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GIS-Based Identification of Potential Sites for Installing Solar Energy Collection Plants in Kathmandu Valley, Nepal

by
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the degree of
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Kathmandu, November 2016

Science Pledge

By my signature below, I certify that my thesis work is entirely the result of my own work. I have cited all sources of information and data I have used in my project report and indicated their origin.

Kathmandu: 21 November 2016	Govinda Ram Paneru
Place and Date	Signature

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Abstract

Renewable energy alternatives are gaining popularity these days due to the large number of benefits offered by them. The movement towards the acquisition of renewable energy resources such as solar photovoltaic (PV) systems, hydroelectricity, wind energy etc. are aiding in the reduction of negative impacts of fossil fuel on the environment.

Solar energy is abundant and free of cost. The technological advancements in the field of solar energy storage and utilization has opened avenues for mountainous countries like Nepal where it is costly to run national electricity grid to each and every household. Solar energy collection plants are one of the best solutions to increase energy availability without polluting the environment. The solar power system consists of solar panels and inverter which can autonomously regulate itself to synchronize with the main grid.

Kathmandu, the business hub and capital city of Nepal is worst hit by this power crisis. Daily life of people has been hindered by long and inevitable load shedding caused due to the low production of electricity. Solar energy is one of the form of Renewable Energy System (RES) which can be used as a sustainable alternatives in Kathmandu district. In such situation, the identification of suitable site for installing solar energy collection plant is crucial in the process of establishment and production of sustainable, clean and low-cost energy alternative as compared to hydroelectricity. The aim of this study is to identify a suitable location for installing solar energy collection plant based on multiple criteria thus by utilizing Geographic Information System techniques and methodologies. Finally, maps of priority sites for solar energy systems are produced and marked as suitable locations for solar energy systems.

Key words: Geographic Information System, GIS, Renewable Energy System (RES), Multi-Criteria Decision Making, MCDA, Alternate energy, solar energy, photovoltaic (PV) systems, GIS-based MCA; AHP

Table of Contents

List of Tables

List of Maps

List of Figures

Chapter 1. Introduction

1.1. Background

In the past decade, Nepal has had a steady growth in the demand for electricity because of less industrialization and lower use of electric appliances by the people. The continued growth in population, industrialization and use of power hungry modern electric appliances has exhausted the capacity for electricity generation and has resulted into a load shedding situation.

The people of Nepal are facing lots of problems due to shortage of electricity. The problem of power shortage has led to many social and economic crises in Nepal. The power shortage has reached such an alarming level that industries here are either running in their minimum capacity or are totally closed. As a result of these, unemployment, poverty and frustration in public against the government are raising.

A recent study conducted by the team of Institute of Engineering, Tribhuwan University Nepal and led by Prof. Narendra Man Shakya has shown that Nepal has a total potential to generate 53,000 megawatts of hydropower in Nepal. This team's estimate was based on the latest water discharge data available with the Department of Hydrology and Meteorology, using Geo-graphic Information System.(KC, 2013)

Renewable energy has gone mainstream, accounting for the majority of capacity additions in power generation today. Tens of gigawatts of wind, hydropower and solar photovoltaic capacity are installed worldwide every year in a renewable energy market that is worth more than a hundred billion USD annually. (IRENA, 2012)

In recent times, the nature and magnitude of global energy demands have changed and increased in an unprecedented manner, especially with today's rapid population growth and modernization (Foster et al., 2010; Sen, 2008).

Solar energy is an attractive as well as a long-term and sustainable alternative for economically weak countries like Nepal. This free source of energy is transmitted from sun and is environmentally clean which is believed to address anticipated future energy demands.

For the promotion and development of alternative renewable energy technologies in Nepal, the government of Nepal established Alternative Energy Promotion Centre (AEPC) in 1996 A.D. AEPC is working as a focal point for the Renewable Energy sector development in Nepal. Other various private organizations, I/NGOs are operating projects related to renewable energy in various parts of country.

1.2. Research Problem and Motivation

Though Nepal is one of the world wealthiest countries in terms of water resources, due to lack of sufficient electricity generation projects, it is ironically facing severe electricity crisis.

The suppressed electricity energy demand deficit forecasted as greater than 100 MW/year is merely an indicator of how deep into trouble we are. (Shrestha & Shrestha, 2014)

In order to address the electricity crisis in the country, government has recently come up with an unfunded mandatory policy which demands all public, commercial and institutional buildings in urban areas of the country will now be required to generate a quarter of their electricity requirement by themselves using solar system. The regulation also applies to private houses with roofs larger than 2,500 square feet in area in metropolitan and sub-metropolitan cities. The government has directed the concerned authorities that for those planning to build new houses in Kathmandu valley, the building permits will be issued only after making sure the new energy requirement is fulfilled.

Until this date, the total capacity of grid connected solar produced by Nepal Electricity Authority is only 100Kw (Nepal Electricity Authority, 2015)which is very low to address the ever increasing demand of electricity.

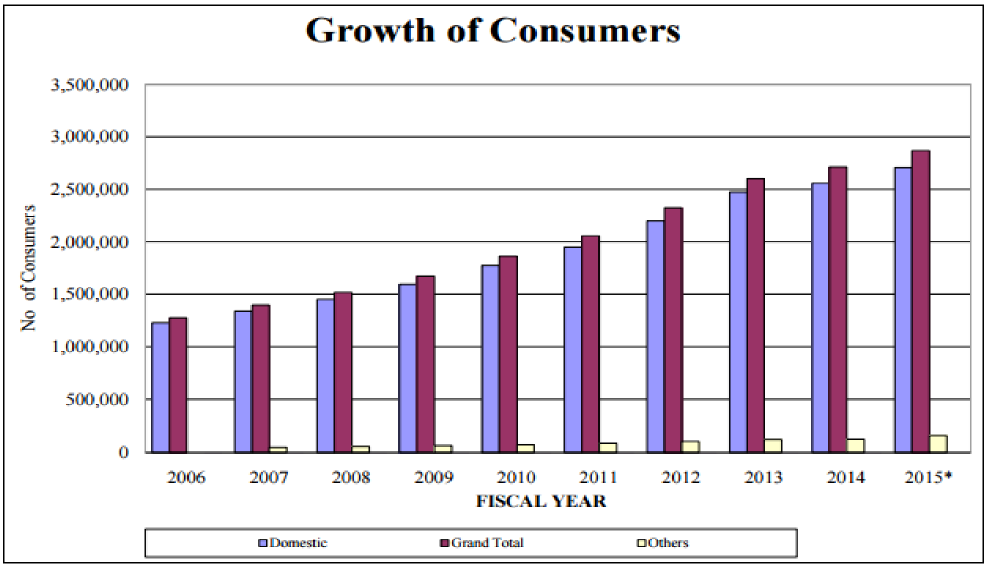


Figure 1: Electricity consumer growth chart

Source : (Nepal Electricity Authority, 2015)

The graph above clearly shows the trend in the growth of electricity consumer. This signifies that the government has to take an urgent initiation to fulfil the current demand and address the future electricity demand as well.

1.3. Objectives of Study

The objective of this study is to identify a suitable location for the installation of solar energy collection plant. This approach is a GIS-based site suitability analysis for the identification location for the installation of solar energy collection plants by incorporating geographical and technical constraints, such as land use, settlement, proximity to road, solar radiation etc.

The result from this study is expected to help alternative energy investors, researchers and other concerned agencies to visualize the most suitable location for the construction of solar power project.

1.4. Limitation of Study

Every research work has some limitations. Keeping the limitations to the minimum, research works are carried out in order to visualize the underlying problem. There are two significant limitations of this research which are presented as follows:

Though the study is confined to identifying suitable area for solar energy collection system based on slope, aspect, land use/land cover, settlement, accessibility and solar radiance, it does not explore the environmental and social factors in the construction of solar power plant.

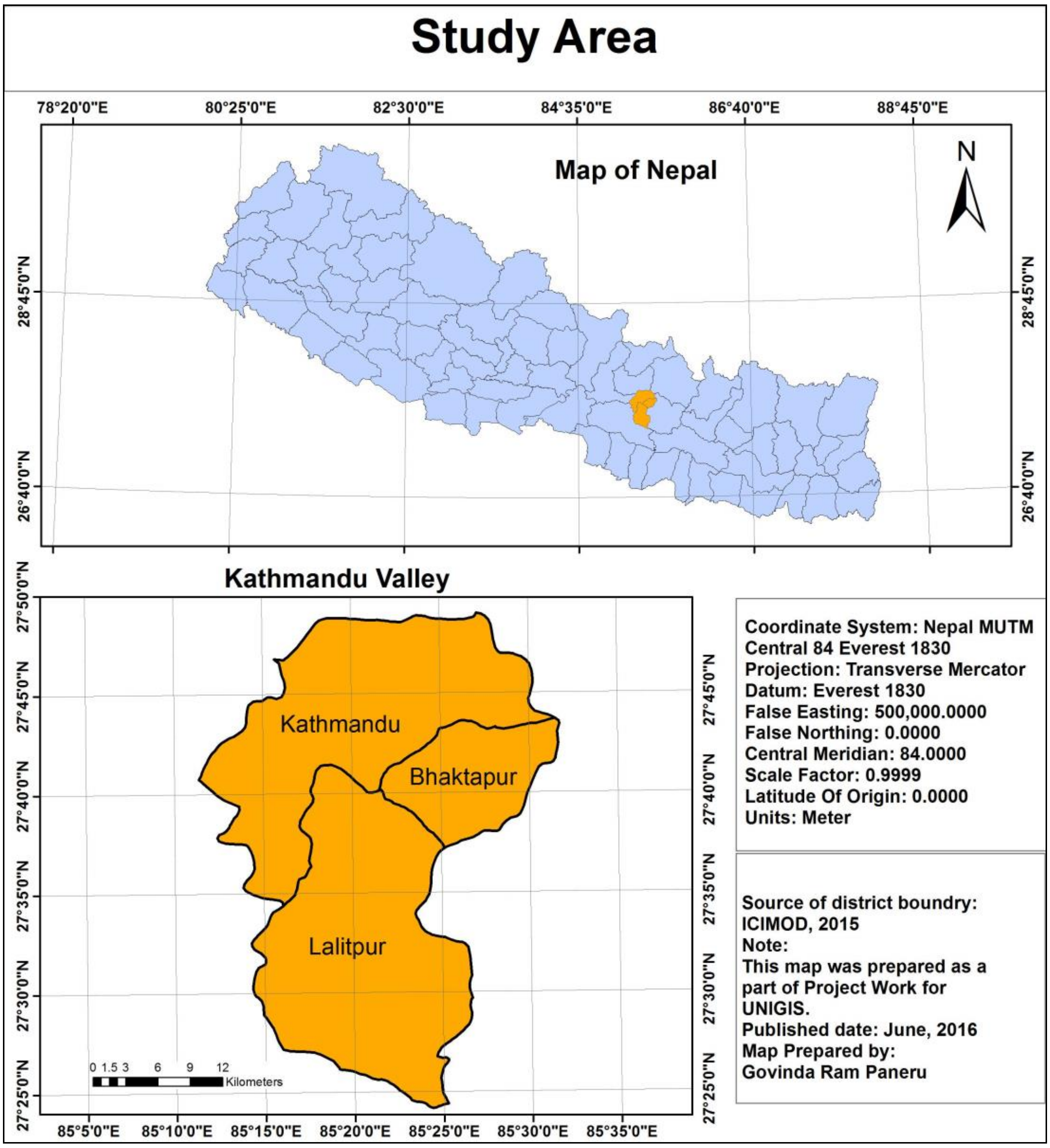
The number of criteria under consideration are very few due to the unavailability of required data. Due to this reason, a high precision result cannot be expected. However, the research presents an overview for solving the chosen problem set.

