Addis Ababa University

College of Natural and Computational Sciences

School of Earth Sciences

Remote Sensing and Geo informatics

A GIS AND REMOTES SENSING APPROACH FOR MODELLING SOLAR RADIATION POTENTIAL SITES FOR GRID CONNECTED PHOTOVOLTAIC POWER PLANT SITE SELECTION:

A CASE STUDY OF EAST SHEWA ZONE IN OROMIYA REGIONAL STATE, ETHIOPIA

By

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A Thesis Submitted to School of Graduate Studies Addis Ababa University
in partial fulfillment of the requirements for the Degree of
Masters of Science in Remote Sensing and Geo-informatics

May 30, 2018

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This is to certify that the thesis prepared by Abayneh Gerbo, entitled "***A GIS and Remotes Sensing Approach for Modelling Solar Radiation potential Sites for Grid connected Photovoltaic power plant sites selection: A case Study of East Shewa Zone in Oromiya Regional State, Ethiopia "*** And Submitted in partial fulfillment of the requirements for the Degree of Master of Science Remote Sensing and Geo informatics compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Advisor Dr. K.V Suryabhagavan **Signature ___________ Date _____________**

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Chair of Department or Graduate Program Coordinator

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Abstract

The exhaustion of fossil fuel resources on a worldwide and climatic effects resulted from the emission Co2 and other gases to the atmosphere has forced world's agenda toward search for alternative Energy sources. Solar energy; is clean, inexhaustible and environment-friendly sources of energy. It can be changed into electricity to satisfy demands through grid connected energy systems, which combine solar and conventional units. The Aim of this study were; modeling solar energy potential, delineate suitable sites for grid connected solar PV farm, and calculate annual electric power generating capacity of solar PV farms in East Shewa Zone . In order to analyses solar energy potential the Study this study Digital Elevation Model (DEM), Geographic Information Systems (GIS) based Multi Criteria Analysis (MCA) and Remote Sensing techniques along pairwise comparison were employed. As result, with a total area of 827 km^2, eastern, southern, central and northern part of the study areas were selected as an ideal location for large PV solar farm. In addition, annual electric power generated from the solar farms was calculated. As a result 1.46 TW electric powers can be generated from the selected sites and fed to Grid connected solar PV system. Based on the analysis result can conclude if the solar energy potential of the study area is fully utilized it can solve energy problem of the zone as well as the country.

Keywords: Solar radiation, GIS, MCA, Photovoltaic, East Shewa

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List of Acronyms

AHP: Analytical hierarchical Process

Cal/cm2/day: calories per square centimeter per da

CO2: Carbon Dioxide

CSA: Central Statistical Agency

CSP: Concentrated Solar Power

DEM: Digital Elevation Model

ESRI: Environmental System research institute

GHG: Greenhouse Gas

GIS: Geographic Information System

ICS: Interconnected System

Kw: Kilo Watt

Kwh/m^2: Kilowatt Hour Per Meter Square

LIDAR: Light Detecting and Ranging

MCA: Multi Criteria Analysis

MCDM: Multi criteria decision Making

MW: Mega Watt

NMA: National Meteorological Agency

Pv: Photovoltaic

RS: remote sensing

SC: Self contained

SRTM: Shuttle Radar Topographic mission

TW: Terra Watt

USGS: United States Geological survey

CHAPTER ONE

Introduction

1.1 Background

Nothing influences our living style more than the availability and utilization of energy. Hence energy is an essential ingredient for our everyday tasks (Priest, 1979 as Sited in Eyaya, 2009) .Energy is the main economic artery of countries all over the world (Taman and Jemlkova, 2003) and can indeed be considered as the primary commodity in economy. The demand for energy is significantly increasing with increases in population and the rapid development of world economy.

The advancement of human civilization including the process of industrialization development in standard of living ,public health and even the development of art and recreation have historically dependent on steadily increasing supply of energy. Today, one of the main problems that the societies are facing is energy generation and sustainable utilization. Most of the energy resources currently relied on are finite and will be depleted because of the increasing demand. In addition, there have been serious local air, water, and soil pollution problems as a result of the consumption of various energy resources. It has become clear that continuing to use fossil fuels is not wise not only due to the global impacts on climate system, but also due to both short term and very long-term impacts on society and the ecosystem (Elliott, 2007).

Renewable and nonrenewable energy sources can be used to produce secondary energy sources such as electricity. One of the renewable energy sources is solar energy, which comes from the sun and can be turned into electricity and heat. Wind, geothermal energy from inside of earth, biomass from plants, and hydropower and ocean energy from water are also renewable energy sources. However, most of our energy consumption is depending on the non-renewable energy sources, such as fossil fuels, oil, natural gas, and coal. While conception of fossil fuels are increasing regardless of their impact on the environment, to day world's agenda focuses on Sustainable energy system in terms of both reliability for economic development and benefits for the environment. According to Tester et al. (2005), the definition of sustainable Energy is the combination of providing energy equally to all people and protecting the environment for next generations.

Solar energy is among the most attractive renewable energy sources available on the planet (Dewitt Haile Mazengia, 2010). One important approach to achieving sustainable development is to take advantage of solar energy.

The sun generates most of the energy required for all physical, biological, and industrial processes on the Earth (Dubayah and Rich, 1996; Fu and Rich, 1999; Podobnikar *et al.*, 2006; Ruiz-Arias *et al.*, 2009). Solar energy has many advantages including being one of the cleanest of all renewable energies, since its operation is silent and does not produce carbon dioxide (CO2) or other GHG emissions. Photovoltaic is import-independent, and can be easily adapted to various scenarios. For example, utility scale photovoltaic can be connected to smart grid networks, and PV can also be adapted to small-scale, off-grid applications such as stand-alone PV power systems on rooftops. According to a comprehensive life cycle assessment on PV technologies, emissions from the photovoltaic industry are very small compared to emissions originating from fossil-fuel based plants (Tisza, 2014).

Because of the Earth’s rotation and revolution about the sun, the amount of incoming solar radiation can vary depending on the latitude at various geographic locations (Fu and Rich, 1999). At the same time topography such as elevation, surface orientation, and obstruction by neighboring surface features can also influence the distributions of incoming solar radiation (Fu and Rich, 2002). Therefore, understanding this potential variation of incoming solar radiation across space can allow people to better use the sun as an energy source (Ruiz-Arias *et al.*, 2009).

Many solar radiation estimation models have been developed in order to measure radiation easier and cheaper than taking multiple sensors to the area to measure the actual radiation. Especially, global radiation estimates have been under development. The models belong ordinarily into these categories: manual theoretical calculations, satellite data estimates, geo statistics or geographic information system (GIS) models. (Shruthi 2007; Alsamamra et al. 2009 as sited Ramachandra Laura Kauria, 2016).

Hence, estimation of solar energy resources in a complex topography on a wide spatial coverage from DEM is fast, cost effective and reliable. Moreover, the solar radiation map derived from DEM can be integrated with other data from various sources within Geographic Information system to identify suitable sites for large-scale PV installations, and reduce risk and cost of potentially large energy investments. Identifying location with optima solar potential is essential for over the increasing demand of power supply as the same time it contribute environment friendly alternative energy sources.

Therefore, The aim of this thesis ,is to assess and estimate solar energy potential for grid connected solar photovoltaic farm in East Shewa by using high resolution DEMs using ArcGIS tools.

Accordingly using GIS and remote sensing techniques, a model which shows the estimated potential for generating electricity through grid-connected photovoltaic power system is presented. Photovoltaic potential sites map is also prepared based on a multi-criteria analysis. As a result 47 area covering of 827 km^2 places were identified for large PV farm with 1.46TW annual electricity potential of the study is investigated.

1.2 Statement of the problem

Ethiopia is Nation endowed with huge amount of water, wind, solar and geothermal Energy potentials. However, regardless of its enormous potentials the energy system is highly dependent on traditional fossil sand biomass and only about 32% of the nation's population has access to electricity (Dewitt Haile, 2010). The country due to owning many watersheds have been using hydroelectric plants to generate electricity**.**

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

To overcome these limitations, other renewable energy sources such as solar photovoltaic must be studied. According the 2012 Study, collaborating with Chinese government; solar and wind energy resource assessment (SWERA), solar and wind master plan for the whole country was prepared. Based on the analysis of this master plan, Ethiopia has a capacity of 1350 Giga watt of energy from wind and annual total of 2.199 million TWH/annum solar energy was roughly estimated.

However, the conditions, which help to select the potential Soar farm site are not properly seated and challenging. According to Saaty (2008), Analytical Hierarchy Process (AHP) of pairwise comparison method often applied for settings of criteria weights in weighed linear aggregation. It provides a hierarchical structure by systematically break down a problem into its smaller constituent parts and then guide decision makers through a series of pairwise comparison judgments to express the importance of the elements in the hierarchy. On this regards GIS is capable of handling, processing and analyzing large quantities of spatial data and valuable in underpinning decision making for the spatial deployment of solar PV in the study area. According to East shewa Bureau of Energy And Industry report (2015) regardless of the increment in population and growing of industry , and other economic activities, the electric power supply of the Zone is endowed with hydro and steam power generating plants, both of them (Hydro at Koka and Melkasa, and steam at Wanji Sugar Factory) are limited to urban centers.

Therefore, the main aim of this study is to show an alternate solar energy solution for that could alleviate electric power supply problem not only the Zone, but Also it could be an additional sources of energy for the whole country. Additionally this study models the solar radiation potential and indicates suitable sites for a PV solar farm by examining different factors. Finally, the electric power that can be generated from the potential is calculated. The study also defines a set of core future research avenues for GIS based solar energy modeling and suitability analysis.

1.3 Objectives of the study

1.3.1 General Objective

The Main Objectives of this thesis is to assess and model solar radiation potential in East Shewa Zone and develop a suitability map for grid connected solar farm sites based on a multi-criteria analysis using GIS and remote sensing analysis.

1.3.2 Specific Objectives

- To identifying factor responsible for solar farm site selection.
- To model the incoming solar radiation.
- To recommend the most Suitable sites for Solar farm establishment in East Shewa.
- To calculate and estimate the amount of electric power generated.

1.4 Research Questions

The following research questions was formulated in order achieve the above objectives.

1. What are the major factor responsible for solar farm site selections?
2. What are the factor affecting the amount of solar radiation at a given space?
3. Which areas are suitable for photovoltaic installation?
4. How much solar electric power will be generated from the study Area?

1.5 Significance of the study

The result of this research will provide us a site with optima solar radiation for grid connected solar farm that could be an additional sources of electricity for the country. The grid connected photovoltaic solar farm can solve energy problems of the study area as well as it can provide additional power to the interconnected system (ISC) at national level. During periods of high incoming solar radiation the PV source would add a surplus of energy to the grid for consumers and would reduce the amount of energy derived from the conventional sources or other areas. The result of this research will help as an input for decision makers on how to implement geospatial tools in modeling renewable energy effectively .In addition to this research will provide a model for calculating solar radiation using geographic information system (GIS) and remotely sensed data in coup up with Multi criteria decision Method .

1.6 Scope of the study

The scope of this thesis will be restricted to modeling solar energy potential, identifying and mapping suitable sites for solar farm sites for PV installation with in the study area of East Shewa Zone. Additionally estimating the solar electric power potential of the study area will be calculated using GIS based multi criteria analysis techniques.

1.7 Organization of the paper

The thesis works is classified in six chapters. **Chapter one** provide**s** the general backgrounds of the study statement of the problems scope of the study objective of the study and also basic research question **related** to this research work is discussed. **Chapter Two** provides an in depth both review of both conceptual and previous works related to the research which is conducted .**chapter three** provides an overview of the data that was acquired for the site selection along with the data resources available at the time of research. This Chapter is also discusses the assessment and determinant method used when choosing relevant data for Suitability Model. **Chapter Four** provides us A step by step analysis of each factor constraint that are responsible for Solar PV plants sites selection was analyzed. The chapter also give emphasize Multi criteria Decision Makings using Analytical Heretical process (AHP). **Chapter five** mainly give emphasis on Analyzing the result and discussion base on the finding results. **Chapter SIX** conclude the thesis report by examining the strength and weakness discovered in the model describe potential future development and touches final opinions.

CHAPTER TWO

2. Literature Review

2.1 Solar energy as a renewable sources of energy

The renewable energy sources origins from solar energy, one way or the other. They are sometimes called flowing energies and can be considered inexhaustible and self-regenerating. There are non-pollutant and pollutant renewable energies. The first group includes solar, wind, hydro, tidal and geothermal energies while the second group includes biomass and biofuel (Cots, 2013).

Renewable and non-renewable energy sources can be used to produce secondary energy sources such as electricity. One of the renewable energy sources is solar energy, which comes from the sun and can be turned into electricity and heat. Wind, geothermal energy from inside of earth, biomass from plants, and hydropower and ocean energy from water are also renewable energy sources. However, most of our energy consumption is depending on the non-renewable energy sources, such as fossil fuels, oil, natural gas, and coal. Although fossil fuels remain cost-efficient and most utilized internationally, the emergence of reducing emission has made high demand for sustainable, economically and environmentally acceptable renewable energy production technologies like wind, geothermal, biomass and solar. Of these technologies, photovoltaic (PV) technology has been found technologically robust, scalable, geographically dispersed and possess enormous potential for producing sustainable source of energy (Pearce, 2002).

