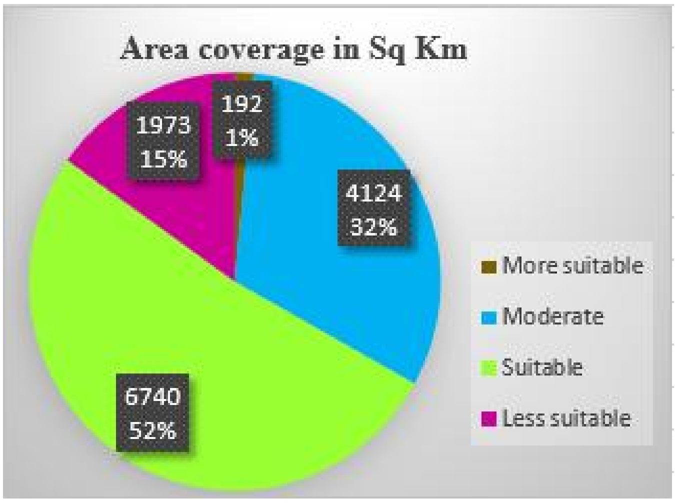

Fig.4-32.Spatial coverage of suitability of factors computed/generated from overlaid factor layer.

The spatial coverage of suitability generated/computed from the weighted overlay of factors layer. Based on the generated output map, the result of the analysis obtained shows that, 192 Sq Km(1.39%) were more suitable, 4124.4 Sq Km (31.87%) moderate, 6739.58 Sq Km(51.9%) suitable and 1972.5 Sq Km (14.73%) less suitable as shown in figure (4-32).

4.6. Solar Farm Suitability map

The net probability of occurrence of suitability in each area is analyzed from the total multiplication of the weight of each contributing factor considered and the constraint using raster calculation to obtain solar farm suitability map; the output of the result of overlaid Boolean constraint layer and the overlaid factors layer were generated as shown in figure below.