This study do not consider the national power grid location data which is another limitation of this study.

1.5. Study Area

The study area selected for this study is Kathmandu valley which is made up of the **Kathmandu**, **Lalitpur** and **Bhaktapur** District covering an area of 933 square kilometres. Kathmandu valley is bowl-shaped. Kathmandu is the capital city of Nepal.

Kathmandu valley is surrounded by four mountain ranges: Shivapuri (at an elevation of 2,800 metres), Phulchowki (2,795 metres), Nagarjun (2,825 metres) and Chandragiri (2,300 metres). The major river flowing through the Kathmandu Valley is the Bagmati. Kathmandu valley is highly populated and is one of the major cities of Nepal. Identification of suitable location for the installation of solar energy collection power plant would be helpful in resolving the current load shedding problem in the Kathmandu valley which is the major reason behind selection Kathmandu valley as a study area.



Map 1: Map showing the study area: Kathmandu valley

1.6. Literature Review

A significant number of studies have been carried out to identify necessary factors that should be considered in site selection process for constructing solar energy collection plant. This section provides a review of existing policies that describes about alternative energy use in Nepal. It also explores on various aspects of GIS based site selection and factors usually considered in the site selection for solar energy collection plant. Along with this, a detailed description of other physical factors that affects the solar power system and performance is provided.

1.6.1. Energy policy of Nepal

Rural Energy Policy, 2006

The Rural Energy Policy, 2006 prepared by the Ministry of Environment, Nepal has mentioned the following points about the solar energy promotion and management under its WORKING POLICIES section:

- Emphasis will be given for the necessary study and research for reducing cost of solar energy technology and its efficient use.
- Arrangement shall be made to operate solar energy technology at community and institutional level by integrating it with irrigation, health, education and drinking water.
- Development of solar energy technologies will be encouraged by integrating it with technologies for drying and cooking of food, purifying water, lighting and communication systems.
- Necessary public awareness activities will be launched to increase the use of solar cookers.
- Solar energy map for whole Nepal will be prepared
- Arrangement shall be made to collect the battery used in solar energy production for recycling or proper management.(Ministry of Environment, 2006)

Subsidy for Renewable Energy, 2000

Ministry of Science and Technology, Alternative Energy Promotion Centre of Nepal released renewable energy subsidy plan with the objectives to support rural electrification thus by protecting environment, and to attract donors and private sector entrepreneurs for investment in this sector.

- It has made the following subsidy provisions in the case of solar home system:
- Solar Home System (SHS)
- Subsidy will be provided to SHS of 10, 20, and 30 Watt peak or more from now onward.

- The maximum subsidy for SHS of 30 Watt peak capacity or more will be Rs 8,000 per system.
- Additional 50% and 25% subsidy per SHS system will be provided to the users in very remote and remote village development committees (VDC) of districts respectively.
- The SHS lower than 30 Watt peak will be provided subsidy up to 50% of their cost.
- However such subsidy amount will not exceed Rs.8000 per system.
- The subsidy amount mentioned above will be reduced every year by 10%.
- The subsidy for SHS installed in Public institutions, mainly school, club, health post/centre, VDC buildings, etc. will up to 75% of the cost. (Ministry of Science and Technology, 2000)

Energy scenario of Nepal

Nepal's total energy consumption in 2011/2012 was about 376.3 Giga Joule. Out of this, electricity contributed about 2.82 % to the energy consumption. Although the share is still small, it was only 1.82 % in the year 2005. Similarly, the share of Renewable energy in the national energy consumption for the year 2011/2012 was only 1.22%. (Water and Energy Commission Secretariat, 2014)

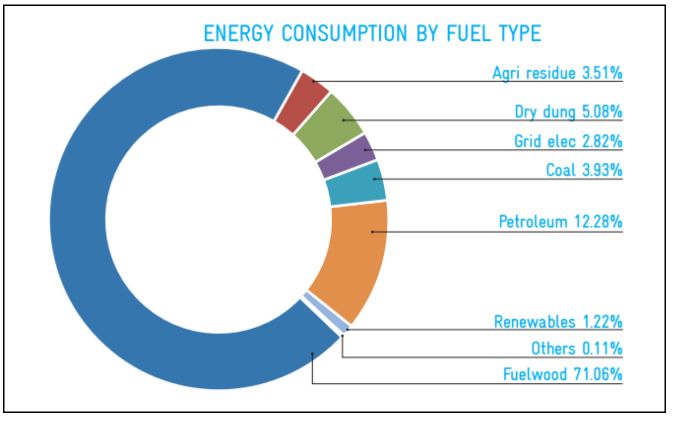


Figure 2: Energy consumption by fuel type

Source: (Water and Energy Commission Secretariat, 2014)

Similarly, according to the Energy Data Sheet published by WECS in June 2014, the energy consumption pattern in the residential sector is shown in the following graph:

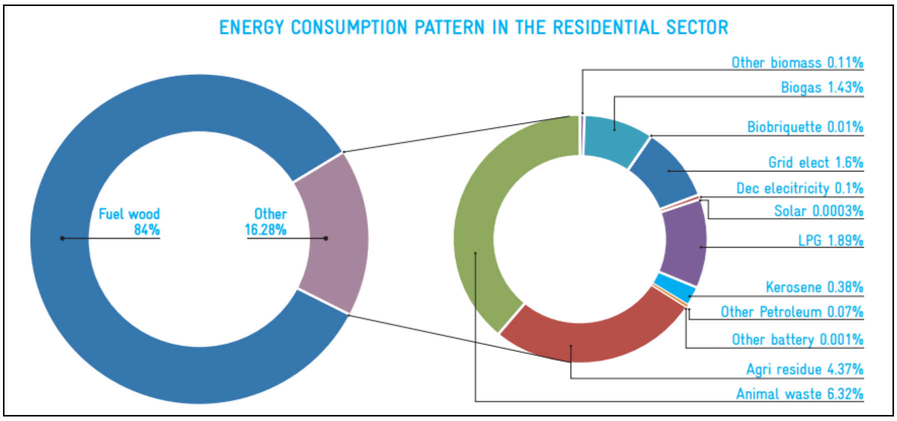


Figure 3: Energy consumption pattern in the residential sector

Source: (Water and Energy Commission Secretariat, 2014)

1.6.2. Institutional provision

Nepal Electricity Authority (NEA)

Nepal Electricity Authority (NEA), a state owned organization is responsible for the supply of electricity throughout the country through the national grid. NEA has the responsibility for the generation, transmission and distribution of electricity and the development and operation of the electricity grid.

The NEA is affiliated with the Ministry of Energy. It is headed by a Board of Directors, whose Chairman is the Minister for Energy. Further members include the Secretary of Finance, the Managing Director of the NEA, representatives from the industrial / banking / trade and consumer protection sector as well as energy experts.(Nepal Electricity Authority, 2015)

Alternative Energy Promotion Centre (AEPC)

Alternative Energy Promotion Centre (AEPC) is a Government institution established on November 3, 1996 under the then Ministry of Science and Technology with the objective of developing and promoting renewable/alternative energy technologies in

Nepal. Currently, it is under Ministry of Population and Environment. It functions independently, and has an eleven member board with representatives from government sector, industry sector and non-governmental organizations. (Alternative Energy Promotion Centre, n.d.)