The sun is the largest energy source of life, at the same time it is the ultimate source of all energy. The sun is a star with surface temperature is about 5800 Kelvin. This temperature derives from reactions which were based on the transformation of hydrogen to helium, the process called Nuclear Fusion, which produce high temperature of the sun and the continuous emission of large amount of energy. Solar energy is emitted to the universe mainly by electromagnetic radiation and approximately one-third of energy radiated from sun is reflected back. The rest is absorbed and retransmitted to the space while the earth reradiates just as much energy as it receives and creates a stable energy balance at a temperature suitable for life (Udayakanthi, 2015).

The sun is the ultimate energy source. In fact, the energy stored in the fossil fuels we burn originated from the sun from back when they were formed. Directly harnessing the sun’s energy for electricity generation provides numerous advantages. Some of the technologies involved with solar electricity generation include solar photovoltaic as well as concentrated solar power (CSP). Solar photovoltaic technology utilizes arrays of panels with photovoltaic cells to convert the sun’s energy into electricity; on the other hand, CSP technology utilizes arrays of mirrors which concentrate the sun's radiation on either one point or in a line, convert that into thermal energy, which can then be converted to electricity (Kit Tsang, 2016).

2.1.1 Solar radiation

Solar radiation is a key factor in determining the amount of electricity produced by PV system, (Zhang, 2015).It is the total amount of energy received on a given surface area and time. It is also called solar irradiation and expressed as "hourly irradiation" if recorded during an hour or "daily irradiation" if recorded during a day. The unit recommended by the World Meteorological Organization is the mega joule per square meter (MJ/m2). If this energy is divided by the recording time in hours, it is then a density of power called irradiance, expressed in watts per square meter (W/m2). Over the course of a year the average solar radiation arriving at the top of the Earth's atmosphere at any point in time is roughly 1366 W/m^2. The radiant power is distributed across the entire electromagnetic spectrum, although most of the power is in the visible light portion of the spectrum (Perez *et al.*, 1986).

2.1.2 Solar photovoltaic technology

Photovoltaic Power system is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. PV power generation uses solar panels comprising a number of cells containing semiconducting material. As long as light is shining on the solar cells, it generates electric power. When the light stops, the electricity stops.

2.1.2.1. Photovoltaic cell module and array

PV cells are made up of semiconductor material, such as silicon, which is currently the most commonly used element in semiconductor industry. Basically, when the light strikes the cell, a certain potion of it is absorbed within the semiconductor material. When energy knocks Semiconductor electrons loose, allowing them to flow freely. PV cells have one or more electric fields that act to force electron that are freed by light absorption to flow in a certain direction.

This flowing of electron is a current and by placing metal contacts on the top and bottom of the PV cell can draw that current off to be used externally. This current, together with the cell's voltage which is a result of its built-in electric field or fields, define the power in Watts that the solar cell can produce. The solar cell is the basic building block of the PV power system. However, it rarely used individually because it is not able to supply an electronic device with enough voltage and power. For this reason, many photovoltaic cells are connected in parallel or in series in order to achieve as higher voltage and power output as possible. Cells connected in series increases the voltage output while cells connected in parallel increase the current. The solar array or panel is a group of several modules electrically connected in series-parallel combination to generate required current and voltage and hence the power.

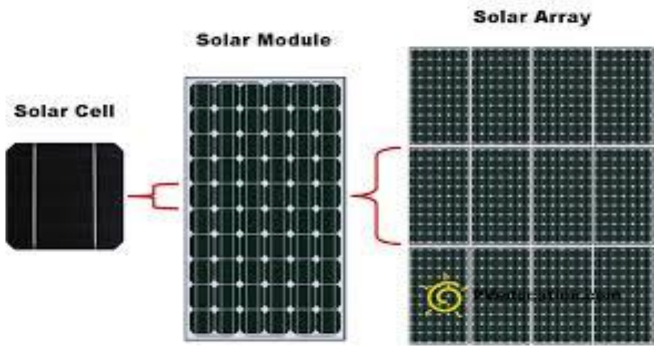


Fig 2.1 Photovoltaic cell, Module and Array

Solar Photovoltaic: Generate electricity through the use photovoltaic cells that converts the solar energy falling on them directly into electricity. Large scale applications of photovoltaic for power generation, either on the rooftops of houses or in large fields connected to the utility grid are promising as well to provide clean, safe and strategically sound alternatives to current methods of electricity generation.

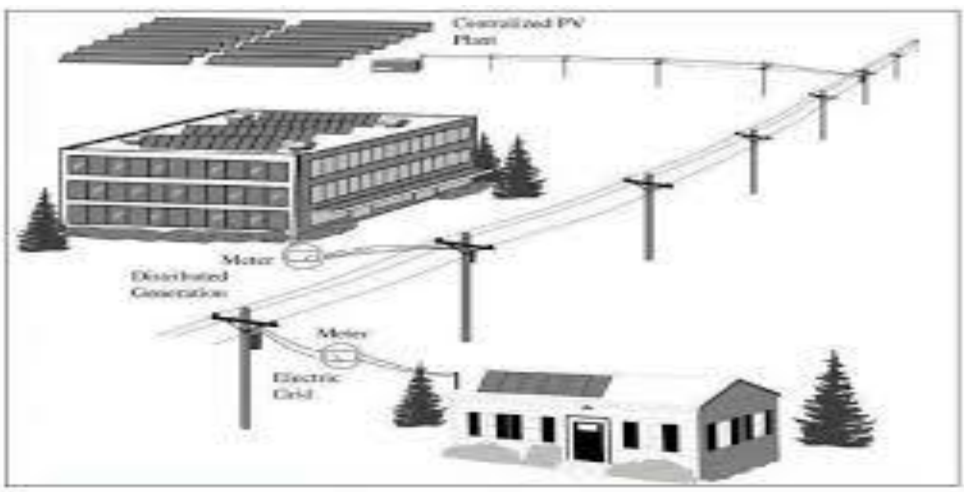


Fig 2. 2 Grid Connected Photovoltaic System.

2.2 Review of Related Studies

Assessment of recent study various related researches are conducted in different parts of the world for modelling soar farm sites for suggesting optimal potential for Pv in stations by using GIS Multi Criteria Decision Making (MCDM).

For instance, Effat (2014) has conducted research on mapping solar energy potential Zone using SRTM And Spatial Analysis in Lake Nasser Region of Egypt.in his study he uses Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) since it is climatic condition is dry the researcher consider it as a major for solar farm site selection from the studies. Uses Analytical Heretical Process (AHP). According to his findings the annual areal solar radiation (global solar radiation) recorded for the study area for the year 2015 lies reaches maximum 1,745,634 Wh/m^2 in the highest radiation areas and a mean equal to 1,603,458 wh/m^2. The percentage of high potential zones reaches 33% of the total study area. This result revealed a great and remarkable potential for harvesting solar energy.

According to Huang and Fu (2009) has conducted research using Solar Analyst ttool to create solar and temperature distribution maps for Yellowstone National Forest. The Spatial Analyst enabled the team to “efficiently implement time consuming processing of this data in a timely fashion. In their work they state that topography is the major factor in determining the spatial variability of isolation. It is therefore fitting that a DEM is the primary input for the Solar Analyst model. They used a 30 m DEM constructed from United States Geological Survey (USGS) though the model accepts DEM’s of various sources and resolution

On the other work Mevlut. (2013) has conducted a research on GIS-Based Solar Farms Site Selection Using Analytic Hierarchy Process (AHP) in Karapinar Region, Konya/Turkey. This paper created a suitability index map for siting large-scale solar farms in the Karapinar region of Turkey. The authors used a combination of GIS and an analytic hierarchy process to determine areas of low, moderate, good, and best suitability. Five criteria with nineteen sub criteria were used to rank the available locations. Data needed for the five main criteria included distance from residential areas, land use information, distance from roads, site slope, and distance from transmission lines. The solar potential was not evaluated as a criterion because the entire study area was estimated to have similar irradiation values. Using GIS software, the siting criteria data was layered and geo processed to show areas with good solar farm potential. Overall, over 40% of the area was deemed not suitable for solar farms while 13.92% of the area was classified as best suitable. The paper presents a simple, yet effective and quick means of identifying good sites for solar farm development.

Li (2013) has engaged GIS and remote sensing techniques for determining the optimal sites for solar panel installation at micro and macro-scales: building rooftop installations at the University of Waterloo main campus and ground-mounted installation in the City of Waterloo, Canada, respectively. DEM extracted from Light Detection and Ranging (LiDAR) and s were used to derive accumulated solar radiation energy under clear-sky and overcast conditions using ArcGIS software. Optimal ground mounted solar panel installation sites were determined using a multi-criteria analysis approach that considered various environmental and socioeconomic factors. He identified building roofs with a southern exposure without obstructions and four potential sites close to the periphery of the city at micro and macro scales. Moreover, Li conducted a questionnaire survey of three Ontario solar companies to obtain information about how solar companies in Ontario select potential sites for solar PV installation. Finally, a feasibility assessment was performed with ground truth information to verify selected sites

In addition to the above international documents there are some local researches are found to be reviewed as follows:

Fikremariyam Teshome (2014) conducted an Assessment of Solar Energy Resources in Ethiopia using GIS-based multi-criteria analysis for modeling solar radiation and potential site selection. From the result the solar radiate. Ion potential of Ethiopia ranges from 0.2 MWh/m^2/year in the lowlands areas to 2.6 MWh/m^2/year in the central highlands. Furthermore, 195 distinct sites with highest suitability score on which 500 TWH electricity per annum can be generated were mapped as potential sites for large scale PV solar farms in Ethiopia.

Rahel Atlaw (2015) conducted a research in titled remotes sensing and GIS approach for grid connected pv solar energy assessment potential modelling and mapping in Dire Dawa, Monthly and annual solar radiation potential of the study area was calculated and Multi-Criteria Analysis (MCA) was applied to map suitable sites for grid connected solar PV farms. In that study ASTER DEM used to generate solar radiation potential of the study area. Analytical heretical process (AHP) was employed to give weight for factor and constraints identified. Based on this parameter areas with optimal solar radiation potential sites were identified. In her research 33 sites were identified and the annual solar energy production was estimated about 6.95 GW/annumIn addition to this by using PV GIS web based software which is designed by EU for estimating solar radiation potential for specified region (point) the researcher tries compare and contrast with the actual solar radiation potential.

Several studies stressed above international and local studies calculating solar radiation potential and selecting suitable sites for solar farm using GIS and remotely sensed data are becoming more important approaches. Based on founding previous studies it can be concluded that using GIS analysis, high resolution DEM, incoming solar radiation potential can be calculated. Therefore, modeling solar radiation potential sites for PV Farm using GIS analysis and Remotely Sensed Data for East Shew Zone will be crucial to improve the electric power supply for the study area as the same time for national level.

CHAPTER THREE

Material and Methods

3.1.1 Location

East Shewa zone is one of the zone in Oromiy Regional State of Ethiopia. Geographically, the Zone lies between longitudes of 7°33′50″N–9° 08′56″N and latitudes of 38° 24′ 10″E–40°05′ 34″E covering a total area of 9636 km^2 (Fig 3.1). This indicates that the zone is entirely found in tropical zone having its associated climate. It is also found in the rift system and has elongated shape.

With respect to its relative location the Zone has physical contact with three regional States of Ethiopia namely: Southern Nations, Nationalities of Peoples, Afar and Amara National Regional States of Ethiopia. Therefore, this zone is boarded to the north by Amhara National Regional State, on the Southeast by Afar National Regional State, to the southeast by Arsi Zone, on the west by Southwest Shewa Zone and by West Arsi Zone in the South. The Zone shares the longest and shortest boarder with Arsi Zone and Afar National Regional State, respectively. Along the northern and southern portion it is narrow.

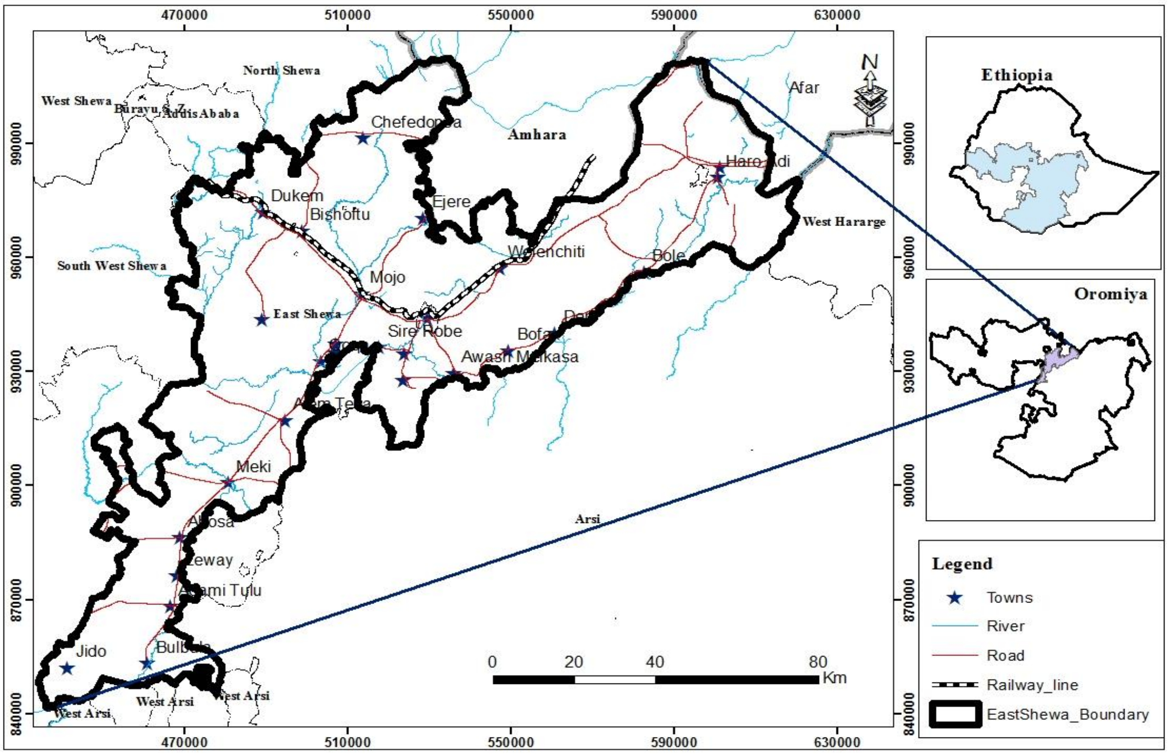


Fig 3.1 Location map of the Study area.