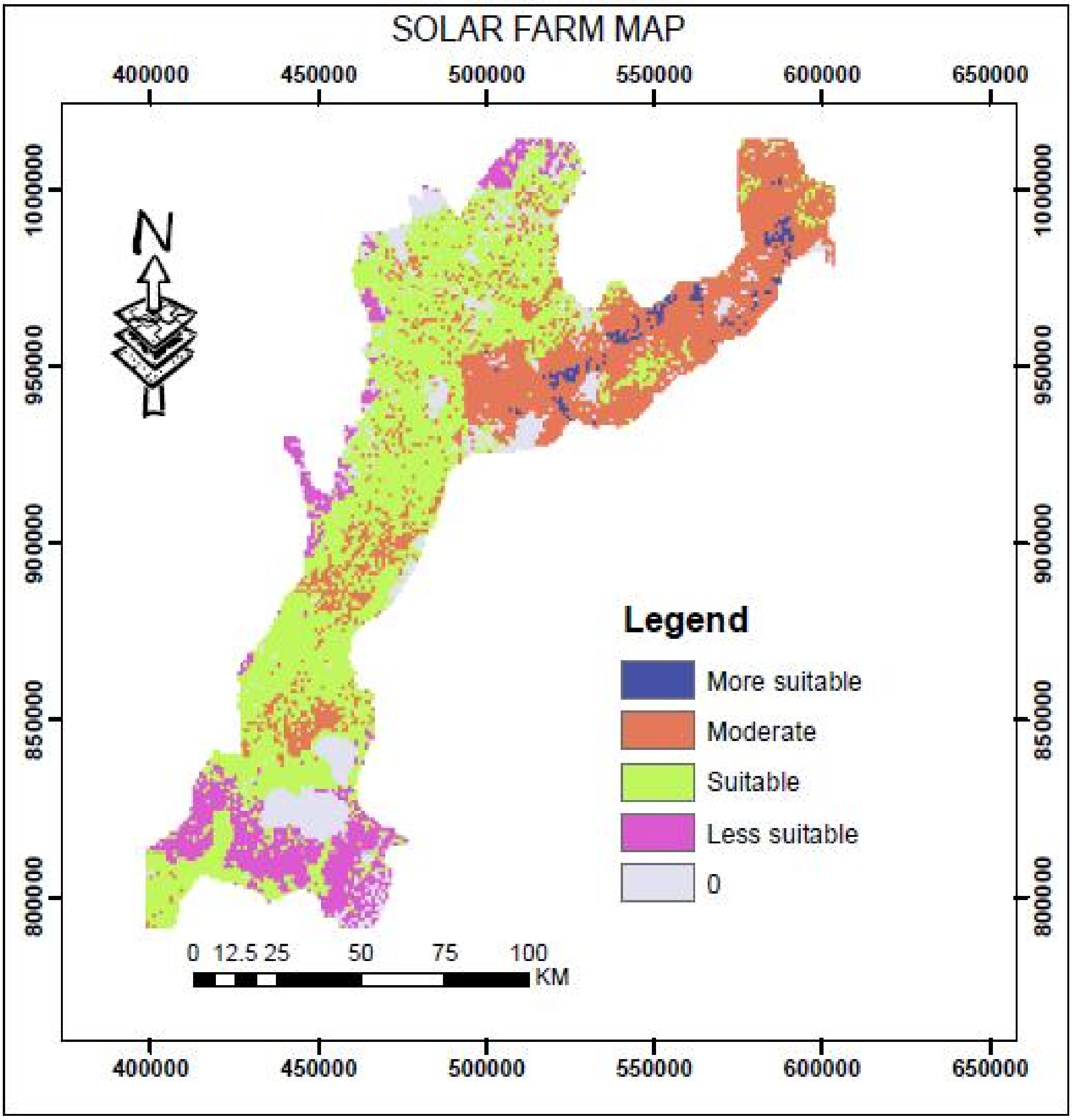

Fig.4-33.Suitability map generated based on the intersection of factors and constraint layer.

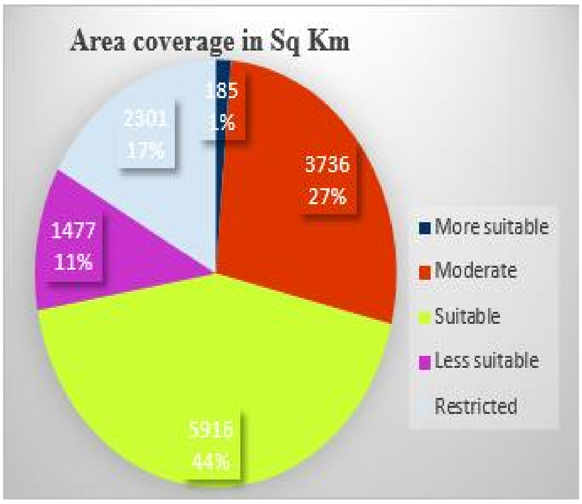

Fig.4-34.Spatial coverage of suitability map from overlay of factor map and constraint layer.

The generated suitability map (figure 4-32), The result of the spatial coverage of suitability of solar farm site generated/computed from the overlay of factors layer and constraint layer showed that 2301km^2 (17%) of the study area is unsuitable as the areas are environmentally, socially unacceptable and economically unfeasible for Solar farm. However, 185 km2 (1%) of the area satisfies the environmental, social and economic criteria set in the previous section and hence identified as more suitable and 27%, 44% and 11% are moderate, suitable and less suitable respectively.

4.7. Technical Potential Assessment of each solar farm sites

The process for generating technical estimates for utility-scale Photovoltaic (PV) begins with excluding areas not suitable for this technology. Renewable energy technical potential represents the achievable energy generation of a particular technology given system performance, topographic limitations, environmental, and land-use constraints. For calculations of solar PV potentials of the suitable (candidates) area, efficiencies and conversion factors which are characteristic for typical large-scale grid-connected systems are used. To develop the technical potential for the suitable area, the following formula was developed by National Renewable Energy Laboratory:

$$TechnicalPotential = Solar\ resource\ availability \times PV\ Module\ Efficienc$$

$$Spacing\ factor \times Available\ area.$$ (US EPA & NREL, 2013)

E=H*(Me/f)*A………………………………………………………………… (4-1)

Solar Resource Availability; for each location on the study area, values for DNI and GHI are available. For the solar PV technology, the study use the GHI value as it presents a close correlation to the amount of energy produced.