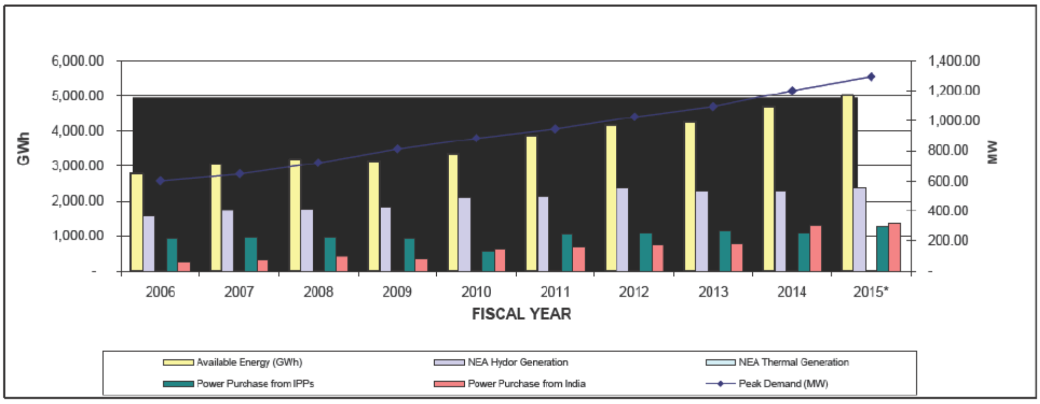
Water and Energy Commission Secretariat (WECS)

The Water and Energy Commission (WEC) was established by GoN in 1975 with the objective of developing the water and energy resources in an integrated and accelerated manner. Consequently, a permanent secretariat of WEC was established in 1981 and was given the name, Water and Energy Commission Secretariat (WECS). The primary responsibility of WECS is to assist GoN, different ministries relating to Water Resources and other related agencies in the formulation of policies and planning of projects in the water and energy resources sector. The objectives and mandates of WEC and WECS have been revised and modified a number of times since their establishment. (Alternative Energy Promotion Centre, n.d.)

1.6.3. Hydro power

A recent study conducted by the team of Institute of Engineering, Tribhuwan University Nepal and led by Prof. Narendra Man Shakya has shown that Nepal has a total potential to generate 53,000 megawatts of hydropower in Nepal. This team's estimate was based on the latest water discharge data available with the Department of Hydrology and Meteorology, using Geographic Information System. (KC, 2013)

According to the Annual Report of Nepal Electricity Authority, Released on 2015, the total number of consumers at the end of fiscal year 2014/15 grew by 5.75% and reached 2.87 million at the end of ficcal year 2014/15. Out of the total number of consumers; domestic, industrial and other remaining consumer categories accounted for 94..4%, 1.48% and 4.18% respectively. (Nepal Electricity Authority, 2015)



Particulars	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015*
Peak Demand (MW)	603.28	648.39	721.73	812.50	885.28	946.10	1,026.65	1,094.62	1,200.98	1,291.80
NEA Hydor Generation	1,568.55	1,747.42	1,793.14	1,839.53	2,108.65	2,122.08	2,357.43	2,273.11	2,288.23	2,365.64
NEA Thermal Generation	16.10	13.31	9.17	9.06	13.01	3.40	1.56	18.85	9.65	1.24
NEA Generation Total (GWh)	**1,584.65**	**1,760.73**	**1,802.31**	**1,848.59**	**2,121.66**	**2,125.48**	**2,358.99**	**2,291.96**	**2,297.88**	**2,366.88**
Power Purchase from India	266.23	328.83	425.22	356.46	638.68	694.05	746.07	790.14	1,318.75	1,369.89
Power Purchase from IPPs	930.04	962.26	958.42	925.74	591.43	1,038.84	1,073.57	1,175.98	1,070.47	1,268.93
Power Purchase Total (GWh)	**1,196.27**	**1,291.09**	**1,383.64**	**1,282.20**	**1,230.11**	**1,732.89**	**1,819.64**	**1,966.12**	**2,389.21**	**2,638.81**
Available Energy (GWh)	**2,780.92**	**3,051.82**	**3,185.95**	**3,130.79**	**3,351.77**	**3,858.37**	**4,178.63**	**4,258.08**	**4,687.09**	**5,005.69**

Note :- Peak demand is for all areas covered by integrated system including supply to India
* Provisional figures

Figure 4: Electricity consumer growth trend

Source: Annual Report of Nepal Electricity Authority, Released on 2015

1.6.4. Solar Energy

Solar energy is one of the best energy solution which is abundant and works without polluting the environment. The technology for utilizing solar energy is advancing day by day and is becoming affordable.

Solar energy is transmitted to the Earth in the form of electromagnetic radiation, which is comprised of photons(Foster, Ghassemi & Cota, 2009). The amount of irradiance reaching a location on the Earth's surface over a specific time period varies depending on global, local, spatial, temporal and meteorological factors(Redweik, Catita & Brito, 2013).

Achieving an accurate estimation of daily, monthly or yearly global solar radiation reaching the Earth's surface is of great importance when developing solar energy resources, especially when determining the optimal location for placing photovoltaics (Rehman & Ghori, 2000). Identifying suitable sites for solar panel placement is beneficial not only ecologically by considering environmentally sensitive areas and land accessibility, but also economically by analyzing energy production potential, existing transmission system, and the solar power market(Gastli & Charabi, 2010).

Nepal is blessed with solar resource and has huge potential to harness the energy. It has on average more than double the solar isolation (kWh/m2/day) than Germany - the world leader in PV installations. In the last five years, the total PV installed in Germany has soared from 6 GWp to 36 GWp. (Shrestha & Shrestha, 2014)

In Nepal, average solar radiation varies from 3.6 to 6.2 kWh/m2 per day; while the total sun shines days is about 300 per year. According to July 2008 assessment of solar and wind energy in Nepal, the commercial potential of solar power for grid connection is about 2,100 MW. Since solar electricity generation systems are easy and quick to install, are very attractive option in many locations in the county. Keeping in line with the Government of Nepal (GON) strategies, the proposed pilot projects of grid-connected solar power generation as a short term opting is being considered for financing by the World Bank. Historically, Nepal's power sector has been dominated by NEA, a 100% Government owned utility. NEA has shown recently interest in PV grid tied system. However in past it had successfully installed only standalone solar system 50 kW at Gamghadi and another 50 kW at Simikot. (Nepal Electricity Authority, 2013)

Japan International Cooperation Agency (JICA) has recently installed 680.4 kWp Grid tied solar system in Sundarighat in 2012 which is operating successfully. (Shrestha & Shrestha, 2014)

1.6.5. Solar energy collection system

The sun is never lasting and abundent source of energy. From the very beginning of the mankind history, sun has become an unavoidable source of energy. Researchs have contributed to the identification of various application areas which is ongoing these days as well. In this modern era, on of the major use of solar energy is to generage electric power by using solar cells to convert energy from the sun, which is termed as photovoltaics.

Photovoltaics research and development has accelerated towards the identification and development of new meterials, cell designs, and novel approaches to solar material and product development. This development in solar energy collection system and continious decline in price has made it affordable due to which it is within the reach to general households as well.

Solar energy can be utilized to generate energy mainly by two different technologies:

a) Photovoltaic (PV) Cell Technology : Discovered in 1839 by Henri Becquerel, the photovoltaic effect allows light energy to be transformed into electricity. This principle is based on semiconductor technology. It consists of using photons to free electrons and create a potential difference across the cell, which generates a continuous electrical current.(Synergie, 2011). This system relies upon the direct conversion of solar radiation into electricity using semiconductors that exhibit a photoelectric effect, such as crystalline silicon or different combinations of thin-film materials .

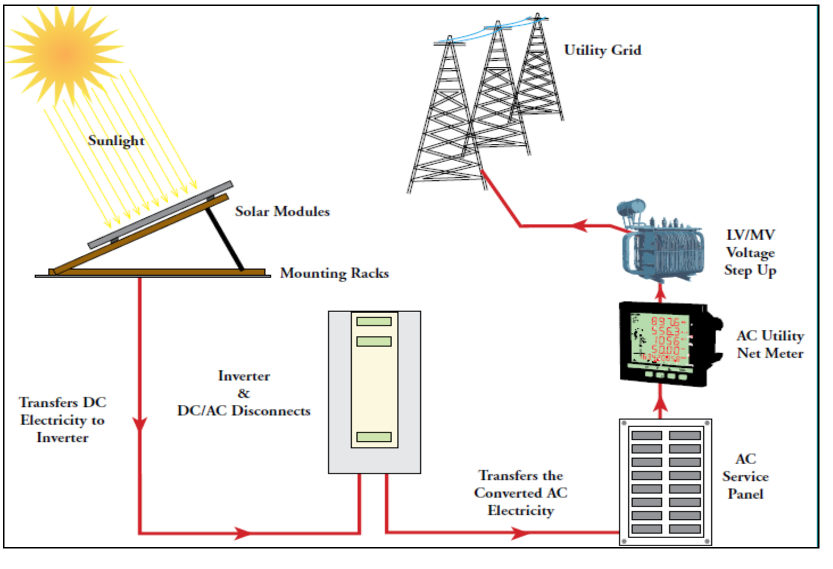


Figure 5: Overview of Solar PV Power Plant

(Source: Utility scale solar power plants; A guide for developers and investers, Feb 2012)

b) Concentrated Solar Power (CSP) Technology relies on concentrating the solar radiation, using lenses and mirrors onto a small area. The concentrated light/heat is then used as a heat source for a conventional power plant; this phenomenon is known as solar thermo-electricity(Muneer, 2011).

Since the focus of this thesis is restricted to electricity generation through PV cells, the following sub-section discusses the elements of a PV system and its various applications throughout the world.

1.6.6. Elements of a Solar PV System

PV cells are the building blocks of a PV system as they utilize the photoelectric effect to convert sunlight into electricity. Although crystalline silicon PV cells are the earliest and most successful PV devices used largely in the world today, they are being gradually replaced by the cheaper thin-films or ribbons, mainly composed of Cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIGS), amorphous and microcrystalline silicon, etc. Generally, PV cells are a few inches across in size and are connected together to form PV modules which are typically 1 square meter in size. These PV modules may be connected and/or combined to form PV arrays which yield a desired output These PV modules represent the core of any PV system.