3.1.2 Climate

The elevation of East Shewa extends from less than 1000 to above 3000 and thus its altitudinal zones ranges between temperate (Dega, 0.2%) to tropical (Kolla, 38.7%) (East Shewa Zone Finance and Economic Development Office, 2014).

The largest land mass of the zone (about 61.1%) is grouped under sub-tropical (Woina Dega). Accordingly, high altitude parts the Zone with elevation over 2500 m (parts of Gimbichu highlands) as well as isolated high peaks in the rift floor experience mean annual temperature of 10–15^{o}C, accounting for about 0.2% of the total area of the zone. Furthermore, mostpartsofthezone, includingthelowerrift scarps and higher parts of the rift floor (sub-tropical) with elevation 1500–2300 m register mean annual temperature of 15–20^{o}C. The northern extreme parts of the zone including pocket areas of the rift floor with elevation less than 1500 m.s.l, being regions of tropical climate, come under mean annual temperature category of 20–30^{o}C (Fig 3.2). The Sunshine duration of the Zone ranges between 10 and 6.5 with average of 8.3 hours a day.

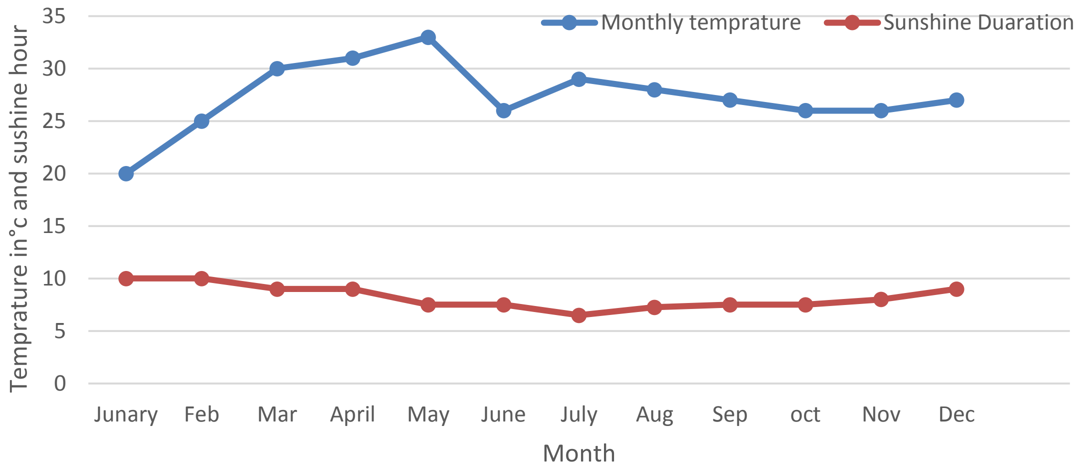


Fig 3.2 Monthly average temperature and Sun Shine Duration of East Shewa-2015. (Source: National Meteorological Agency).

3.1.3Population and Economy

According to national population housing census of 2007, the total population of East Shewa Zone was 1,159,062 out of this 598279 are men and 560783 are female and it is also projected to be 1477187 in July out of this 762146 are male and 715041 are female in both urban and rural areas.

3.1.4 Geology

According to the information obtained from Zonal Atlas of East Shewa (1999), the landmass of East Shewa zone being part of the Rift Valley System belongs to the Tertiary and Quaternary sub-classifications. Hence this Zone comes under the category of recent volcanic and sediments and the Rift Valley System. Pleistocene recent volcanic sediments cover mainly northeast of the zone. This part of the zone is still tectonically unstable, relative to adjacent landmasses. Cinder cones like Mount Fentale are still presumed to be active.

The extensive recent volcanic ash that lies on the surface to the west of Mount Fentale and the ever expanding Beseka Lake indicate that the zone is still unstable. The Lakes Region of the Zone is also an area of recent volcanic and seismic activities. The other signal of instability of the zone is the existence of hot springs and fumaroles in several partsofthezone. Another words, the zone is well known by its geothermal from Gergedi hot spring in the western side of Wonji Gafarsa and the Sodere in Melkasa near Awash River. The main landscapeinzoneand its surrounding consists of fault controlled depressions covered with sediments and volcanic domes and cones. More importantly, the Zone is endowed with different minerals. These minerals include diatomite, clay, pumice, scoria, sand ignimbrite, volcanic ash (Finance and Economic Development of East Shewa, 2014). Quaternary sediments, which account for about 21.8% of East Shewa Zone, cover the southeastern part of the zone. Quaternary Volcanic/basalts cover 20.4% of the zone, which cover the northeastern part of the zone including larger portions of Adama, Boset and Fentale districts of the zone. On the other hand, the larger portion of the zone is under Pleistocene-Pliocene complex which western part of Arsi Negele, Adami Tulu Jido Kombolcha, Liben Chuqala, Bora, Dugda, Lome and Ade’a districts of the zone.

3.1.5 Soil

Andosols extend over larger portions of Adami Tullu Jido Kombolcha, Boset, Dugda, Adama, Lume and Bora districts of the zone, which accounting for about 23.43% of the land area of the zone. Vertisols cover the larger portion of Ada’a, Liben Chukala and northernLumeandit makes up 14.61% of zonal land surface. This type of soil is mainly used fo rgrazing purposes. Phaeozems cover larger portions of Dugda and Bora, and smaller portions of Ade’a, Adama and Liben Chukala districts of the zone. It covers about 13.14%ofthetotalof the zone. In East Shewa, fluvisols are found in localized areas of Adama, Boset and Fentaleas well as Dugda and Bora districts of the zone, along the valleys of the Awash and Mekirivers, the shores of Lake Ziway accounting for about 5.72% of total area of zone. Cambisolsoccur in about 15.09% of the total area of the East

Shewa zone. They are mainly found in Liben Chukala, Fentale, Boset, Ade'a, Gimbichu and Fentale districts of the zone Lithosols (13.8%) are soils of limited depth with continuous hard rock within 10cmofthesurface.Itcovers smaller portions of Dugda, Bora, Liben Chukala, Gimbichu, Ade'a, and Boset and Fentale districts of the zone.

3.1.6Topography

East Shewa Zone can be categorized under rift system of Oromiya since about 93% of the total area of the zone is completely located in rift system. Furthermore, rift system of Oromiya covers 10% of the total area, and also boarded in the west by edge of western escarpment, in the east by edge of eastern escarpment, Afar depression and Lake Chamo bounded in the north and south respectively. Based on altitudinal elevation the Oromiya rift system distinguished in three categories. These include: The Northern section of Oromiya Rift system ranges in altitude from 1500–2000 m.The Middle Awash valley that covers large parts of east shewa zone ranges in altitudinal elevation from less than 1000 up to 1500 meters. In addition, this part of the rift valley consists of cinder volcanic cones like Mt-Fentalle (2002 m) in Fantalle district and Mt.Chukuala (2989 m) with Creator Lake found in liben chukuala districts Mt.Yerer (3099 m) along the border of Ada'a district and Akaki special Zone.

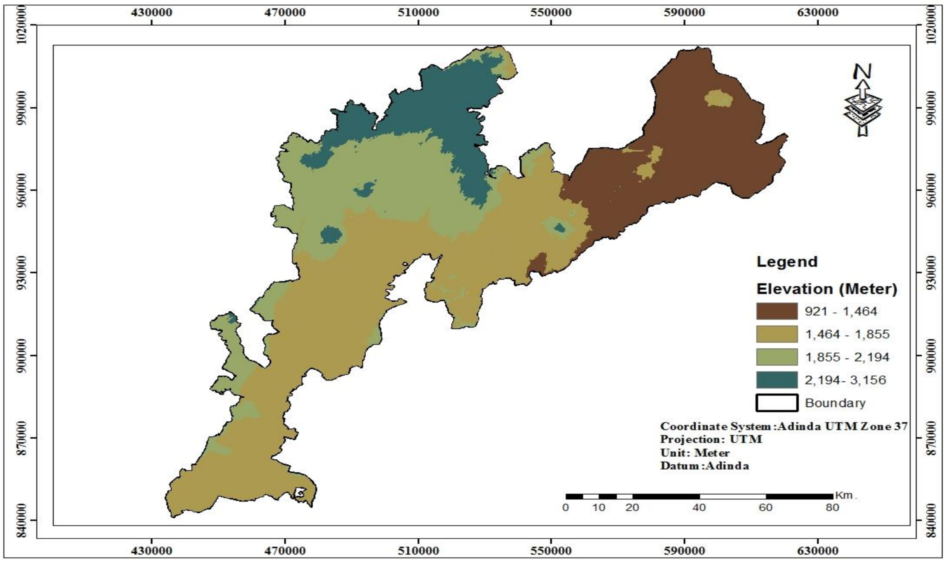


Fig: 3.3 Topographic Map

3.1.7 Land-Use and Land-Cover

Land-use and land cover map the study area classified in to six land-use and land-cover classes were identified and mapped using Landsat 8 satellite imagery from USGS. The total land size of the Zone is 9936 km^2. The land use types in the study area are classified into six classes (Fig 3.4).

These are agriculture, bare-land, and Built up area, Plantation, Shrub and Water Body. From these Agricultural land cover takes the major portion (5850 km^2) and bareland (2218 km^2), built-up Area (542 km^2) plantation largely sugar plantation (697 km^2) shrubland (564 km^2) and water body (65 km^2), respectively (Table 3.1)

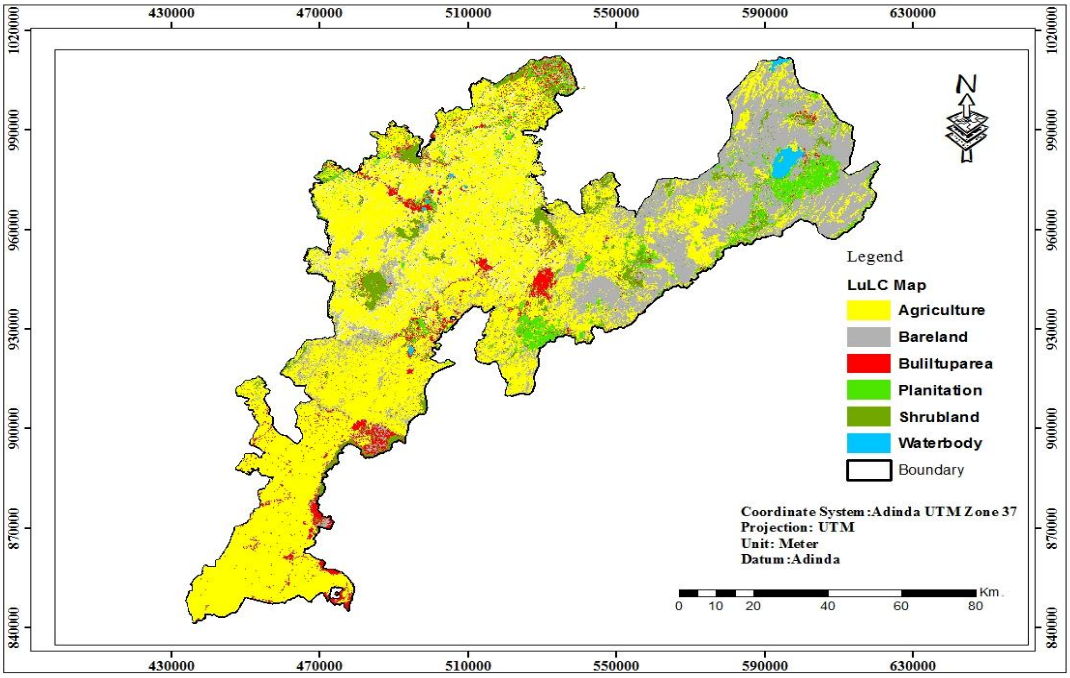


Fig 3.4: Land-use and land-cover map.

Table 3.1: Land-use and land-cover area of the study area.