PV Module Efficiencies; according to the National Renewable Energy Laboratory (US EPA & NREL, 2013), as a conservative efficiency value for solar cells, the analysis assumes a PV module efficiency of 16.5%.

Spacing Factor or alternatively the "ground cover ratio" (GCR) or footprint is a value for estimating the actual land use (ground areas) compared to the area of the actual panels. This factor depends on the type and characteristics of the PV plant, but an average factor for large PV installation is on the order of 5 (meaning that the ground area needed is 5 times higher than the actual area that "collects" solar radiation. For PV the main factors which lead to additional space requirements are collector spacing areas, and electrical equipment especially for large scale applications.

Available Area is equal to the area calculated in the GIS analysis (meaning that the suitable area obtained from the analysis).

Therefore, the technical potential of all candidates site are calculated as follows using equation 4.1:

$$E= H*(Me/f)*A$$

For PVsite1, E= 1054.85 kwh/m^2/year *(16.5%/5)*8.746=304.45GWh/year

Power(P) = E/t=304.45 GWh/year/(5h*365) = 166.82MW

E_{PV2} = 1054.85 kwh/m^2/year *(16.5%/5)* 16.22 = 564.62GWh/yr, P = 309.38MW

E_{PV3} = 1054.85 kwh/m^2/year * (16.5%/5) * 10.27 = 357.49GWH/yr, P = 195.89MW

E_{PV4} = 1054.85 kwh/m^2/year * (16.5%/5) * 13.18 = 458.79GWh/yr, P = 251.39MW

E_{PV5} = 1277.5 kwh/m^2/year * (16.5%/5) * 13.74 = 579.24GWh/yr, P = 317.40MW

E_{PV6} = 1277.5 kwh/m^2/year * (16.5%/5) * 13.95 = 588.097GWh/yr, P = 322.25MW

Table 4-12.Summary of technical potential computed from the candidate's site using equation 4-1.

List of site	SRP(kwh/m^2/year)	Me/f	Area	E(Gwh/yr)	Power (MW)
PV site 1	1054.85	16.5%/5	8.746	304.45	166.82
PV site 2	1054.85	16.5%/5	16.22	564.62	309.38
PV site 3	1054.85	16.5%/5	10.27	357.49	195.89
PV site 4	1054.85	16.5%/5	13.18	458.79	251.39
PV site 5	1277.50	16.5%/5	13.74	579.24	317.40
PV site 6	1277.50	16.5%/5	13.95	588.097	322.25

4.8. Evaluating Candidate Solar farm Sites

Technical and economic criteria like size of the site, distance from nearby transmission line, distance from the main road and the technical potential of the study area are the determinant criteria used to evaluate potential solar farm site so as to choose the best suitable from the candidates sites (EIA, 2014).

I. Size: Size of solar farm is one of the determinant criteria for collection of more energy, since radiation potential is measured in per meter square of land. From sustainability and economical point of views, larger size of land that will serve to collect more energy than small size of land. This is because selecting large sized solar farm site can minimize the cost of another site selection and design. A utility scale solar developers defines the ideal area for a well-designed solar plant must be greater than 100ha (Miller & Lumby , 2012).

Table 4-13.Spatial coverage of the suitable candidate's site.

List of Candidates site	**Area coverage in Sq Km**
PV site 1	8.746
PV site 2	16.22
PV site 3	10.27
PV site 4	13.179
PV site 5	13.739
PV site 6	13.947

Where, PV = Photovoltaic

II. Distance from the main road: For evaluating solar farm site, distance from the main road of the study area is also another very important criterion from economic point of view. Site far from the main road of the region is not preferable due to high transportation cost that will be incurred during its life time. Therefore, site close to the main road of the area is more preferable than far sites. The analysis of all the candidate sites with proximity distance following the roads showed that, PV site 1 and PV site2 located at 334m and 658 m respectively, PV site 3, PV site 4 and PV site5 was located at 1802m ,987m and 573.67m respectively from Nazreth - awash Arba while the road Nazreth - Awash Arba passes through PV site6. Hence, from transportation point of view, PV site 6 is the most suitable sites of all candidate sites.