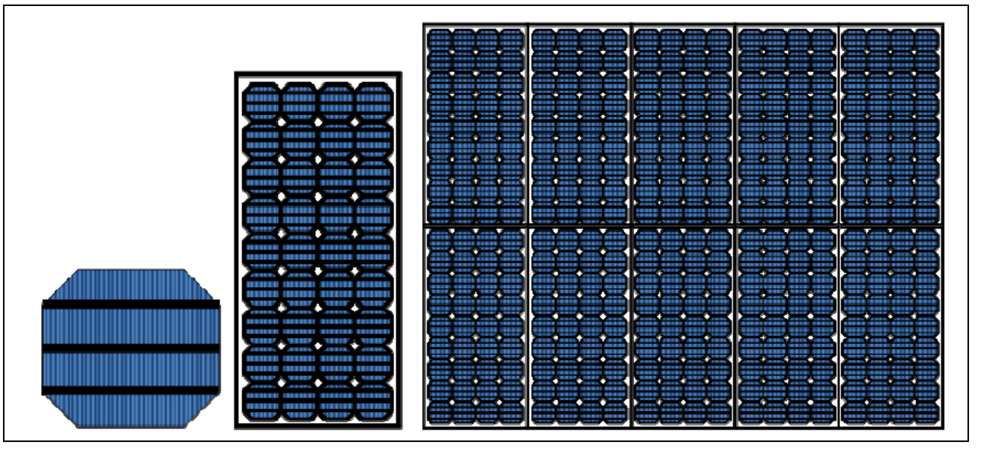


Figure 6: Depiction of PV system modularity

However, a PV system cannot be complete without the balance of system conponents, which include, power conditioning equipment (inverters, maximum power point trackers, etc.); mounting hardware, electrical connections and if required, batteries. Depending on the size of the system, type and positioning of the power conditioning equipment, the need for energy storage, grid-interconnection standards/policies, efficiency and overall system costs, there exists a variety of PV system topologies such as central. string, multi-string and ac-module topology.(Muneer, 2011)

1.6.7. Geographical information system (GIS)

A geographic information system is designed to capture, store, display, communicate, transform, analyze, and archive georeferenced information, that is, information tied to specific locations on the Earth’s surface. Geographic information systems enhance and to some extent replace the traditional role played by maps, but are also capable of handling information in the form of satellite images of the Earth’s surface, as well as information from surveys and administrative records that have been georeferenced. (Goodchild, 2009)

GIS is used in almost every study areas where location is envolved. To name few, survey, education, agricultrue, natural resource management, disaster management, public safety, land management and planning are examples of areas where GIS is used as a baseline tool for planning, designing, reporting and similar activities.

GIS and Site selection

Before the widespread availability of computational mapping technologies, planners relied heavily on hand drawn depictions derived from multiple sources often shown at varying scales.

A single map is not sufficient to make a decesion on site assessment and selection. Various factors and reliable information sources have to consulted to itentify geographic relationships, implications, cost-benefits and suitability. GIS incorporates a complete set of tools, information, data and procedures which can help in the strategic planning and selection of sites for targeted purpose.

The modern GIS tools are capable to analyze, classify and categorize spatial data which are fundamental feature required in site selection.The GIS-based approach to land-use suitability analysis stems from the application of land drawn overlay techniques used by American landscape architects in the late nineteenth and early twentieth century.

1.6.8. GIS and multi-criteria decision modelling

GIS has been used more often as an analytical tool, representing mathematical relationships between spatial data, such as map layers with various information The newest use has been the application of GIS as a decision support system in multi-criteria decision analysis methods (MCDA) or multi-criteria analysis (MCA) through the coupling of GIS and MCDA software (Eastman, Jin, Keym, *et al.*, 1995)

It is hard to make decision when multiple criterion have to be considered. To make this job easier, Multi-criterion decision analysis methods have been developed to support complex decision making when multiple, conflicting factors are involved. The MCDA approach takes account of all criteria in a given issue, helps to structure the problem, provides a model which can be overseen and offers a process that leads to a rational, validated decision.

The combination of GIS tools with MCDA techniques provides a support for the decision maker in all stages of a decision process, such as design, choice and visualization (Malczewski, 1999)

The first step of an MCA process is to formulate problems of project, and to establish a set of criteria that will form a basis for the project requirements (San Cristóbal, 2012). The next step is to determine priorities of criteria by assigning weights that show the relative importance of criteria in MCA (Wang, Jing, Zhang, *et al.*, 2009). After this, a multi-criteria method is selected and applied to rank alternatives, and then finally propose optimal solution based on the best ranked alternative (Wang, Jing, Zhang, *et al.*, 2009). This framework makes its contributions through decision-aiding science, formulating recommendations, while decision makers maintain their freedom to make choices. The final decision belongs to the decision makers regarding how to interpret the scientific conclusions (Haurant, Oberti & Muselli, 2011)

1.6.9. Analytical Hierarchy Process (AHP)

Different rules can be applied during the MCA decision-making process. The weighted product method (WPM), weighted sum method (WSM), fuzzy set method, and analytical hierarchy process (AHP) are the commonly used approaches (e.g., (Gastli & Charabi, 2010; Wang, Jing, Zhang, *et al.*, 2009). In particular, AHP is used to combine the priority for all levels of the hierarchical structure(Gastli & Charabi, 2010). According to (Pohekar & Ramachandran, 2004; Wang, Jing, Zhang, *et al.*, 2009), AHP is the most popular method for prioritizing the alternatives for its understandability in theory and the simplicity in application.

Calculation of Incoming Solar Radiation

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). For the high performance and longivity of Solar power production plant, it must be instulled in the site with higher solar irradiation in order to generate adequate electricity for supporting energy demands. This depends on the average level of sun exposure that a site experiences throughout the year. According to research studies, solar radiation striking a specific location on the Earth’s surface can be measured or estimated by different methods depending on the types of data available:

a. Geostatistical Techniques: Solar radiation data obtained from dispersed weather stations are utilized to generate a solar radiation map by using geostatistical techniques.(Rehman & Ghori, 2000)

b. Multivariate Statistical Methods: By the use of Artificial Neural Networks(ANN) and Radial Basis Function(RBF) networks for estimating solar radiation in locations where collection equipment is not available(Sfetsos & Coonick, 2000).

c. LiDAR point cloud data : Three-dimensional LiDAR point clouds have been successfully used as inputs to solar radiation estimation models. These models can be implemented and computed within commercial or open-source GIS solutions, such as SAGA GIS(Redweik, Catita & Brito, 2013).Well known models include the solar analyst in ArcView, spatial radiation tools in ArcGIS, and GRASS r.sun (Charabi & Gastli, 2011a; Redweik, Catita & Brito, 2013)

d. Satellite Imagery : Geostationary satellites, such as METEOSAT 7 and Geostationary Operational Environmental Satellite (GOES), perform continuous and reliable meteorological observations from space; thus, they provide the opportunity to derive information on the solar irradiance for a large area.(Broesamle, Mannstein, Schillings, *et al.*, 2001)

For the purpose of this thesis work, Area Solar Radiation tool developed by ArcGIS (Spatial Analyst) has been used. This tool is based on the LiDAR point cloud data methodology. Solar PV systems are gaining popularity in many parts of Nepal. The estimated market potential is huge and about 8278.9kW of PV power is currently being used in various public and private sectors in Nepal(Alternative Energy Promotion Centre, 2010). On average Nepal has 6.8 hours of sunshine per day with the intensity of solar insolation ranging from 3.9 to 5.1kWh/m2 (national average is about 4.kWh/m2/day. (Shrestha & others, 2006)

1.7. Outline of the thesis

This thesis consists of four chapters in total. The contents in these chapters are outlined as follows:

Chapter 1: It introduces the research work along with research problem and motivation. Objectives and limitation of study are also discussed here. Study area and literature review concludes this chapter.

Chapter 2: This chapter revolves round the Data and methodology of this research work. It covers various related topics such as data types, data sources, software used, research methodology, data processing and other related subtopics.

Chapter 3: Method, result and discussion are covered in this chapter. The detail method followed along with the result are housed in this chapter.

Chapter 4: This is the concluding chapter of the whole research work. It contains the conclusion of the work with recommendation for future works.

Chapter 2. Data and Methodology

2.1. Data Types and Data Sources

The data for this study were obtained through a variety of sources and had a variety of spatial references. All of the acquired data were projected to the **MUTM Everest Geographic Coordinate System** of the Central Meridian 84.

The data used for this study are as follows:-

S.N	Description	Data type	Source Projection	Source
1.	DEM	Raster	WGS84	Data provider: NASA/METI Name of Sensor: ASTER **Type of sensor:** Global DEM (GDEM) Product format: GEOTIFF **URL:** http://earthexplorer.usgs.gov/
2.	Land use / land cover	Vector	Everest 1830	Dept. of Land use
3.	Roads	Vector	WGS84	ICIMOD
4.	Aspect	Raster	Everest 1830	Derived from DEM
5.	Slope	Raster	Everest 1830	Derived from DEM
6.	Solar Radiation	Raster	Everest 1830	Derived from DEM, cross verified with data from Department of Hydrology and Meteorology, NASA

Table 1: Description of data used for the study

2.2. Software Used

ArcMap 10.2 has been used throughout the whole process to apply various operations on the data files. AHP v2 is specifically used for the weight setting of factor criteria. Google Earth, Microsoft Office 2013 and Adobe Acrobat are other software used during the study period.

2.3. Research Methodology

This study is oriented towards the identification of most suitable land in Kathmandu Valley for the construction of Solar Energy Collection Plant. For this purpose, DEM of Kathmandu valley along with road data, solar radiation data and land use/land cover data are used.

The major operations performed over the DEM of Kathmandu valley are to create Aspect, Slope and Solar Radiation data. Finally these are reclassified before performing weighted overlay operation.