Land-use and land-cove classes	Area in (km^2)	Area in (%)
Agriculture	5849	58.4
Bareland	2218	21.63
Settlement	542	5.45
Plantation	697	8.4
Shrubland	564	5.5
Waterbody	65	0.65
Total	9936.721	100

3.2 Data and Software

3.2.1 Spatial Data

Several spatial and non-spatial datasets were obtained from different data sources in (Table 3.2) and processed using multiple GIS tools for mapping and analysis purposes. For this study Shuttle radar Topographic Mission (SRTM) Digital Elevation Model with 30 m resolution version 2 is used. It was released without charge as a contribution to the Global Earth Observing System in September 23, 2014. The DEM was used to calculate and generate solar radiation potential, topographic characteristics such as elevation, slope inclination, terrain orientation and shadowing effects of the neighboring terrain features that affect the amount of incoming solar radiation. Other necessary input data were collected from field and secondary data were obtained from concerned organizations and reused from earlier studies.

Table 3.2: List of Spatial data

Data	Source	Purpose
Landsat 8 OLI Imagery 2017	USGS(United states geological Survey)	In order to generate land use land cover
Shuttle radar Topographic Mission (SRTM) Digital Elevation Model with 30m resolution	USGS	In order to model solar radiation
Google sat images	Goggle satellite maps	verification
Transmission lines (power grid)	Ethiopian Electric Utility	Used as a criteria
Road network	Open source	Used as a criteria
Topographic information	Ethiopian Mapping Agency	
Land cover	Self-generated	Used as a criteria and factor
Urban settlement Map	Central Statistics Agency	Used as constraint

3.2.2 Software

In order to do achieve the objectives the research and to analyze the spatial data which are listed in the above section (Table 3.3) that used to as an input for the final out put different software packages are used for analyzing different image processing, Spatial Analysis, statistical analysis and also for compilation the report these are listed in the following tables

Table3.3: List of Software

Software Name	Application
ERDAS Imagine 14	Image processing and data analysis
Global Mapper	Terrain visualization
IDRISI Silva	Pair wise comparison
ArcGIS 10.3.	Database creation, dataset preparation, overlay analysis, map and lay out preparation etc…
MS Office 2013	Documentation, statistical analysis and presentation

3.3 Methodology

In order to achieve the objectives that have mentioned in the above section of the proposal different data sets will be used in coup up with different spatial analysis. Theses includes generating solar radiation using solar radiation tool in ArcGIS and PvGIS ,generating land use land cover map of the study area ,setting factor and criterion for the analysis using different parameters including slop, aspect ,land use land cover ,distance from the main road, distance from rivers, electric power for the overall study area is going to be analyzed. The overall work of this proposed research is shown in the following flow chart diagram (Fig 3.5)

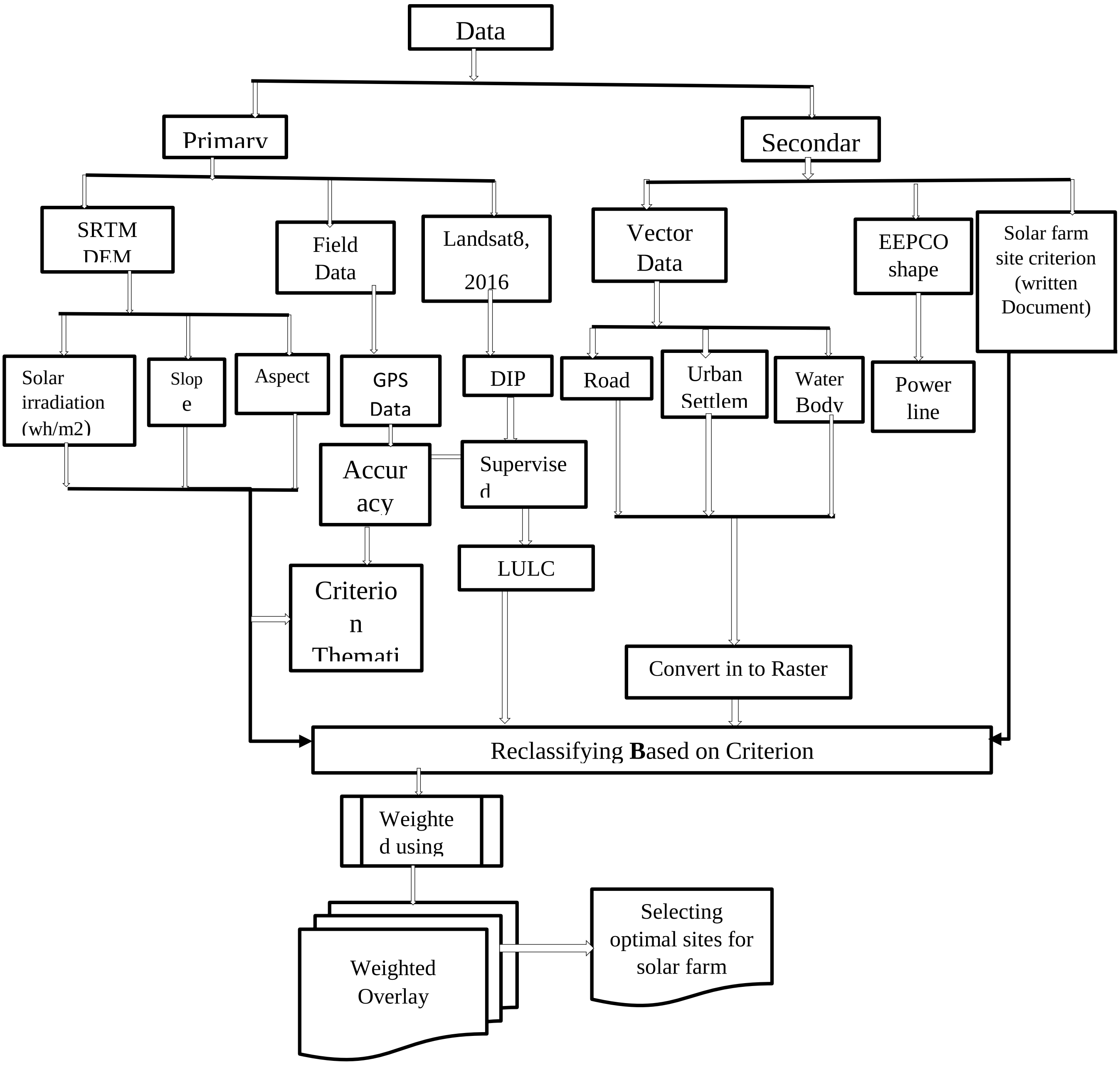


Fig 3.5: Flowchart of the Methodology

3.3.1Modeling Solar Radiation

Solar radiation reaching the surface of the earth shows considerable spatial and temporal variation at the local and on a global scale. On a global scale the major controlling factors are the latitude, distance from the sun, and time of year (Esri, 2014). Whereas at the local scale major sources of spatial variation are elevation above sea level, surface inclination, surface orientation, and shadowing effects of neighboring terrain features. These topographic parameters can be modeled and derived from high resolution DEM. As a result, the most important input to calculate solar radiation was an accurate, geo-referenced and high resolution DEM dataset. As mentioned earlier, for this study 30 meter resolution Shuttle radar topographic Mission (SRTM) is used to Global Solar radiation potential of the study Area.

3.3.2. GIS-based Multi-Criteria Analysis

Site selection process for large-scale soar Photovoltaic Solar farm installation involves various social, technological, environmental and economic aspects. In this Regards the application Of GIS-based Multi-Criteria Analysis (GISMCA) provide a flexible tool that is able to handle and bring together wide range of variables assessed in different ways and thus offer useful support to the decision maker in indicating at suitable Sites (Taha and Daim, 2013). It is a process that transforms and combines spatial data and value judgments to obtain information for decision making (Malczewski, 1999).

Multi Criteria Analysis (MCA) is widely used as a spatial analysis tool in energy evaluation and environmental fields. Such methods are integrated in GIS, to select best site for certain activity. It is thus possible to get continuous suitability maps, and thus provide an optimal framework for the integration of environmental, economic, and social factors that affect land suitability for a certain use. Accordingly the MCA method is applied in this study.

In order to perform suitability analysis for PV solar farms in East Shewa, Solar radiation potential, aspect, slope, land cover, Distance from urban Settlement , distance to roads and power transmission grid were selected as criteria and processed using a GIS basedmulti criteria analysis. All the input datasets were changed into a common 30 m resolution raster and reclassified in to four classes.

3.4. Solar electricity potential Calculation

One of the objective of this research is to estimate the amount of electricity that can be generated with the Zone .For solar electricity calculation using mean annual solar radiation values, first them. Annual solar energy need to be calculated using an equation that was used on previous study referring Charabi and Gastli (2010a).

The equation (1) below used to calculate the annual solar energy generated based on total area of suitable sites, estimated area
factor of panel coverage and the efficiency of modules.

$$EGP = SR*CA*AF*\eta \quad (1)$$

Where,

EGP is Electric power generation potential per year (GWh/year)

SR is annual mean solar radiation received per unit area (GWh/m2/year)

CA is calculated total area of suitable site (Km2)

AF is area factor, indicates what fraction of calculated areas can be covered by solar panels (%)

η is PV system efficiency (%).

The electricity generation potential was calculated by taking PV efficiency of five different solar cell materials. For this research the efficiency (η) value is adopted from the national Renewable Energy Laboratory of USA (Gaur and Tiwari, 2013; Green, *et al.*, 2012)

The calculations also assume that at least 50 percent of the total area can be covered by solar panels. Annual potential of electricity generation from suitable sites for large scale PV solar farms using different types of Solar Cell materials computed as follows. After calculating the annual solar energy potential, the annual electric power generating capacity can be obtained using equation 2:

Power = Energy/Time OR GW = GWh/h ------------------------------------ (2)

Where,

GW is the annual power obtained from the calculated potential energy

GWh is the annual potential energy obtained from the sun and h is calculated annual sunshine hour.

CHAPTER FOUR

Data Analysis

4.1 Identification and Evaluation of Criteria

Criterions for solar farm site selection are identified and discussed in two forms as factors and constraints. In the factors criteria identification, factors that had an effect on site selection for grid connected solar systems are quantified and mapped based on deferent literatures (Table4.1). The same procedure is used for identifying and mapping constraining criterion00s in order to select best sites for grid connected PV solar farm in east shewa.

4.2 Factor criteria development

All identified factors that affect grid connected PV solar farm site selection are reviewed in their order of importance. Solar radiation potential, aspect, slope, land cover, power grids, roads and Urban Settlement. In this study the datasets of solar radiation potential, land cover, population density, proximity to existing road and power transmission networks, and distance to rivers as well as slope and aspect were processed based on different related literatures and studies conducted in different areas (Charabi and Gastli, 2011; Janke, 2010; Li, 2013 and Uyan, 2013). By considering these criterion each factor and constraint is analyzed for selecting potential sits for large Pv plant Installation is conducted as follows (Table 4.1)

Table 4.1: Developed Criteria for Pv Solar farm site selection

Criteria Identification		**Solar power plant**	
Category	**Criteria**	**Ideal condition**	**Reference**
Potential solar power	Feasible power values	Higher value	Aydin *et al.*, 2013
Land properties	Slope	Stable topography ≤ 5%	Janke , 2010
			Janke, 2010
Proximity	Existing Roads	Lower values	Tegou et al. 2010
	Existing Power grid	Not far as 20 Km	Tegou et al. 2010
	Populated area	Sparsely populated	Janke , 2010

4.2.1Solar Radiation Potential Factor

Solar radiation potential factor is most determinant factor for grid connected solar farm site selection. Since it defines the electricity production capacity of the photovoltaic power plant. It expresses the amount of radiation that reaches on every square meters for every year and it indicates weather the amount of solar radiation is high or low .In order to locate areas receiving high amounts of solar radiation, total global solar radiation was processed for the total surface area of East Shewa. As a result an the Maximum Estimated solar Radiation is 4,911,566.5 kilowatt hour per square meter per year While the Minimum Solar radiation is 64.397438 kilowatt hour per square meter per year. As we cans see from the insolation factor Map (Fig 4.1) Most of Eastern, central and part of North west with red and yellow color indicates area receiving high amount of solar radiation this indicates that the areas have favorable conditions for large PV farm Installation irrespective others factors hat hinders the installation of PV farm with in the Zone (Constraints).