III. Distance from the nearby transmission line: Evaluation of candidate solar farm sites with the distance from the nearby transmission line area can minimize technical losses during the transmission are proportional to the length of the distribution line and reduces the costs of cabling. Accordingly, the analysis of the sites with distance from the nearby transmissions in GIS environment shows that the transmission lines (koka - Awash - D/Dawa passes through PV site1, PVsite2 and PVsite3 was located at 807m and 1403m respectively away from koka - Awash - D/Dawa and PV site 4, 5 and 6 located at 835m, 637m and 594.6m respectively away from Koka - Awash - D/Dawa). Therefore, from distance nearby transmission line point of view, PV site 1 is the most suitable site of all candidate sites.

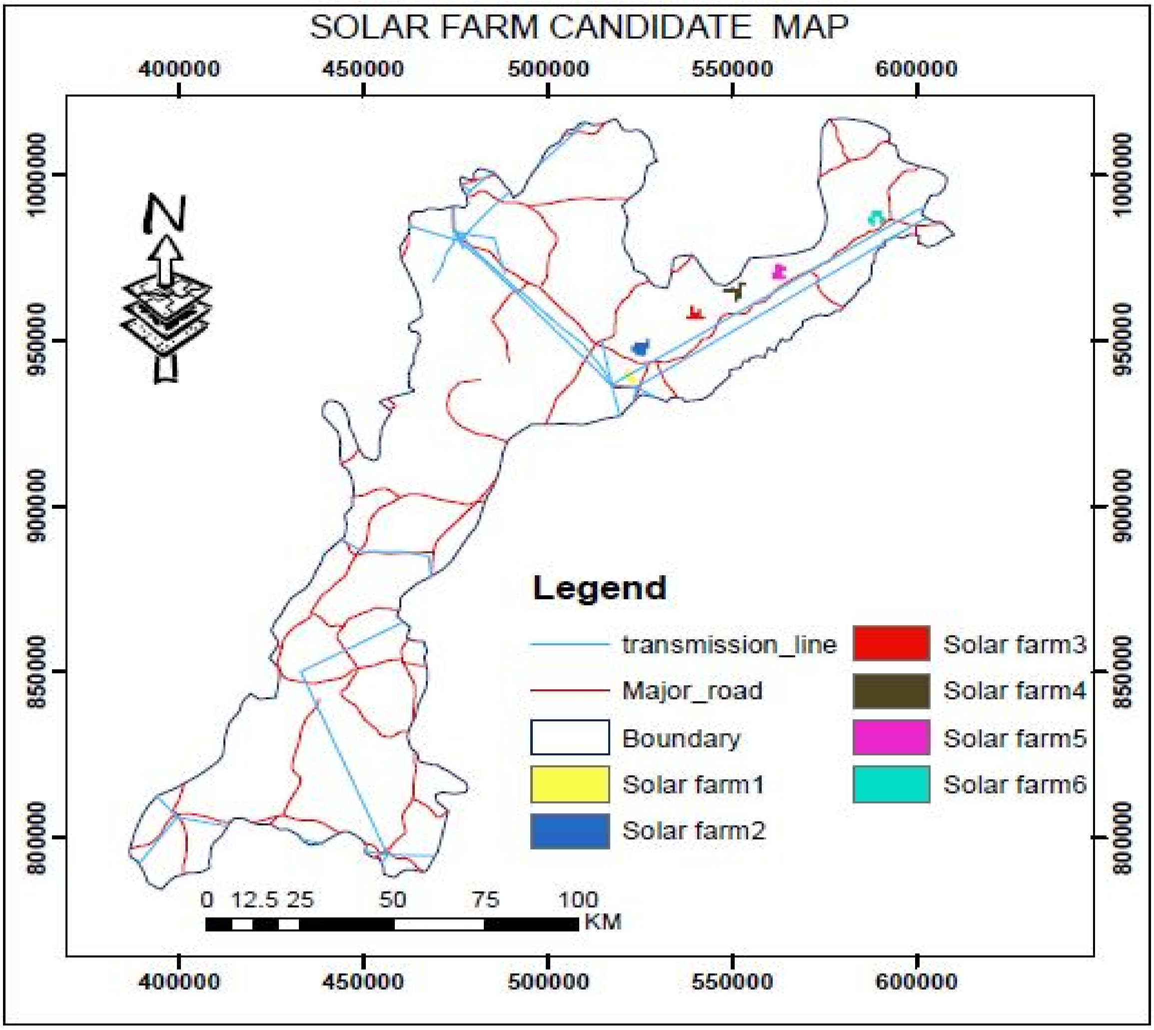

Fig.4-35.Candidate sites generated using the intersection of factors and constraint layer.