Similarly, Land use/Land cover (LULC) data was also reclassified. Road data was processed in order to get the Euclidean distance and finally they were reclassified.

In the weighted overlay process, Aspect, Slope, Solar Radiation, LULC and Road data were used. AHP is applied as influence factor for each layer. The restricted areas in the LULC layers along with their buffer were identified and then weighted overlay analysis was performed. Finally different classes of suitable sites were identified and separated.

The whole process has been depicted in the flowchart diagram below:

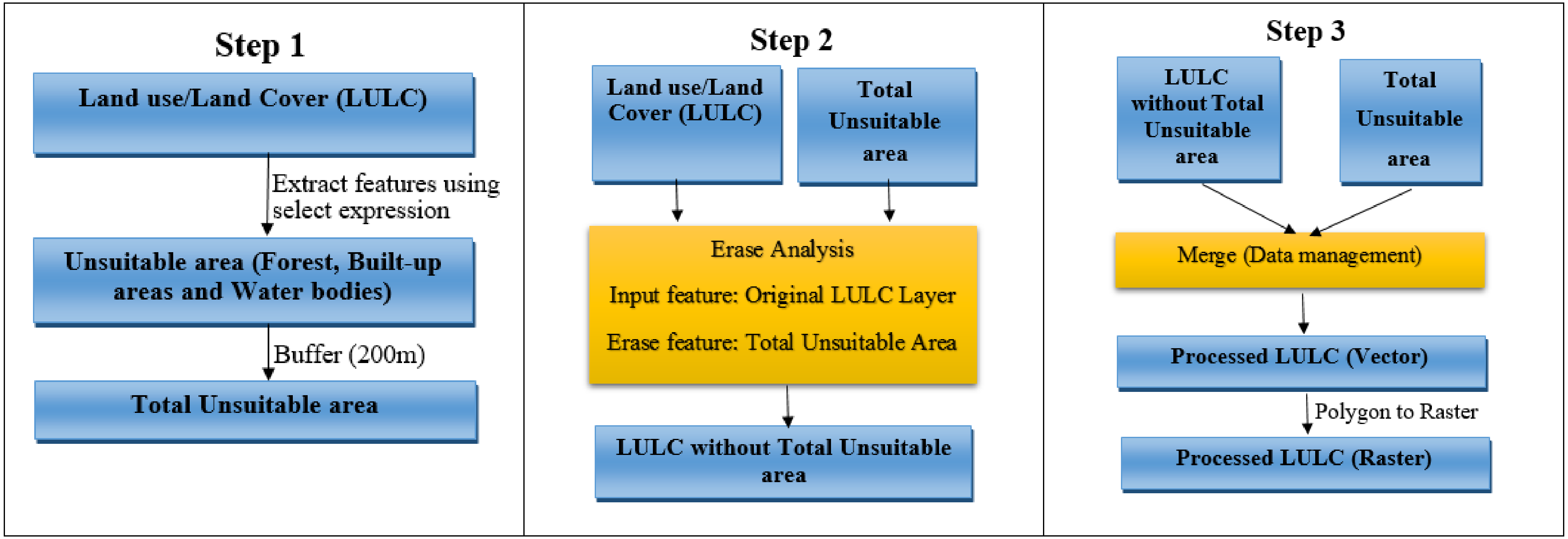


Figure 7: LULC data preparation process flow diagram

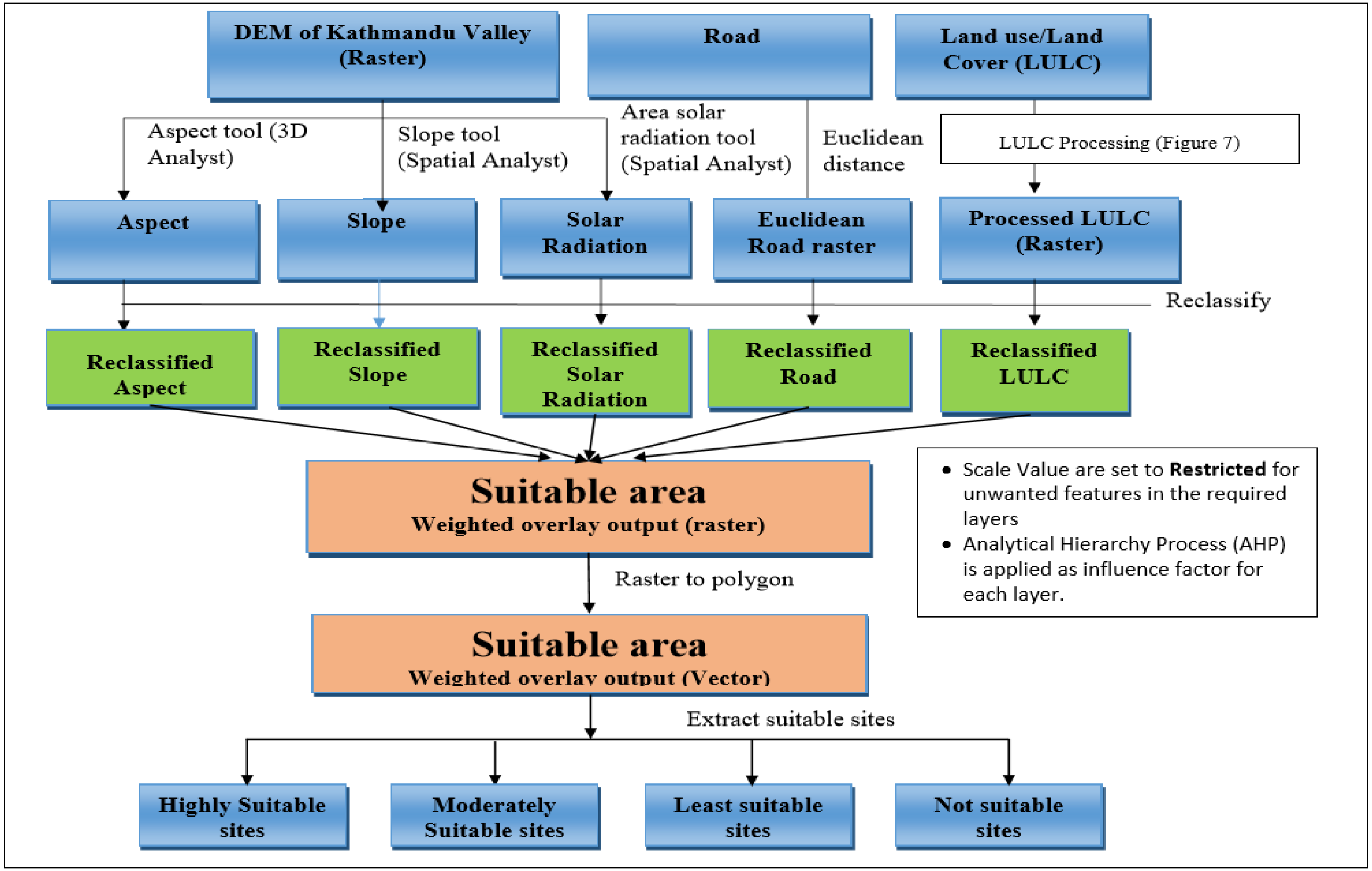


Figure 8: Process flow diagram of research work

2.3.1. Spatial multi-criteria analysis

GIS applied on site selection: GIS is an innovative integrated technology base on many disciplines such as Computer science, Geography, Cartography, Statistics, Remote sensing, Land surveying and Navigation. With a period of nearly 50 years of development, together with the popularization of the Internet, GIS has been widely immersed in the people's daily life like Global Positioning System (GPS) navigation. In the Land Management domain, GIS has been applied efficiently to deal with the geo-spatial data for screening and evaluation, facilitating the optimal site selection. A number of tools are available to determine the optimum site (Witlox, 2005).

Traditional methods of GIS site selection are based on the transformation of effective layers into a classified map, such as using a Boolean model (Louviere, Hensher & Swait, 2000) or Index Overlay operations (((Nikolakaki, 2004),(Alesheikh, Soltani, Nouri, *et al.*, 2008), (Alesheikh & Sadeghi Naeeni Fard, 2007),(Kallali, Anane, Jellali, *et al.*, 2007)). Nowadays, the GIS approaches used in the site selection usually are network analysis, spatial analysis, proximity analysis, MCA with AHP, FAHP or ROM, etc. In the case of this study, GIS-based MCA with AHP is utilized.

2.3.2. Analytical Hierarchy Process (AHP)

AHP, which was proposed by (Saaty, 2008), is a structured technique for decision making based on a hierarchical framework constructed through mathematical pairwise comparisons. The weights for the decision making criteria are derived from the pairwise comparisons of the relative importance between each two criteria (the sum of the weights equals to 1). (Saaty, 2012) portrayed a scare for the pairwise comparisons, where the judgments are represented by a degree of importance (Table 1). The reciprocals of the numbers are adopted to represent the inverse relationship (Vahidnia, Alesheikh & Alimohammadi, 2009).

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

Table 2: Scale for pairwise comparisons

It is necessary to verify the consistency after the gaining of weight values (Chen et al., 2010). The consistency index (CI) and consistency ratio (CR) are depicted as Equation (1) and Equation (2) below:

$$CI = (\lambda_{max} - n) / (n - 1) \qquad (1)$$

Where n = the number of the criterion,

λ_{max} = the biggest eigenvalue of the comparison matrix.

$$CR = (CI)/(RI) \qquad (2)$$

Where RI = a constant corresponding to the mean random consistency index value based on n.

The AHP procedure generally is consisted of six steps ((Lee, Chen & Chang, 2008); (Hosseinali, Alesheikh & others, 2008)):

1. As for the initial unstructured problem, define it and make the aims clearly as well as be sure what results expect to get.
2. Analyse the complicated problem, set the elements influenced into specific criteria.