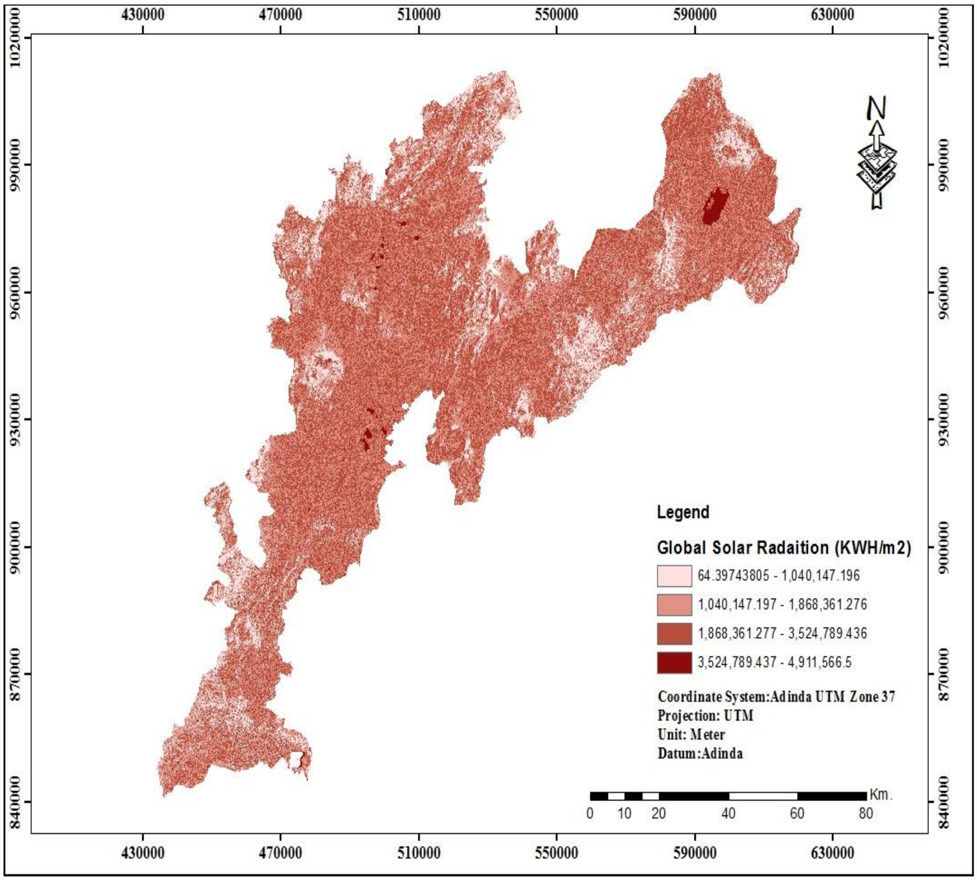


Fig 4.1 Global solar radiation map of the study area.

4.2.2 Aspect factor

The computed aspect factor results nine different directions that the slopes were facing measured clockwise from north N, NE, NW, E, SE, S, SW, W, and flat areas. The raster data was then reclassified in to four classes. The reclassification process combined The South, South East and South West, the Northeast facing slopes with Northwest, the East with West, and the stand-alone class of North facing slopes with flats (Fig 4.2) .Based on their convenience for grid connected solar PV farm site. Since the study area is in the northern hemisphere, the south-facing aspect angles (south, southeast and southwest) were grouped in order to gain the advantage of obtaining areas receiving higher amount of incoming solar radiation per annum. This is because in northern hemisphere, the north side of slopes is often shaded, while the southern side receives more solar radiation for a given surface area insolation because the slope is tilted towards the sun and it is not shaded directly by the earth itself.

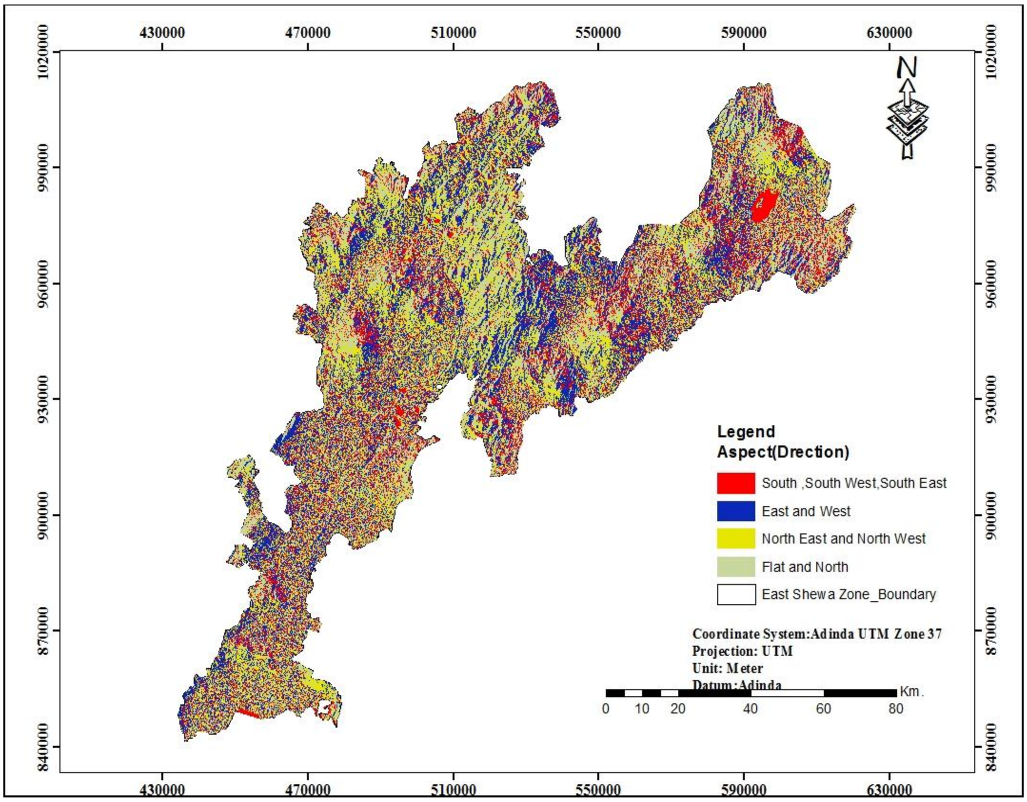


Fig4.2: Reclassified aspect map.

4.2.3 Slope Factor

Topography plays an important role in selection of Suitable sites for large PV solar farm over an area. The importance mainly depends on the aspect angles and slope. The gentle the slopes are, the greater the importance of this type of area therefore, using the spatial analyst extension slope tool in ArcGIS software, a slope map in Degree is created From DEM and reclassified. As indicated in (Fig 4.3) areas indicated in Green and lemon color are with slope less or equal to 10 degrees, these are very gentle slopes and were considered as most suitable for a grid connected solar PV sites. On the contrary areas labeled in orange and red, colors were considered as unfavorable because such areas are having steeper slopes that is not recommendable for a grid connected solar farm site.

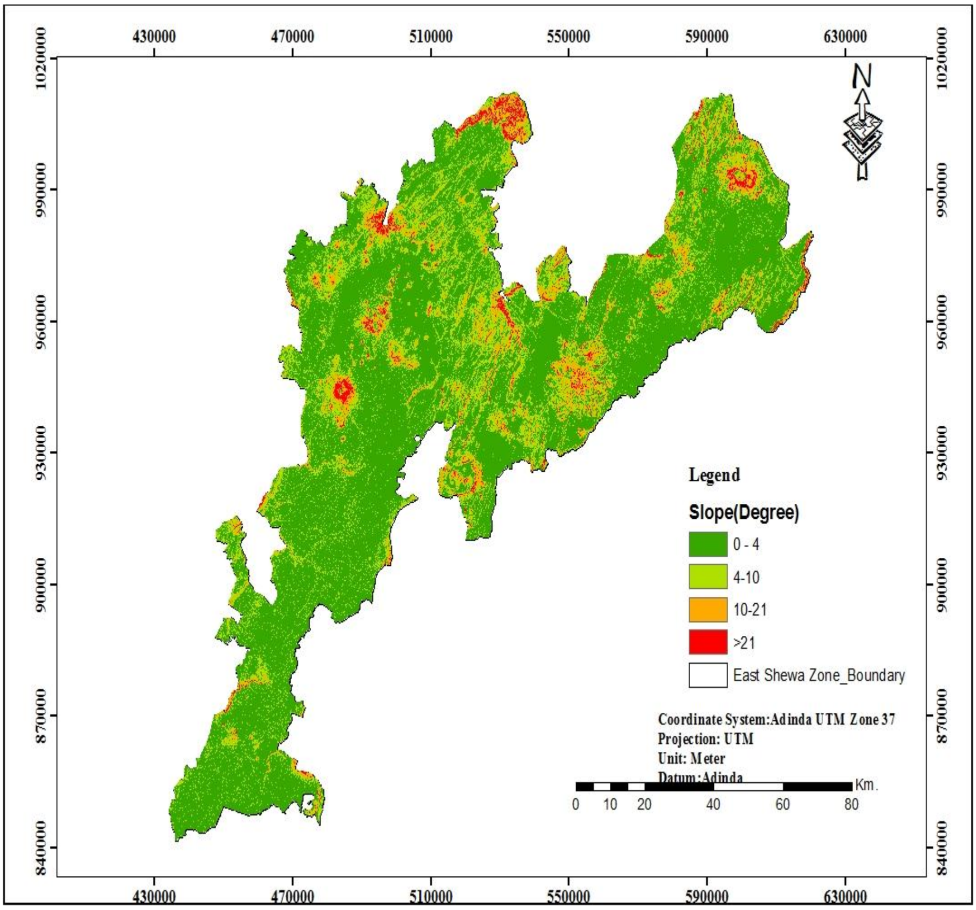


Fig 4.3 Reclassified slope map

4.2.4 Distance from Power Gridlines

Power line Accessibility to Large Pv Solar Farm Sites is considers to be the Major factor this is because the Availably of near bay Transmission Power line help to transfer the electricity to people without additional investment for constructing Transmission lines. For this Analysis a transmission line from Ethiopian Electric Utility (EEU) shape file is used. Euclidian Distance was employed in order to see how far or near the Pv Solar farm from the Transmission lines (Fig 4.4). From the result Areas not farther 3km which is indicated in white is High Suitable areas where as distance between 3 to 7 km is taken as Suitable, areas with distance of 7 to 12 is considered as moderate and the area beyond 12 km taken as low suitable according to the classification criteria which is employed.

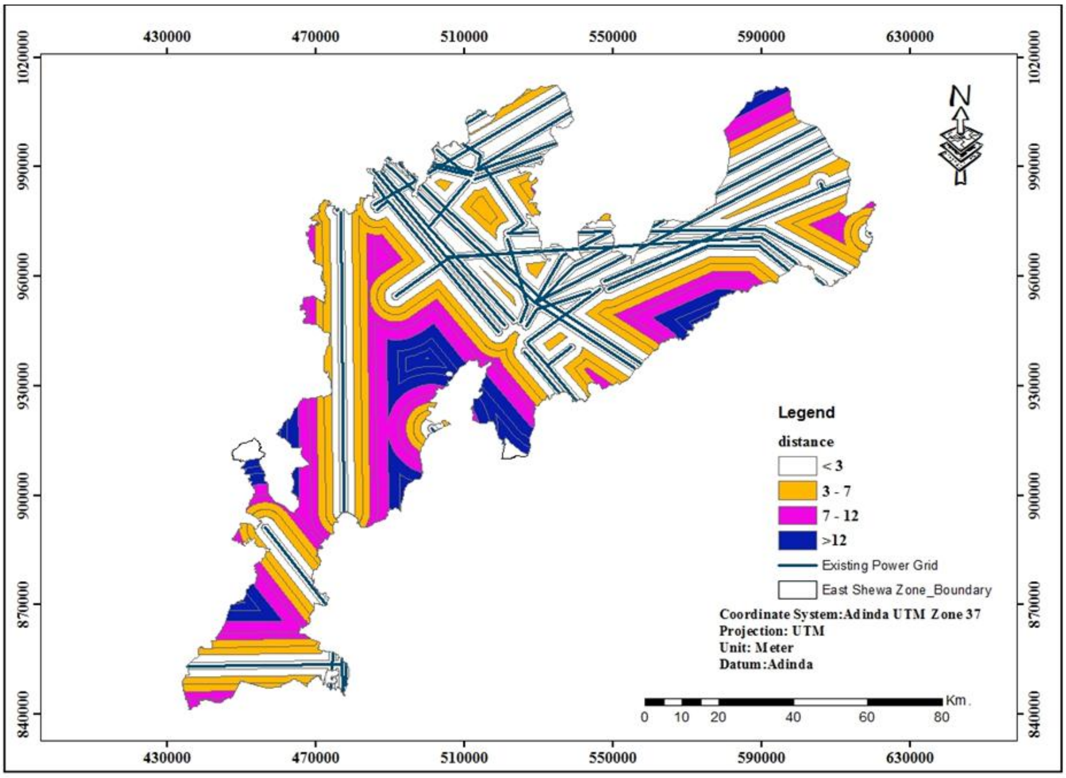


Fig 4.4: Reclassified distance to transmission line map.

4.2.5 Road Factor

Road accessibility is important factor throughout the whole life cycle of a solar farm installation. It is required for construction and installation, maintenance and dismantling of the solar plant. Its importance could also depend on the technology used; solar plants with tracking systems have typically higher maintenance requirements. Only main and secondary roads are considered in the Euclidian distance function was employed (Fig 4.5.). The result was then reclassified in terms of proximity. Areas closer to road; an area has a proximity distance of 3 km of distance indicated in White color from the map bellow are considered suitable for a solar farm site. These roads are beneficial for any type of equipment that needs access to a site for maintenance or development purposes. Roads located at a distance of greater than or equal to seven km indicated in blue colors from the map are considered as inaccessible.