Table 4-14.Candidate solar farm sites with respect to those evaluating criteria value.

List of sites	Area in Sq Km	Distance from road(m)	Distance from nearby transmission line(m)	Technical potential(MW)
PV1	8.746	334	Passes through	166.82
PV2	16.22	658	807	309.38
PV3	10.27	1802	1403	195.89
PV4	13.18	987	835	251.39
PV5	13.74	573	637	317.40
PV6	13.95	Passes through	594	322.25

As described above, the criteria are conflicting to each other, MCE solves such decision problem so as to choose the most suitable solar farm site by considering all the four criteria at a time for the entire candidate solar farm site.

AHP weight derivation method for other evaluation criteria such as area of solar farm, distance from nearby transmission line, value of their potential and distance from road is shown in Table 4-15. The result of weight assignment shows the importance of those criteria, potential is more important for evaluating solar sites.

Table 4-15.Pair wise comparison matrix of the four determinant criteria.

	TP	SIZE	DTL	DR	Weight	%Weight
TP	1				0.5083	50.83
SIZE	1/3	1			0.2653	26.53
DTL	1/3	1/3	1		0.1512	15.12
DR	1/5	1/3	1/3	1	0.0752	7.52
Sum					1	100

CR=0.07, consistent since 0.07<0.1

Where, TP= Technical potential, DTL= Distance from nearby transmission line and DR= Distance from nearby road

Table 4-16.Comparison of the calculated weight for each candidate solar farm sites based on their potential.

	PVS6	PVS2	PVS5	PVS4	PVS3	PVS1	Weight	%Weight
PVS6	1						0.4518	45.18
PVS2	1/3	1					0.2346	23.46
PVS5	1/5	1/3	1				0.1315	13.15
PVS4	1/5	1/3	1/3	1			0.0899	8.99
PVS3	1/7	1/5	1/3	1/3	1		0.0547	5.47
PVS1	1/7	1/5	1/3	1/3	1/3	1	0.0374	3.74

The consistency ratio CR= 0.07, acceptable; 0.07<<0.1

Table 4-17.Comparison of the calculated weight for each candidate solar farm sites based on their size.

	PVS2	PVS6	PVS5	PVS4	PVS3	PVS1	Weight	%Weight
PVS2	1						0.4138	41.38
PVS6	1/3	1					0.236	23.6
PVS5	1/3	1/3	1				0.1605	16.05
PVS4	1/5	1/3	1/3	1			0.0858	8.58
PVS3	1/5	1/3	1/3	1/2	1		0.0683	6.83
PVS1	1/7	1/5	1/5	1/3	1/3	1	0.0356	3.56

The consistency ratio CR= 0.05, acceptable; 0.05<<0.1

Table 4-18.Comparison of the calculated weight for each candidate solar farm sites based on their distance from nearby transmission line.

	PVS1	PVS6	PVS5	PVS2	PVS4	PVS3	Weight	%Weight
PVS1	1						0.3917	39.17
PVS6	1/3	1					0.2495	24.95
PVS5	1/3	1/3	1				0.1712	17.12
PVS2	1/3	1/3	1/3	1			0.1058	10.58
PVS4	1/7	1/5	1/5	1/3	1		0.0496	4.96
PVS3	1/7	1/5	1/5	1/5	1/3	1	0.0323	3.23

The consistency ratio CR= 0.08, acceptable; 0.08<<0.1, where PVS= PV site

Table 4-19.Comparison of the calculated weight for each candidate solar farm sites based on their distance from nearby road.