3. Apply pair wise comparisons among these criteria to set up the comparison matrices.
4. Adopt some methods such as Eigen value method to estimate these criteria's relative weights.
5. Check the consistency ratio of the matrices to make sure it is ok for the weight settings
6. Determine the most appropriate weight settings and get an overall rating for these criteria.

Nowadays, AHP has been extensively studied and refined in a wide variety of decision situations, in fields such as administration, commercial and industrial activity, public health and education ((Boroushaki & Malczewski, 2008); (Wallenius, Dyer, Fishburn, *et al.*, 2008); (Linkov, Satterstrom, Steevens, *et al.*, 2007); (Mohajeri & Amin, 2010); (Raharjo, Xie & Brombacher, 2009); (Saaty, 2008)). As in the MCA, it is especially important to determine the criteria weights, and the AHP is very popular mathematical approach to settle the problem of complexity. In the GIS domain, AHP is typically used with MCA for site selections or land suitability evaluations.

2.3.3. Multi-Criteria Analysis (MCA)

MCA is a procedure that typically multiplies conflicting criteria that are essential to be evaluated in decision-making. It has a wide application whether in our daily lives or in professional settings. As (Charabi & Gastli, 2011a) elaborated, "The principle of the MCA is to condense complex problems with multiple criteria into finest ranking of the best scenarios from which an option is selected". The criteria are weighted according to their importance, and their weights have a more or less favourable influence on the final decision than another (Diakoulaki & Karangelis, 2007).

GIS-based MCA includes two essential parts: factor criteria and constraint criteria. Each of the criteria is introduced as a map layer irrespective whether it is a factor or a constraint criterion. Factor maps are represented as spatial distributions to display the opportunity criteria and the quality of achieving an objective. Constraint maps are limitations or restrictions which prohibit certain elements to be taken into account the analysis (Malczewski, 1999). Correspondingly, the GIS-based MCA includes two major methods: weighted summations procedures and Boolean overlay operations (Charabi & Gastli, 2011a).

As for the weighted summations procedures, the weighted linear combination of factor criteria is shown as Equation (3) below:

$$S = \Sigma W_i f_i \quad (3)$$

Where S = Suitability to the objective being considered,

W_i= Weight of factor i [the sum of all weights equal 1],

f_i = Criteria score of factor i.

As for the Boolean overlay operations, the formula for the constraint criteria is depicted in Equation (4) as following:

$$C = C_1 * C_2 * \ldots * C_n \quad (4)$$

Where C = Integrated constraint

C_n = Criteria score of constraint n

After the factor criteria and constraint criteria being settled separately, the GIS-based MCA process integrates them together by multiplying S with C, and gets the final result.

2.3.4. Data processing

Considering the GIS methods to be used in this study, the data need to be converted to raster format before multiplying them to get the results. In this study, the cell size value 30 m of the original DEM data is set as the unified cell size. Several layers have to be pre-processed. After being overlaid, conversion from shape file to raster, making them easier to be reclassified in the further data processing needs to be carried out.

All the data obtained for this study were first converted to the Everest 1830 Geographic Coordinate system through custom made geographic projection in the Data Management Toolset in ArcGIS.

By utilizing the ArcGIS tools such as Aspect, Slope, Area Solar Radiation, the main criteria are extracted from the DEM data. There are altogether four factor criteria (slope, aspect, solar radiation and distance from road) and one constraint criteria (Land use/ Land Cover) that are taken into account for further processing such as reclassifying the maps and unifying scales.

2.3.5. Criteria Setting

a) Factor criteria:- A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration

The five factor criteria include:

Slope: Constructing Solar Energy collection system in places with high slopes has many demerits like risks of soil related hazards and high expense in construction of roads to the site. Hence, the flatter the slope or lesser the elevation gradient of the location, the better it is suited for a construction site.

Aspect: It is another determining factor for the selection of site that is most suitable for installing solar PV modules. Out of the nine different directions (N, NE, NW,E, SE, S, SW, W, and flat areas) the direction with highest solar exposure are given higher importance.

Solar Radiation: The amount of incoming solar radiation determines the amount of electricity that a particular PV module can generate. Though sun is abundant all around the world, its intensity and hours of sunshine per day makes difference in solar insolation. On average Nepal has 6.8 hours of sunshine per day with the intensity of solar insolation ranging from 3.9 to 5.1kWh/m2 (national average is about 4.kWh/m2/day (Shrestha & others, 2006)

Distance from Road: Sites having easy access to roads are suitable for construction of Solar Energy Power Plant .Roads facilitate transportation of construction materials easy and help in transportation of maintenance personnel in cases of problems. Hence, the nearer to roads a site is, the better it is suited.

The specific requirements for these factor criteria are shown in the Table below:-

Factor	Setting
Slope	The flatter the slope, the better.
Aspect	Direction with highest solar exposure are better
Solar Radiation	Area having higher solar insolation is better
Distance from Road	The nearer to road, the better.

Table 3: Factor criteria setting

b) **Constraint criteria:** A constraint serves to limit the alternatives under consideration; element or feature that represents limitations or restrictions; area that is not preferred in any way or considered unsuitable. The constraint criteria Land Use/ Land Cover (LULC) is included in this study in order to account for the selection of suitable location and hence some of the categories in LULC are to be excluded while considering sites suitable for locating solar PV installation site.

Constraint	Setting
LULC	Forest, Water bodies and built-up areas along with 200 meters buffer from each of these are considered as Unsuitable area.

Table 4: Constraint criteria setting

The criteria setting was done base on the reviewed literature from scholars. Summary of criteria used for solar panel installation site selection from reviewed literature are as follows:

Variable/criteria	Description	References
Slope	For industrial-scale PV installations the slope can be a very important economic/ technical criterion; the higher the gradient, the more investment is required to flatten the ground. A too high slope, or a disadvantageous orientation could result in the decrease of the PV units' efficiency	(Šúri & Hofierka, 2004)
Aspect	The aspect should be south facing or horizontal; solar panels located on south-facing slopes will have a higher solar power output than those located on north-facing slopes.	(Bravo, Casals & Pascua, 2007)
Direct Normal Irradiance or solar potential	The higher incoming solar radiation the better. Solar radiation data can be obtained or estimated by various approaches. It provides information of solar potential to area of interest	(Bravo, Casals & Pascua, 2007); (Pletka, Block, Cummer, *et al.*, 2007); (Clifton & Boruff, 2010)
Proximity to roads	Proximity to roads minimizes cost in infrastructure construction and maintenance but may contribute to vandalism, dust and other concerns	(Clifton & Boruff, 2010);
Land cover or land use profile	Solar PV power plants will ideally be built on low value land; Usability and availability of suitable land has to be considered with long term economic and environmental impact	(Bravo, Casals & Pascua, 2007);(Pletka, Block,Cummer, *et al.*, 2007); (Charabi & Gastli, 2011b)

Table 5: Criteria setting based on reviewed literature

Weight setting on the factor criteria by **Analytical Hierarchy Process (AHP)** was done using AHP (pairwise matrix comparison) software. The weightage and consistency index (CI) were calculate for the processing of the result.

Chapter 3. Method, Results and Discussion

3.1. Analytic Hierarchy Process (AHP)

We all make decisions. What we do in our everyday life is the result of some kind of decision that we make consciously or unconsciously. To make a decision, we gather information related to the subject of interest which helps us to understand the occurrence, factors, results and other similar factors about it.

Decision making, for which we gather most of our information, has become a mathematical science today(Greco, Figueira & Ehrgott, 2005). It formalises the thinking we use so that, what we have to do to make better decisions is transparent in all its aspects. A decision making process involves many criteria and sub-criteria which are ranked to get the best alternatives for a better decision making.

The **Analytic Hierarchy Process (AHP)** is a theory of relative measurement with absolute scales of both tangible and intangible criteria based on the judgment of knowledgeable and expert people. How to measure intangibles is the main concern of the mathematics of the AHP. In the end we must fit our entire world experience into our system of priorities if we are going to understand it. The AHP reduces a multidimensional problem into a one dimensional one. Decisions are determined by a single number for the best outcome or by a vector of priorities that gives an ordering of the different possible outcomes. (Saaty, 2008)

The ultimate objective of this study was to select most suitable site in Kathmandu Valley where solar energy collection plant could be installed. For this purpose, many criteria were considered and were compared, weighted and evaluated. The literature and researches performed in this domain by many researchers and scholars were instrumental in determining criteria for this study.

AHP consists of four steps.

1. Define the problem and state the goal or objective.
2. Define the criteria or factors that influence the goal. Structure these factors into levels and sublevels.
3. Use paired comparisons of each factor with respect to each other that forms a comparison matrix with calculated weights, ranked eigenvalues, and consistency measures.
4. Synthesize the ranks of alternatives until the final choice is made.