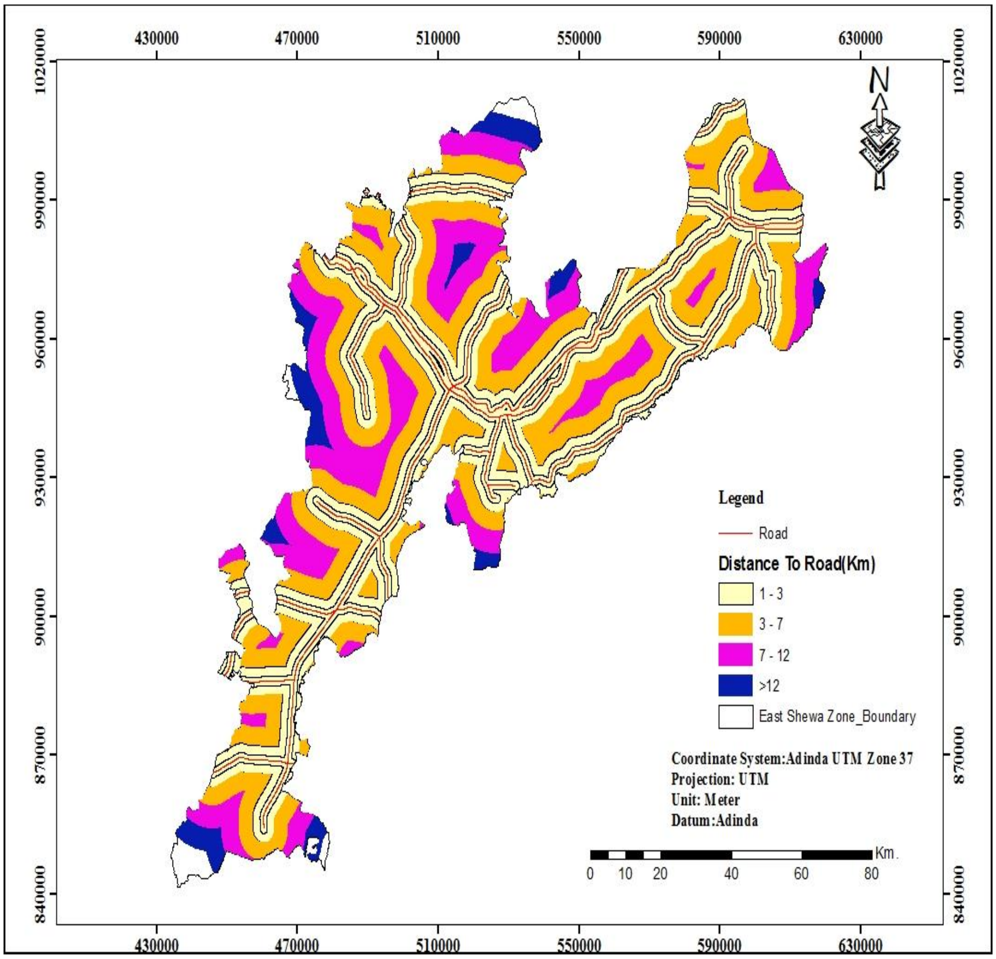


Fig4.5 Reclassified road map.

4.3 Constraint map

In order to develop a solar energy farm on a certain site, as it is necessary to identify factors that contribute for suitability, constraints should also be identified. For instance, batteries used for solar PV cover a relatively large area; forest covers shall be avoided to protect the environment. Dusty and sandy surface shall also be avoided to prevent the power station from coverage of such particles that affects efficiency. Besides, power station site shall avoid bad geological conditions such as large geological fault, rocky, muddy and easily flooded areas to keep power station safe. Accordingly the constraining or restrictive factors in the study area are identified and discussed as follows.

4.3.1 Urban Settlement and River Constraint

The placements f large PV Solar farm sites needs a place where sparsely populated Areas. Urban area by its Nature it is highly populated result it is no recommend to build large Pv Solar farm in urban Area. Therefore Areas 2 km Buffer from urban boundary taken as constraint whereas areas beyond the buffer Zone taken As Suitable. On the other hand River is also considered as a Constraint it is not recommendable to deploy solar farm nearer to flood Palins the same is true for rivers because they might get flash flood and cause disaster to the PV solar farm. Accordingly 1 km buffer distance was employed in order to protect the Pv Solar farm from flood (Fig 4.6) to exclude as non-suitable for PV solar farm site. The following figure shows both urban and river constraint map of the study area.

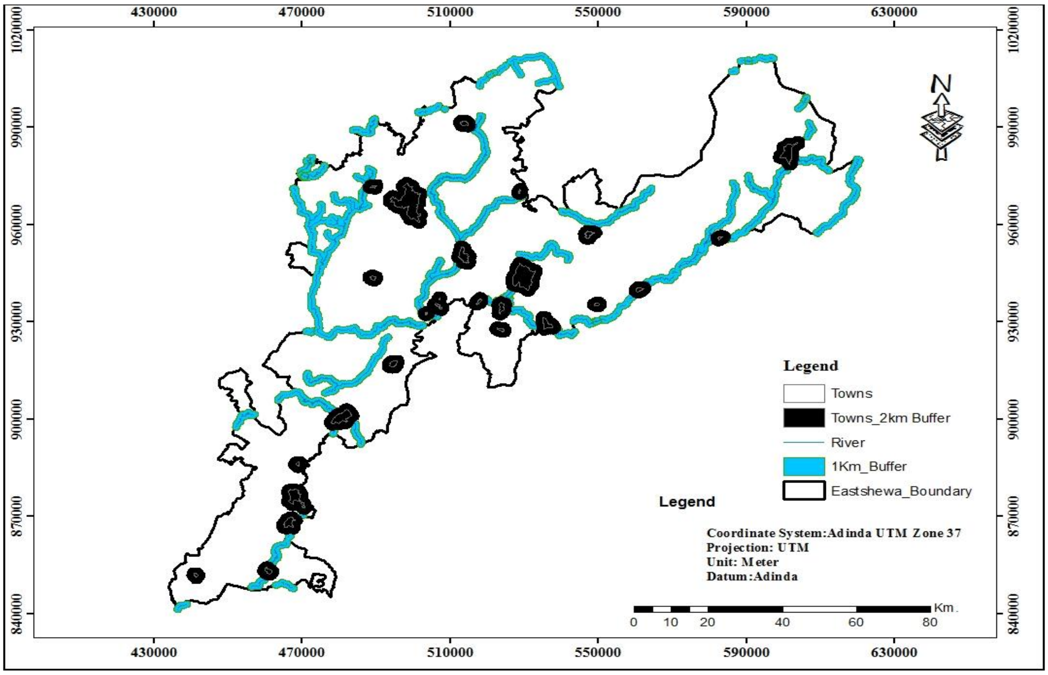


Fig 4.6 River and Urban Settlement Constraint map

4.4 Weight Criteria

In Suitable Site selection processes it is mandatory to give a computed weight value for each participating criteria as per their relative importance in the desired development. Among various MCA techniques that applied to evaluate land suitability, Analytical Hierarchy Process (AHP) is the most common method. Analytical hierarchy process is a decision analysis tool that enables users to compare different variables and their relationships to each other. The outcomes are structured in a hierarchical way simplifying a very complex scientific decision making process (Saaty, 2004). Likewise in this study AHP was used to assign weights to each factor criterion, and thus govern their relative importance in the final decision adopted within the model. The method is based on pair-wise comparison within a reciprocal matrix, in which the number of rows and columns is defined by the number of criteria. Accordingly, it is necessary to establish a comparison matrix between pairs of criteria, contrasting the importance of each pair with all the others. Subsequently, a priority vector was computed to establish weights. These weights are quantitative measures of consistency of the value judgments between pairs of factors (Saaty, 1992). Saaty's scale of measurement is used as follows: S = {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1 / 2, 1,2, 3, 4, 5, 6, 7, 8, 9}. Accordingly for this study a pairwise comparison matrix was designed and the comparisons ratings are provided on a nine point continuous scale, which was proposed by (Eastman, 1995) the following (Table 4.2) shows the level of importance of each criteria based on their level of importance.

Table 4.2 Nine-point importance scale

1/9	**1/7**	**1/5**	**1/3**	**1**	**1/3**	**5**	**7**	**9**
extremely	**very**	**Strong**	**Moderate**		**equal**	**Moderate**	**Strong**	
Very Strong extremely								

Less importance ⟶ High Importance

4.5. Weighted overlay

In order to obtain suitability map of the study area, a series of climatic and topographic factor layers were aggregated based on their calculated weights. The suitability map obtained reflects the carrying capacity of the land for hosting a grid connected solar energy farms where a decision methodology (Multi criteria Evaluation and Analytical Hierarchy process) has been applied. Constraining (Exclusion areas) such as forests, exposed rocks, densely populated areas, flood Plain Rivers were not considered and excluded from this assessment. The suitability map (Fig 4.1) indicated with grid value of 1 show large portion of the study area is suitable to deploy a grid connected solar power plants. However these does not mean that the whole area indicated in the figure is used for solar farms, rather it is diminished after the constraint criterions are overlaid and feasible sites (Fig 5.5) are then masked out to gain the final suitability map

4.6 Criteria Standardization

4.6.1GIS-based Multi-Criteria Analysis

Solar radiation potential, slope, distance to road, distance to power transmission grid, aspect, land cover and distance to water source were the selected criteria for suitability analysis for large scale PV solar farms in Ethiopia. As mentioned earlier, in order to create a suitability map that identifies potential sites, the input datasets needed to be changed into a raster with a common resolution. Therefore, these criteria datasets were converted into raster with 30 m resolution and reclassified from 1 to 4, and indicates non-suitable, not suitable, marginally suitable, moderately suitable and highly suitable, respectively (Table 4.2). Based on related literature and previous studies the selected criteria were defined as follows (Charabi and Gastli, 2011; Datta and Karakoti, 2010; Gastli and Charabi, 2010a; Janke, 2010; Li, 2013; Turney and Fthenakis, 2011; Uyan, 2013).

Table 4.2: Derived factor maps and ranking

Factors	Unit of Measurement	Suitability Level				Weight (%)
		1	2	2	4	
		High Suitable	Suitable	Moderately Suitable	Less Suitable	
Solar Radiation	Kwh/m2	3,524,789.4 - 4,911,566.5	1,868,361.2-3,524,789.4	1,040,147.2-1,868,361.2	64.4-1,040,147.2	33.73
Aspect	Direction	S,SE,SW	E&W	NE & NW	Flat &North	11.41
Slope	Degree	0-4	4-10	10-21	>21	29.06
Distance to Power Grid	Km	< 3	3-7	7-12	>12	16.62
Distance to main Road	Km	1-3	3-7	7-12	>12	9.18

The calculated weight values express the importance of each criterion to the other criteria. Therefore, the pairwise comparison matrix (Appendix 2) developed for this study gives calculated weight for each criterion with an acceptable consistency ratio (CR) of 0.09. All the reclassified and weighted input datasets were combined using ESRI‟s Weighted Overlay tool. Figure 5.3 shows a raster data with highly suitable, moderately suitable, least suitable and non-suitable reclassified layers.

CHAPTER FIVE

Results and Discussion

5.1 Results

In order to Select sites for large Pv Solar farm sites In east Shewa Zone a 30 m Shuttle radar topographic Mission (SRTM) was used to calculate annual solar radiation. In order to select suitable sites different criterion and factor were identified and being analyzed by using GIS analysis tools and Multi-Criteria Analysis (MCA) was applied to map suitable sites for grid connected solar PV farms. In addition to solar radiation potential; topographic characteristics such as aspect and slope, land cover, urban settlement, roads and power grid of the study area were considered in the suitability analysis. In addition to these electricity potential of the study area is commuted from the meal solar radiation.

5.2 Multi criteria Result

Based on related literature and previous studies (Charabi and Gastli, 2010; Janke, 2010; Li, 2013; and Uyan, 2013) the selected criteria were defined in the above (Table 4.1). By using Analytical Hierarchy Process (AHP) with Idrisi Salva 2012 with a consistency Ratio of 0.09 weighted values is assigned for each factors (see Table 4.1). By using GIS overlay analysis tool suitable sites were identified and all criterions were divided into four major suitability classes; highly suitable, suitable, moderate and non-suitable area are identified (Fig 5.1)

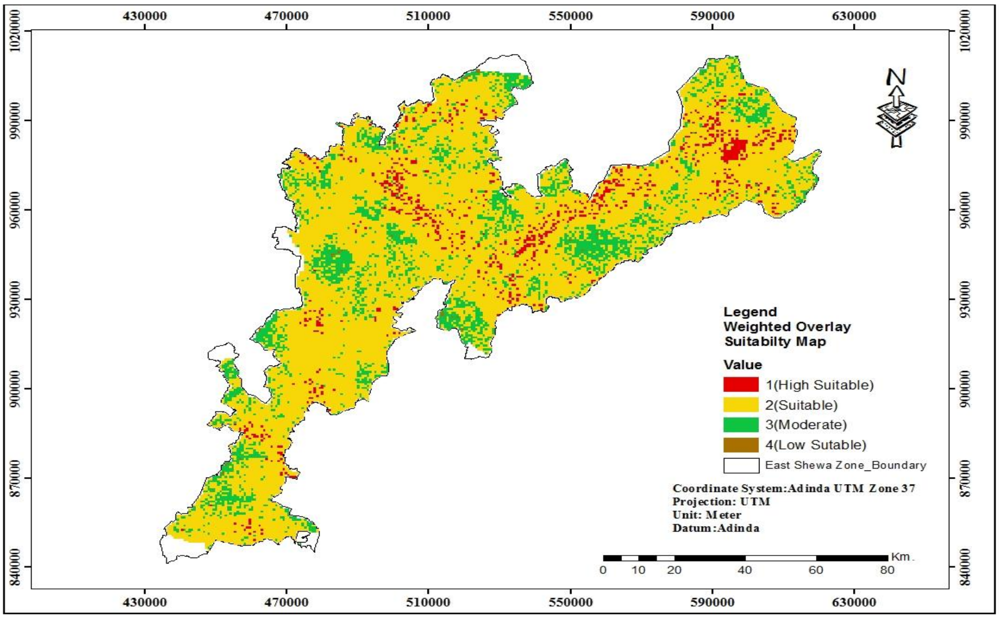


Fig 5.1 Grid connected solar Photovoltaic Suitability map.