	PVS6	PVS1	PVS5	PVS2	PVS4	PVS3	Weight	%Weight
PVS6	1						0.3199	31.99
PVS1	1	1					0.3199	31.99
PVS5	1/3	1/3	1				0.1527	15.27
PVS2	1/3	1/3	1/2	1			0.1113	11.13
PVS4	1/5	1/5	1/3	1/3	1		0.0615	6.15
PVS3	1/7	1/7	1/5	1/3	1/3	1	0.0346	3.46

The consistency ratio CR= 0.03, acceptable; 0.03<<0.1

The result of the analysis shows that solar farm site 6 with weight of 0.4518 is the most suitable site while solar farm site1 with weight of 0.0374 is the least suitable site from technical potential point of view and also solar farm site 2 with weight of 0.4138 is the most suitable site whereas site1 with weight of 0.0356 is the least suitable site from area (size) point of view. From distance nearby the transmission line, solar farm site1 with weight of 0.3917 is most suitable while solar farm site3 with weight of 0.0323is the least suitable site. Moreover, from distance from nearby road, solar farm site1 and 6 with weight of 0.3199 is the most suitable site and solar farm site 3 with weight of 0.0346 is the least suitable.

To solve the conflicting decision problems of choosing the most suitable site, all the evaluating criteria were considered at a time in MCE methods. Hence, weight for all candidate solar farm were derived from multiplying criteria weight and solar farm site's weight that are derived in relation to that criteria and then summing the corresponding products as shown in table below.

Table 4-20.Weight and rank of the candidate solar farm sites.

C/sites	TP	SIZE	DTL	DR	weight	% weight	Rank
	0.51	0.27	0.15	0.07			
PVS1	0.51*0.04	0.27*0.035	0.15*0.39	0.07*0.32	0.111	11.1	4
PVS2	0.51*0.24	0.27*0.414	0.15*0.11	0.07*0.11	0.258	25.8	2
PVS3	0.51*0.06	0.27*0.068	0.15*0.03	0.07*0.03	0.056	5.6	6
PVS4	0.51*0.09	0.27*0.086	0.15*0.05	0.07*0.06	0.081	8.1	5
PVS5	0.51*0.13	0.27*0.161	0.15*0.17	0.07*0.15	0.146	14.6	3
PVS6	0.51*0.45	0.27*0.236	0.15*0.25	0.07*0.32	0.353	35.3	1

Table4-18 shows that solar farm site 6 with weight 0.353 (35.3 %) is the highest compared to other sites. This shows that the site satisfies the criteria set in the previous section relative to the rest sites. Solar farm site 3 with weight 0.056 (5.6 %) is the least. Moreover, solar farm site 2 and 5are with the second and third highest weight of 0.258 (25.8 %) and 0.146 (14.6 %), respectively.

Table 4- 21.Suitability rank of candidates/solar farm sites.

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List of Candidate sites	%Weight	Power(MW)
PVSite6	35.3	322.25
PVSite2	25.8	309.38
PVSite5	14.6	317.40
PVSite1	11.1	166.82
PVSite4	8.10	251.39
PVSite3	5.60	195.89

4.9. Discussion

4.9.1. Modeling Scheme

Considering the geographical location and climatic conditions of East shoa zone, solar energy can provide a considerable energy source for the country.

Case studies of GIS based models for solar energy site selection used in Carrion et al's, Charabi & Gastli (2011) and Janke (2010) studies, the combination of Analytical Hierarchy Process (AHP) with multi-criteria GIS modeling has been applied in different geographic locations and contexts. The previous studies develops two-steps frameworks; in the first step, the map of unsuitable regions is extracted based on the defined constraints. In the second step, factor maps was developed based on defined criteria. Next, by overlaying these factor layers, the final map for exploiting solar photovoltaic (PV) plants was developed.

In present study, like the previous studies this paper used the combination of Analytical Hierarchy Process (AHP) with multi-criteria GIS modeling for the development of solar photovoltaic power plant site. Unlike the previous studies, this study develops four step-frameworks; in the first step, the map of unsuitable regions is extracted based on the defined constraints using Boolean overlay of constraints. In the next step, in order to identify the suitability of different area, 10 defined criteria are identified. Based on these criteria/factors, the study develops the factor map using Analytical Hierarchy Process(AHP), the suitability of solar farm site obtained and constraint area masked by the cross intersection of constraint and factor map. In the third step, the technical potential of all the solar farm sites/candidates site was assessed. Lastly, the selected sites was evaluated, prioritized and ranked.