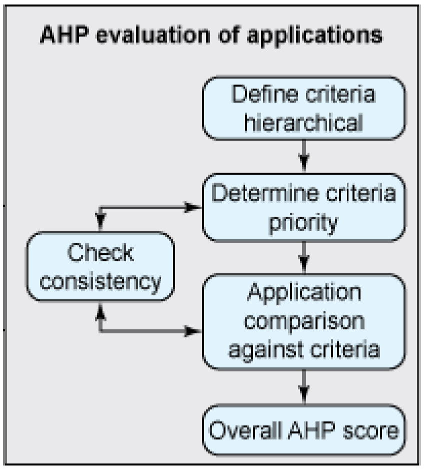


Figure 9: AHP evaluation process diagram

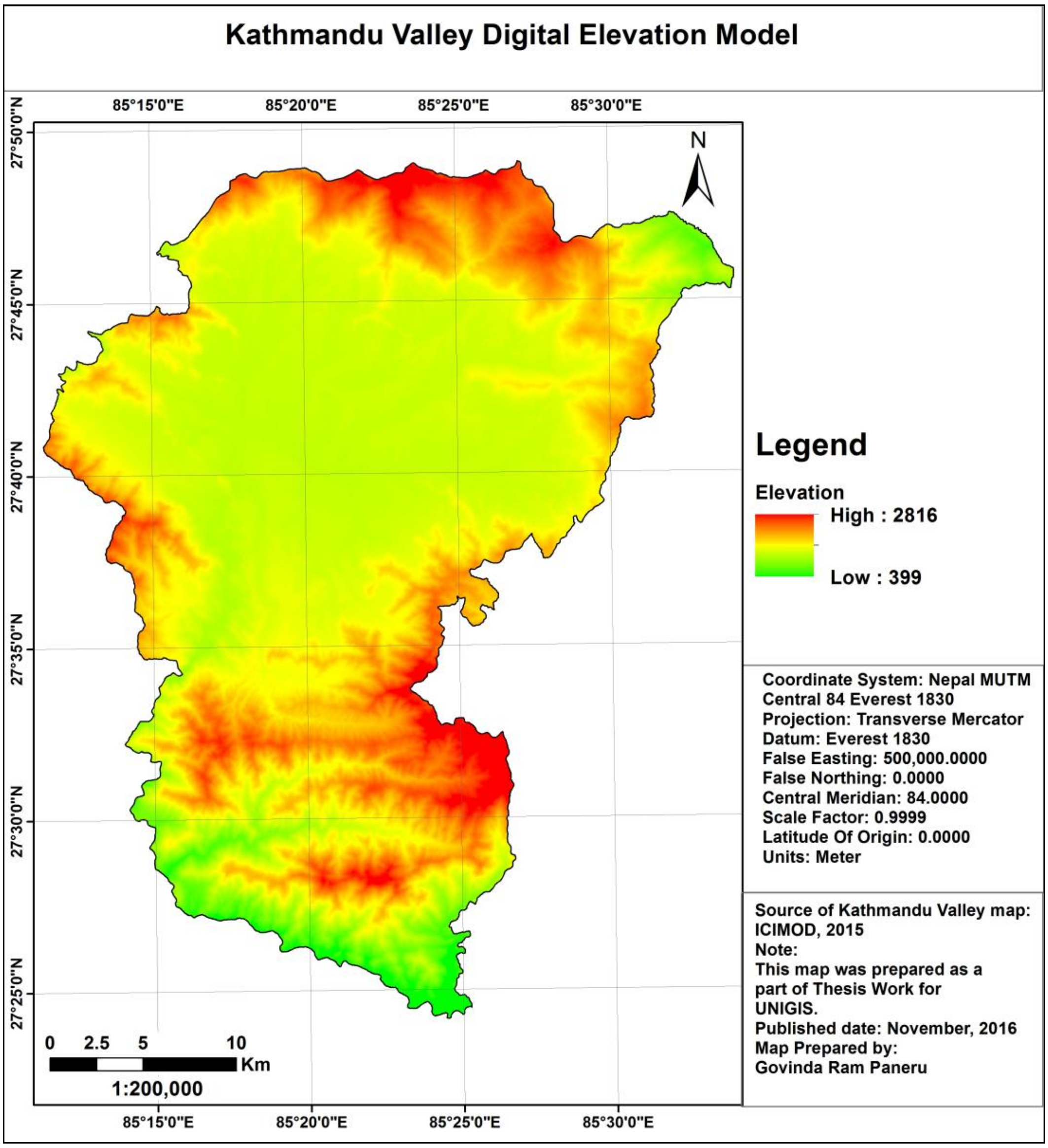
(Source: https://www.ibm.com/developerworks/cloud/library/cl-assessport/)

For this study, six criteria were considered. These criteria were studied in detail for their characteristics, advantages and effects on the construction of solar energy collection plant.

As shown in the flowchart diagram in Figure 7 above, slope, aspect and radiation raster were derived from the DEM of Kathmandu valley. Other two criteria; Road, and LULC data were used for AHP. The following sections describes the systematic approach that was taken using GIS to achieve the objectives of this study.

3.2. Digital Elevation model (DEM) of Kathmandu Valley

For the purpose of this study, DEM of Kathmandu valley was obtained from NASA/METI (http://earthexplorer.usgs.gov/). The sensor was ASTER Global DEM Using this DEM, Slope, Aspect and Solar Radiation raster data were obtained.

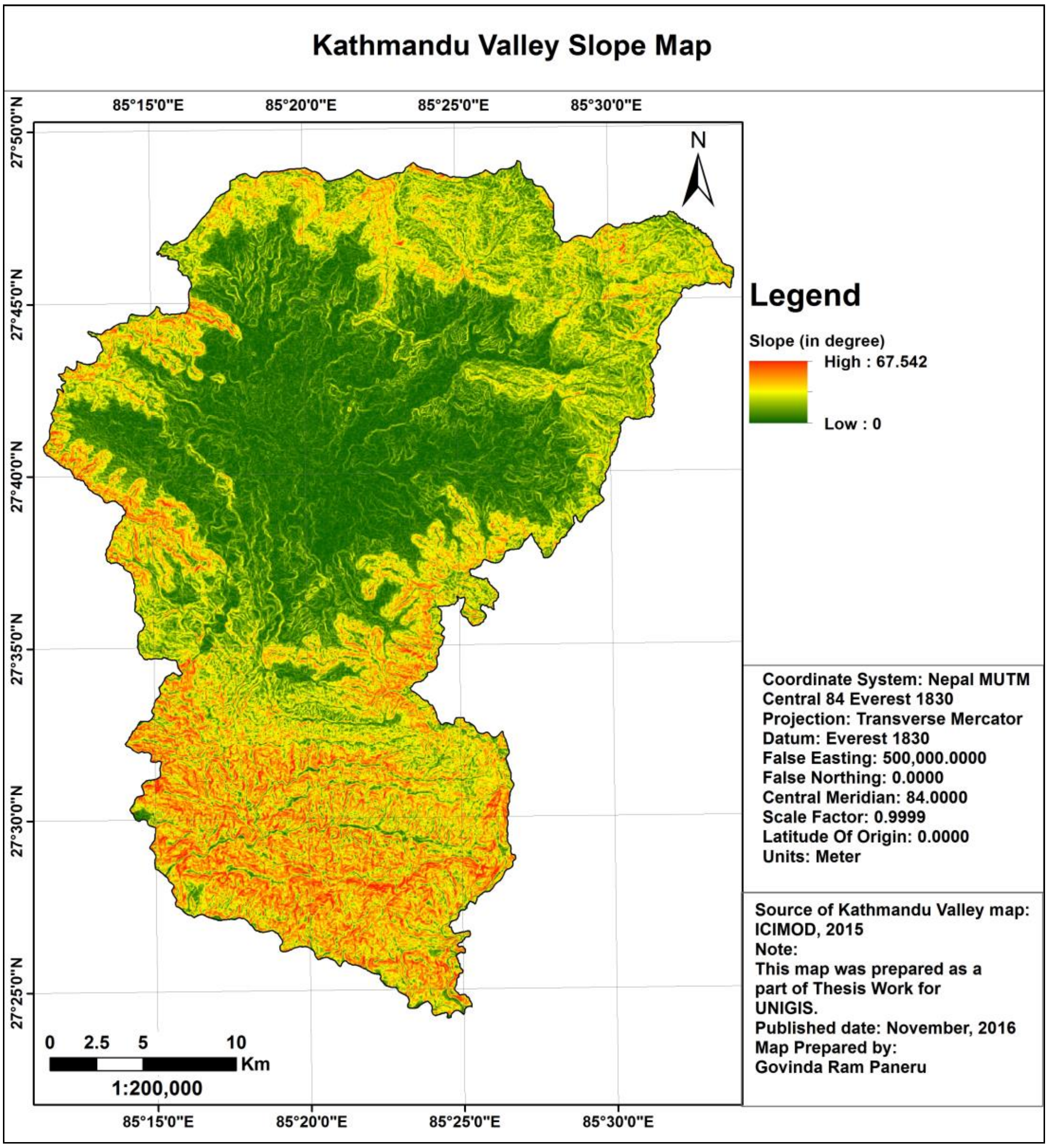


Map 2: Digital Elevation Model (DEM) of Kathmandu valley

3.3. Slope

The slope raster was obtained from the DEM of Kathmandu Valley Raster data. Slope tool in ArcMap was used to create Slope raster having resolution of 30 meters.

The slope of Kathmandu Valley ranges from 0 degree to 68 degrees which can be seen from the slope map below.



Map 3: Slope map of Kathmandu valley

Slope of land plays a vital role in the construction of any kinds of infrastructure. Moreover, the degree of inclination has major role in determining the intensity of solar radiation that hits the installed solar panel. In such case, selection of best angle of elevation is a key in obtaining the optimum result.