5.3 Spatial Distributions of PV Solar Farms Sites

Based on the Computed weighted Value using in Pairwise Comprise in Coup up with weighted overlay analysis of Multi Criteria Analysis 47 locations with Optimum Solara radiation potential are selected for Grid Connected large Pv Solar farm with in the Zone (Fig 5.2 and 5.3). Eastern part of the zone including Fentale and Boset Worde has higest number of Sites .In central part LommeWoreda in the Northern part Gimichu and Adea Woreda ,in Southern parts of the Zone Dugda Bora Woredas follows .the rest of the werdas including Adama,Liben,Adamituu Jido combocha has few number of Solar farm selected .

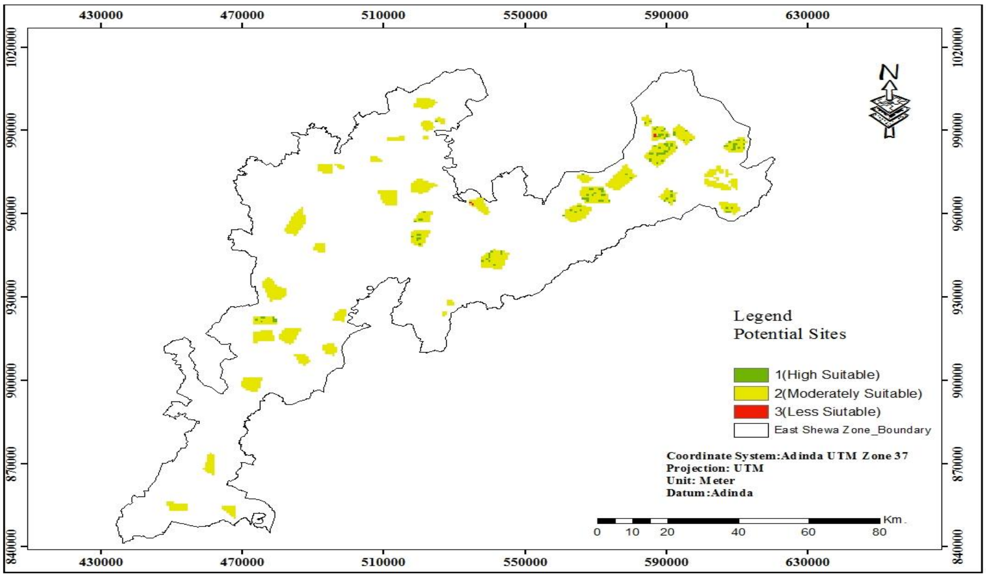


Fig 5.2: Photovolitc power farm site Suitability Index Map.

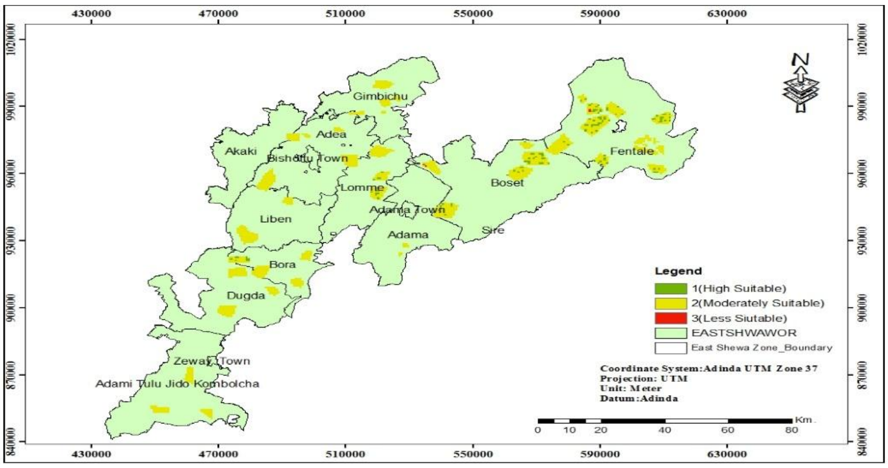


Fig 5.3 Photovoltaic power farm site distribution Map.

5.5.1. Results of Solar electric power capacity

Based on the Analysis made earlier the computed mean solar radiation found from SRTM DEM was Kwh/m^2/year and the total calculated area calculated Suitable Sites was 827 km^2 which 8.3% of the total area of the study Area. According to Solar and Energy Master Plan the panel efficiency value were obtained poly crystalline Silicon (Poly C-Si) with 20 percent efficiency was taken .the electricity potential calculation Assume that at least 50 percent of the selected Area can be covered by Solar Panel. By applying the formula in equation (1) 1.464 TW energy per Annam can be Generated

5.6 Discussion

In order to make results from this study more practicable and up-to-date, latest available data and software's are used. For instance, Area solar radiation tool in ArcGIS the monthly and annual global solar radiation solar radiation potential modeling for east shewa zone. The solar analyst tool considers site latitude and elevation, slope, aspect, daily and seasonal shifts of the sun angle, effects of shadows cast from the surrounding topography and the atmosphere. Therefore, two tiles of a 1 degree by 1 degree most recent 30m SRTM DEM was used as primary input. The quality of calculated solar radiation output determined by the DEM resolution as well as parameters used such as time interval and sky size resolution.

Higher resolution DEM with smaller time interval and bigger sky size results more accurate output but also considerably increases calculation time. Thus, to achieve reasonable result in short processing time, solar radiation of the study area was calculated for 2,800 sky size and 0.5 hour interval.

In order to select ideal site for grid connected solar PV farms in East Shewa . Multi Criteria Analysis of Analytical Heretical Process (AHP) was employed where various topographic, economic and environmental factors such as solar radiation potential, land cover, slope, aspect angle, distance to existing road and power grid network, and urban settlement were taken into account. In this process criterions were identified, standardized, weighted and finally aggregated using the weighted overlay function in Arc GIS and suitability map of the study area was obtained. As a result, 47 sites with a total area of 827 km^2 located in different Woreda's over the boundary of east shewa were defined as suitable for grid connected solar PV farms.

Finally, for annual solar energy potential estimation and electric power generating capacity calculation, mean annual solar radiation and annual sunshine hour was used. The result showed 1.46 TW electric powers per annum can be generated. This study shows how remotely Sensed

Data, coupled with GIS Analysis tools could successfully Show and map spatial variations of solar radiation over an area.

Thus, the information presented here can help Government agencies like Ethiopian electricity power service who are responsible for generating and providing electricity power as means of an alternative sources of energy for the zone. Moreover, the methodology implemented in this study appears acceptable for determining the possible plant capacity for an arbitrarily chosen area.

CHAPTER SIX

Conclusion and recommendations

6.1 Conclusion

The development in economic activity and rapid growth of population increase the demand for energy. In order to full fill the energy demand different energy sources are used through human history. Biofuel, petroleum, gas are the major sources of energy and these energy sources depleted throughout time because the emission high amount of CO_2 made from these sources of energy now a days our planet faces climate change problems.

In order to overcome these problem worlds agenda facing towards renewable Sources of energy like Hydro power, Wind Power and Solar Energy alternative energy Sources. The problem that our world facing are being seen in our countries. Therefore, the Aim of this Study Was to Select Sites for Large Solar Farm (photovoltaic power plant) Sites in East Shewa the District in Oromiya Regional State, Ethiopia. In order to know the solar potential of the Zone Modelling of the Solar Radiation from 30 DEM was used and different spatial Data layers were used to analyses in Coup up with GIS Multi criteria and pairwise Comparison were employed to sect Best sites for large Pv farm. According to the result which is computed 47 sites were selected for large Pv solar farm with in the Zone and an estimated 1.46 TW electricity will be generated if these sites are exploited.

6.2 Recommendations

Mapping solar radiation of a given area is crucial for exploiting the resource effectively and efficiently .the Use digital elevation Model we can easily analyses the solar radiation over area.in order to analyses the solar radiation high resolution Data like LIDAR (Light Detecting and ranging) could give better results.

In Addition to these high Speed Computers with consistence supply of electricity is require to run the solar radiation model .this is because running solar radiation Model took several hours When we come to result, the study area has an absolute advantages for constructing large PV solar farm these due proximity of Power line is close in areas where there is high potential sites. Most of the selected sites are close to the main road that easily facilitates the supply of equipment's for PV. Since some Constraint that hinder the PV farm are identified. It easy to launch any Project over the selected sites. I this regard government officials that are working on the electricity supply should understand the solar electric potential of the study Area.

More over the researcher recommend further studies on solar radiation with optimal potential should be studied using high resolution data's.

References

- Central Statistics Authority of Ethiopia (CSA), (2007). The 2007 national census statistics.
- Charabi, Y., and Gastli, A. (2010). GIS assessment of large CSP plant in Duqum, Oman. *Renewable and Sustainable Energy Reviews*, 14(2), 835–841.
- Charabi, Y., and Gastli, A. (2011). PV site suitability analysis using GIS-based spatial fuzzy multi-criteria evaluation. *Renewable Energy*, 36(9), 2554–2561
- Dawit Hailu Mazengia ,(2010).”Ethiopian Energy Systems- Potentials, Opportunities and Sustainable Utilization”. A thesis Presented to Uppsala University for the partial fulfillment of the degree of Master of Science (MSc) in Sustainable Development.
- East Shewa Zone Finance and Economic Development Office, (2014)
- Dongrong Li(2013):” Using GIS and Remote Sensing Techniques for Solar Panel Installation Site Selection” A thesis presented to the University of Waterloo in fulfillment of the thesis requirement for the degree of Master of Science in Geography.
- Dubayah, R 1991, *Using LOWTRAN7 and field flux measurements in an atmospheric and topographic solar radiation model*, IEEE, Helsinki, Finland.
- Eyaya Belay,(2009). “Modeling site suitability for wind farm using remote sensing and GIS: The case study of Adama Woreda” . Master’s Thesis Submitted to school of Earth Science, Addis Ababa University.
- Fikremariyam Teshome. (2014). Assessment of Solar Energy Resources in Ethiopia using GIS-based multi-criteria analysis for modeling solar radiation and potential site selection.
- Fu P. and Rich PM. (2002). A geometric solar radiation model with applications in agriculture and forestry, *Computers and Electronics in Agriculture*, **37**:25–35
- Fu, P. and Rich, P.M. (1999). Design and implementation of the Solar Analyst: an ArcView extension for modeling solar radiation at landscape scales.**In**: *Proceedings of the 19th Annual ESRI User Conference*, San Diego, USA.