Based on multi-criteria approach, investigation and analysis of the results have been presented in the previous section for a total of the study area, where the obtained result stands in one of the five defined classes of more suitable, moderate, suitable, less suitable, and unsuitable.

4.9.2. Hierarchy of Factors

The output of the multi criteria model was efficient where the most suitable location was found to be within close proximity to the most suitable locations of each individual factor. As The foundational factor of this analysis, and as all literature reviews had previously done, the photovoltaic potential mapping was listed as the top factor receiving the highest weight. Carrion Et al (2007) Weighted slope as second highest in the model. In the same instance Janke (2010) had weighted the transmission grid, which Carrion et al had not included in the study, as second highest. The land access was the third lowest weight corresponding to the study by Charabi & Gastli (2011) and succeeding this was the large and small urban areas that were weighted lowest in Carrion et al’s study.

Unlike the previous studies, sunshine duration, which the previous studies had not included in their study and land use/cover were weighted as the second and the third highest rank and succeeding this, transmission grid and major road weighted as the fourth and fifth highest rank respectively.

The main weakness or gaps observed from the previous studies was the omission of certain important criteria such as sunshine duration and temperature, these criteria has great influence on final suitability because the sunshine duration is the climatological indicator of the area and the temperature has the inverse relationship with the solar panel performance.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The rapid growth in the level of greenhouse gas emissions, the increasing amount of energy demand, and the increase in fuel prices are the main driving forces for turning to renewable sources of energy. Solar energy has few adverse environmental effects compared to conventional fossil fuels, such as greenhouse gas emissions or smog-causing pollutants, has become a preferred source of energy. The goal of this study was to select, identify and map the most suitable sites for solar photovoltaic power plant using multi criteria modeling in East Shewa zone. This study demonstrated the use of spatial analysis, GIS and RS techniques for identifying potential solar panel installation sites at macro-scales.

The final solar farm site suitability map reveals that the study area was divided in to five different classes. The area under more suitable, moderate suitable, suitable, less suitable and unsuitable (restricted area) stands at 1%, 27%, 44%, 11% and 17% respectively.

Renewable energy technical potential represents the achievable energy generation of a particular technology given system performance, topographic limitations, environmental, and land-use constraints. For calculations of solar PV potentials of the suitable (candidates) area, efficiencies and conversion factors which are characteristic for typical large-scale grid-connected systems are used to achieve the estimated energy generation of more suitable solar farm site.

In this study, the more suitable site were categorized in to six solar farm classes, and evaluated, prioritized and ranked depending on their estimated technical potential, size, distance from nearby the road and distance from nearby transmission line and the result showed that PV site 6 is the most suitable solar farm site of all candidates. This shows that solar farm site 6 was the highest compared to other sites, and satisfies the criteria set in the analysis relative to the rest sites while solar farm site 3 were the least. Moreover, solar farm site 2 and 5 are with the second and third highest, respectively.

5.2. Recommendation

In this study an effort is made to develop GIS based multi criteria analysis to carry out solar farm site selection analysis in east shewa zone, and the study presents that the use of GIS technology for solar farm site selection analysis is appropriate and necessity in solar energy development planning. Therefore, based on the literature review, analysis was made, result obtained, conclusion drawn and the recommendations forwarded as follows:

- Web based mapping application should be developed for solar energy siting and show potential improving information, dissemination, increase public participation and awareness in solar farm development.
- The present study developed based on elsewhere scenario because of there is no siting criteria and standards for solar farm development. Therefore, the concerned body or institution should work on preparation of standards and necessary document for solar power plant siting.
- The designer should consider the design standard which is appropriate for seismic intensity value of the area and also consider the tilt angle of the solar module, because the tilt angle of each solar module is equal to the latitude of the point and faces toward the south; since the region is found in the northern hemisphere.