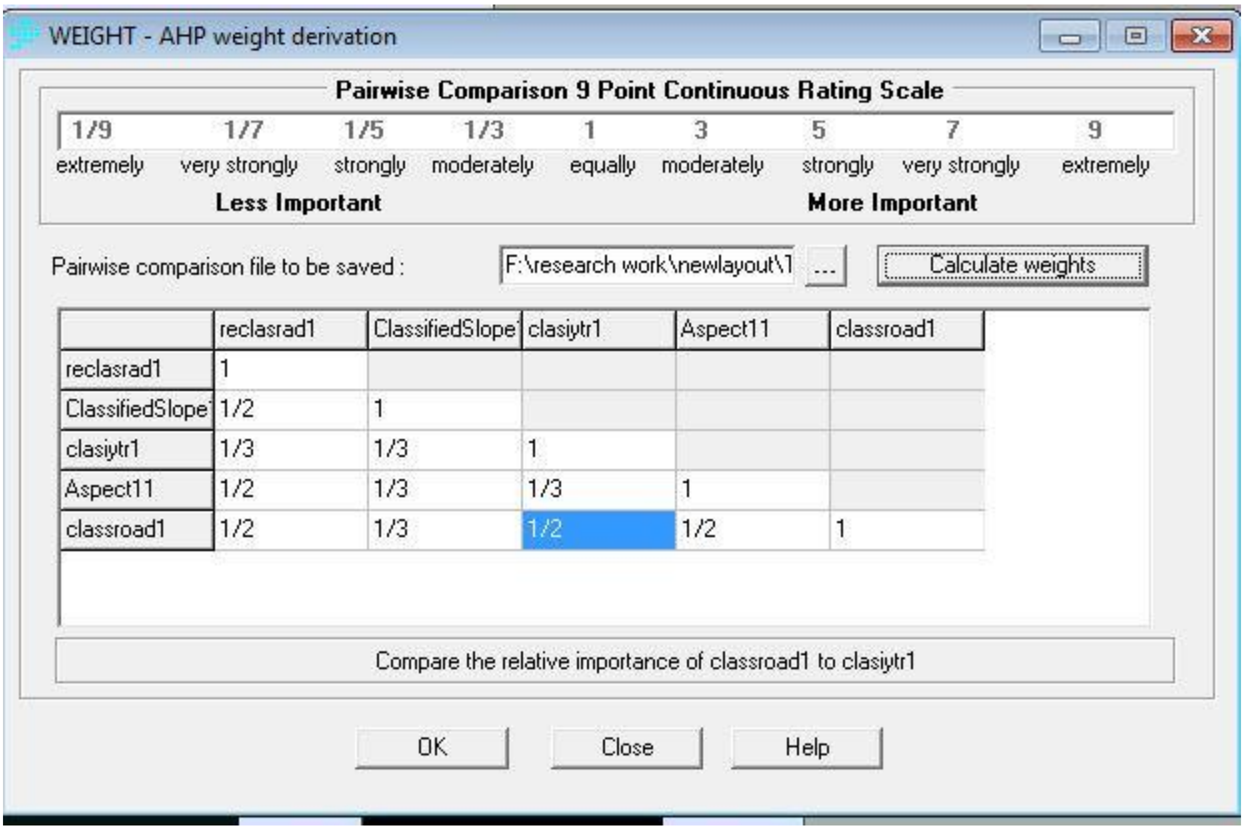
- Gastli, A., & Charabi, Y. (2010a). *Siting of large PV farms in Al-Batinah region of Oman*. Paper presented at the Energy Conference and Exhibition (EnergyCon), 2010 IEEE International.
- Gastli, A., & Charabi, Y. (2010b). Solar electricity prospects in Oman using GIS-based solarradiation maps. *Renewable and Sustainable Energy Reviews, 14*(2), 790–797.
- Hala Adel Effat(2014): "Mapping Solar Energy Potential Zones, using SRTM and Spatial Analysis, Application in Lake Nasser Region, Egypt" International Journal of Sustainable Land Use andUrban Planning [IJSLUP] ISSN 1927-8845 Vol. 3 No. 1, pp. 1-14 (2016)
- Hala Adel Effat, (2013): "Selection of potential sites for solar energy farm in Ismailia Governorate,Egypt using SRTM And Multi criteria Analysis". International journal of advanced remote sensing and GIS.
- Hofierka J. (2008). Distributed Assessment of Solar Resources for Energy Applications in Slovakia.
- Janke, J.R. (2010). Multicriteria GIS Modeling of Wind and Solar Farms in Colorado. *Renewable Energy*.
- Jie Zhang (2015). Assessment of renewable energy potentials based on GIS and RSA case study in China. A doctoral dissertation submitted to the Faculty of Spatial Planning at TU Dortmund University in partial fulfilment of the requirements for the degree of Doctor of Engineering.
- Ma Jiangtao et al. (2012) Master Plan Report of Wind and Solar Energy in the Federal Democratic Republic of Ethiopia, Hydro China Corporation ,July 2012
- Malczewski, J. (1999). *GIS and multicriteria decision analysis*: John Wiley & Sons.
- Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. *Program Plan.* 62(3), 65.
- Mani N.D And Penmaya Ningshen. (2016). "USING GIS AND REMOTE SENSING TECHNIQUES FOR SOLAR HOTSPOTS INSTALLATION IN THIRU NAGAR, DINDIGUL DISTRICT". Mechanical Engineering: An International Journal (MEIJ), 2016 Vol. 3

- Mohammed Kareemuddin And Dr. Shaik Rusthum ,(2016).”Solar pv optimum site selection using remotes sensing data ,GIS and Image processing techniques , A case study of Chilkur Village RR District” , Telangana .international journal of innovative technology and Research , March 2016.2;2812-2823
- Nakanishi, T. (2010). “Identifying and Viewing Rooftop Solar Potential: A Case Study for the City of Redlands, California” Master’s thesis, University of Redlands.
- Pearce, J.M. (2002). Photovoltaic: A path to sustainable futures. 34 (7), 663-674.
- Rahel Atlaw, (2015). “An integrated approach of GIS and remote sensing for grid connected PHOTOVOLTAIC solar energy potential modeling and mapping : in case of Dire Dawa, Ethiopia”.Master's thesis in Gis And remote sensing in Addis Ababa University ,2015
- Robert J. Peckham • Gyozo Jordan(Eds.) ,(2007). Digital Terrain Modeling, development and application in policy support 1Environment”.
- Saaty, T 1992, *Decision-Making for Leaders*, RWS Publication, Pittsburgh, USA.
- Saaty, T. (2004). Rank from comparison and from ratings in the analytic hierarchy network processes. *European Journal of Operational Research*. 2, 168.
- Salvador Bonjoch Cots(2013). Collection, Transportation, Storage and Conversion of Solar Light, Energy system for a single-family house”.Master of Science in Engineering Technology Natural Resources Engineering, Luleå University of TechnologyDepartment of Civil, Environmental and Natural Resources Engineering.
- Shengli Huang And Pinde Fu(2009). Using the solar radiation analysis tools in ArcGIS Spatial Analyst, ESRI.
- Suri, M. Hofierka, J. (2004). A New GIS-based Solar Radiation Model and Its Application to Photovoltaic Assessments. *Transactions in GIS*. (8), 175–190.
- Tegou, L.I., Polatidis, H. and Haralambopoulos, D.A. (2010). Environmental management framework for wind farm siting: Methodology and case study. *Journal of Environmental Management*. (11), 21–34.

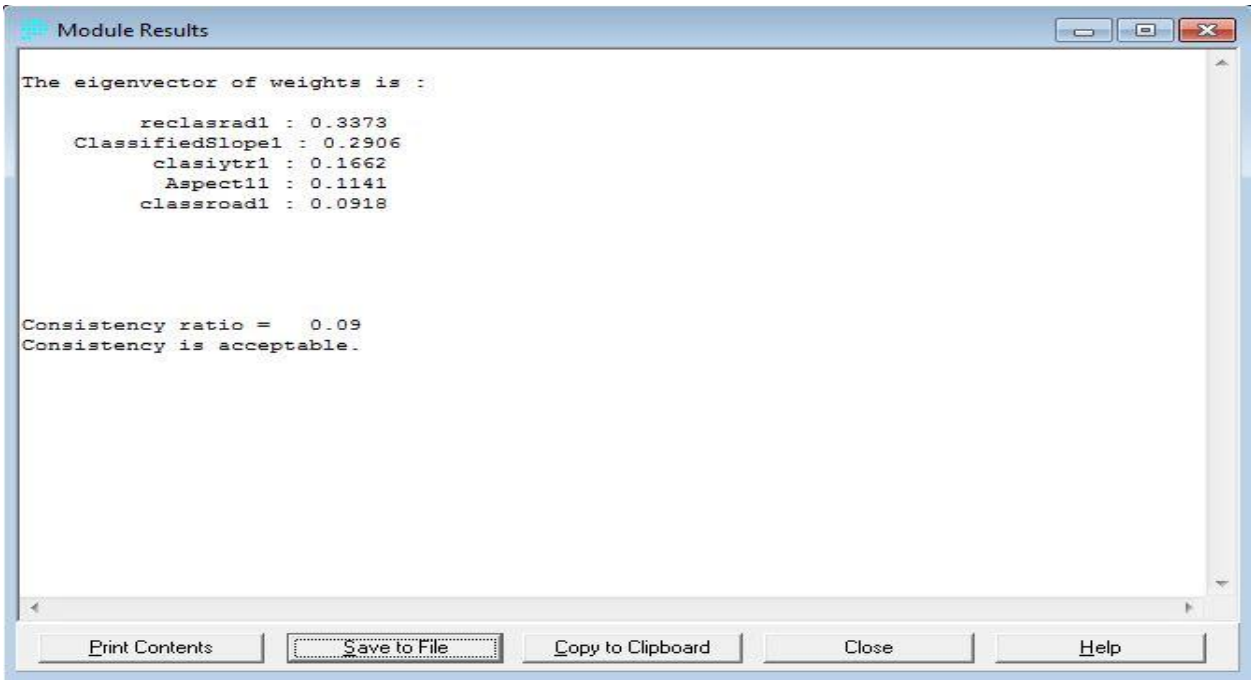
- Uyan, Mevlut. (2013). GIS-Based Solar Farms Site Selection Using Analytic Hierarchy Process(AHP) in Karapinar Region, Konya/Turkey.Renewable and Sustainable Energy Reviews 28 (December): 11–17. doi:10.1016/j.rser.2013.07.042.
- Yee Kit Tsang (2016). Site Suitability Analysis: Small-Scale Fixed Axis Ground Mounted Photovoltaic Power Plant In Fresno, CA, A Thesis Presented to the Faculty of the USC Graduate School University of Southern California In Partial Fulfillment of the Requirements for the Degree Master of Science(Geographic Information Science and Technology).

APPENDICES

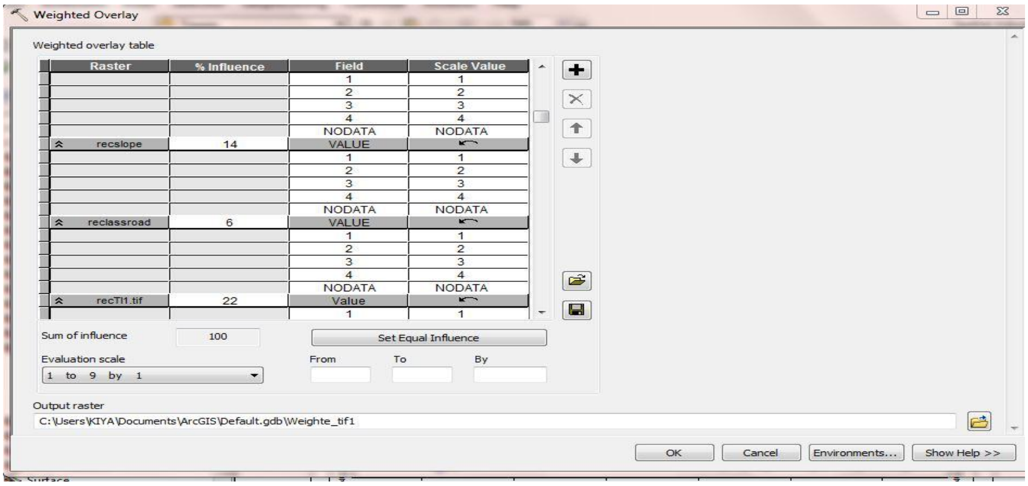
Appendix I pair wise comparison



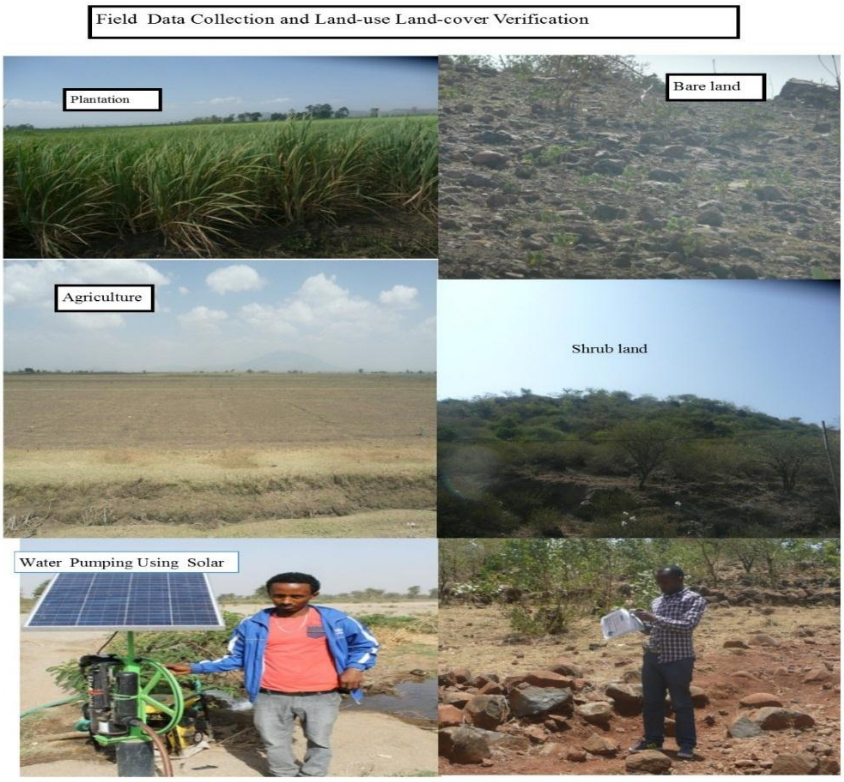
Appendix II Pairwise Comparison result



Appendix III Wei 2ghted Overlay Analysis



Appendix IV Field Observations



Declaration

I hereby declare that the thesis entitled **"*A GIS AND REMOTES SENSING APPROACH FOR MODELLING SOLAR RADIATION POTENTIAL SITES FOR GRID CONNECTED PHOTOVOLTAIC POWER PLANT SITE SELECTION: A CASE STUDY OF EAST SHEWA ZONE IN OROMIYA REGIONAL STATE, ETHIOPIA*"**. Has been carried out by me under the supervision of Dr. K.V Suryabhagavan, Department of Earth Sciences, Addis Ababa University, and Addis Ababa during the year 2018 as a part of Master of Science program in Remote Sensing and Geo-informatics. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Abay neh Gerbo

Signature ________________________________

Date ____________________________________