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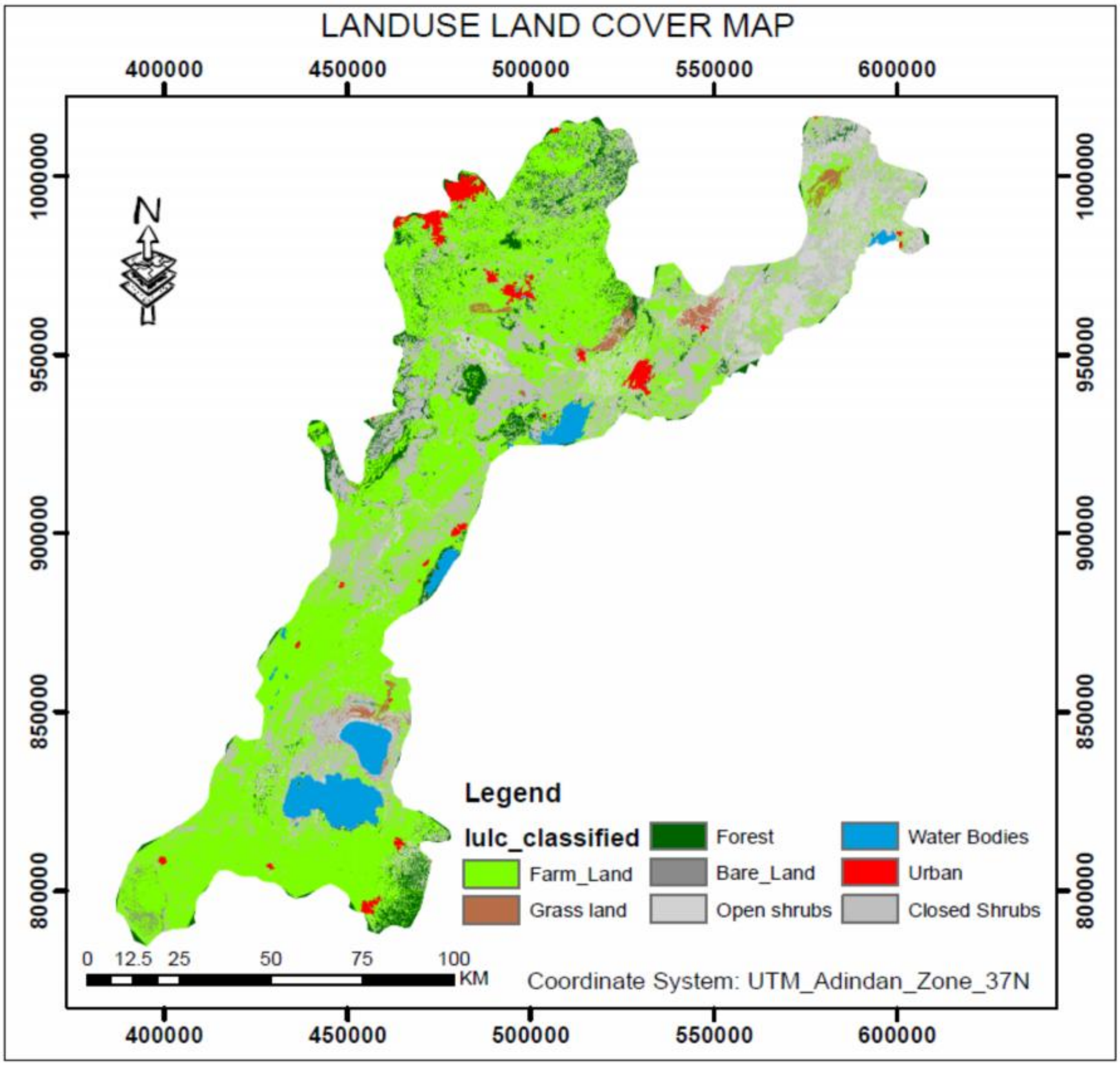
APPENDIXES

Appendix A: Classified Land use Land cover of the study area and its error matrix



CLASSIFICATION ACCURACY ASSESSMENT REPORT

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Unclassified	0	10	0	---	---
Farmland	90	80	70	77.78%	87.50%
Grass land	0	11	0	---	---
Forest	110	70	71	63.64%	100.00%
Bare Land	0	0	0	---	---
Open shrubs	101	130	90	90.00%	69.23%
Water Bodies	30	30	30	100.00%	100.00%
	0	0	0	---	---
Urban	30	30	30	100.00%	100.00%
	0	0	0	---	---
Closed Shrubs	30	30	30	100.00%	100.00%
Totals	391	391	321		

Overall Classification Accuracy = 82.05%

Overall Kappa Statistics = 0.7753