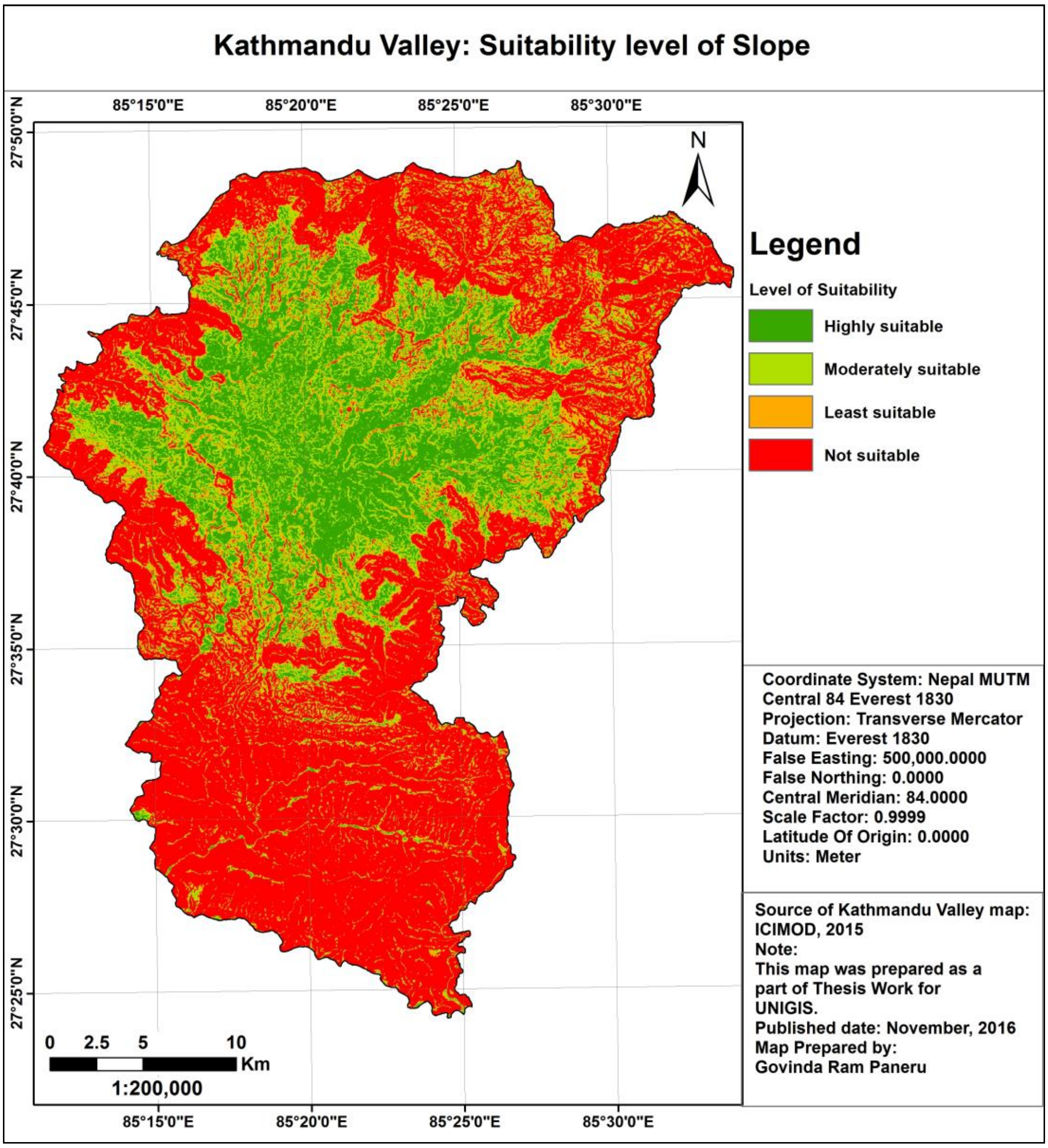
For this reason, the slope of land in Kathmandu valley were reclassified according to the reviewed literature and corresponding slope raster was obtained.

Reclassification of Slope

S.N	Degrees	Reclassified values	Suitability ranking
1	0-5	4	Highly suitable
2	5 - 10	3	Moderately suitable
3	10 - 15	2	Least suitable
4	>15	1	Not suitable

Table 6: Reclassification of slope values

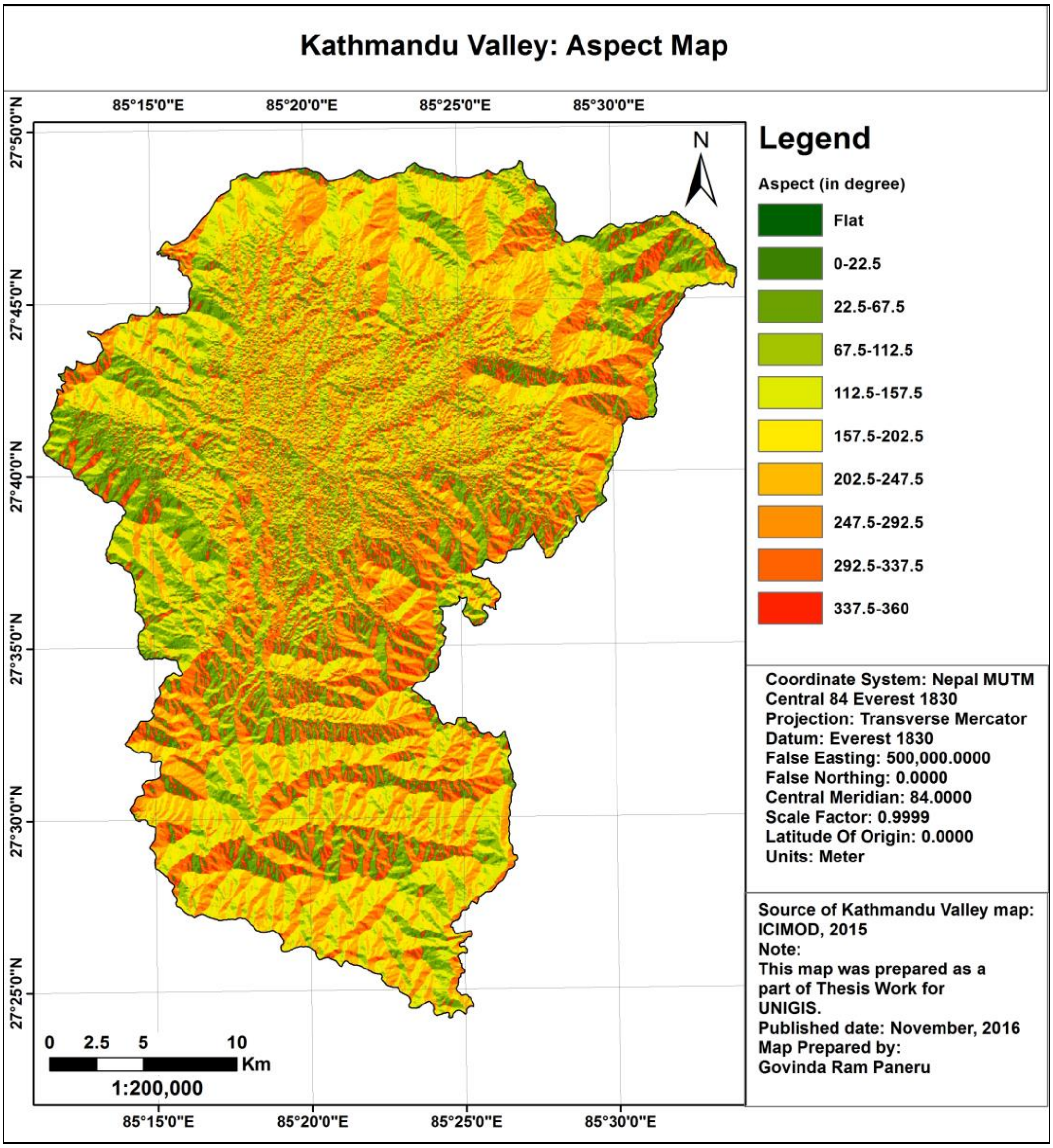
The following map shows the slope of Kathmandu valley after reclassification.



Map 4: Slope suitability map of Kathmandu valley

3.4. Aspect

The aspect raster was obtained from the DEM of Kathmandu Valley Raster data. Aspect tool in ArcMap was used to create aspect raster having resolution of 30 meters. In the aspect raster of Kathmandu Valley, each cell in the grid is assigned a number between 0 and 360, depending on the direction, in degrees, that the cell faces. Aspect value of -1 signifies the flat surface. Aspect is useful because it determines the solar potential of the particular area that are under considering.



Map 5: Aspect map of Kathmandu valley

Reclassification of Aspect

The aspect was then reclassified into four rankings for their suitability. For this, South direction was given the value 4 (Highly suitable) because south-facing areas will have a higher solar power output and North direction was given the value 1 (Not suitable). The following table shows the reclassified values along with the suitability ranking.

S.N	Direction / Degrees	Reclassified values	Suitability ranking
1	• Flat (-1) • South (157.5 - 202.5)	4	4- Highly suitable 3- Moderately suitable 2- Least suitable 1- Not suitable
2	• South East (112.5 - 157.5) • South West (202.5 - 247.5)	3	
3	• East-South East (90-112.5) • West- South West (247.5 - 270)	2	
4	• West-North West (270-292.5) • North West (292.5 - 337.5) • North (337.5 - 0; 0 - 22.5) • North East (22.5 - 67.5) • East - North East (67.5 - 90)	1	

Table 7: Reclassification of aspect values

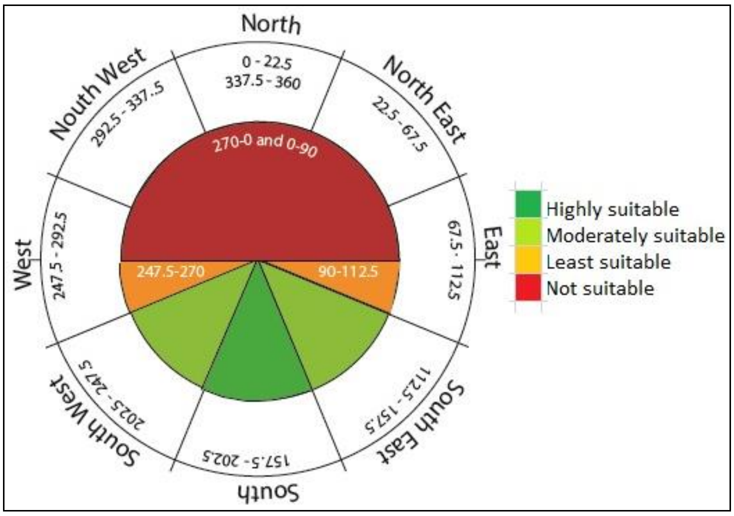
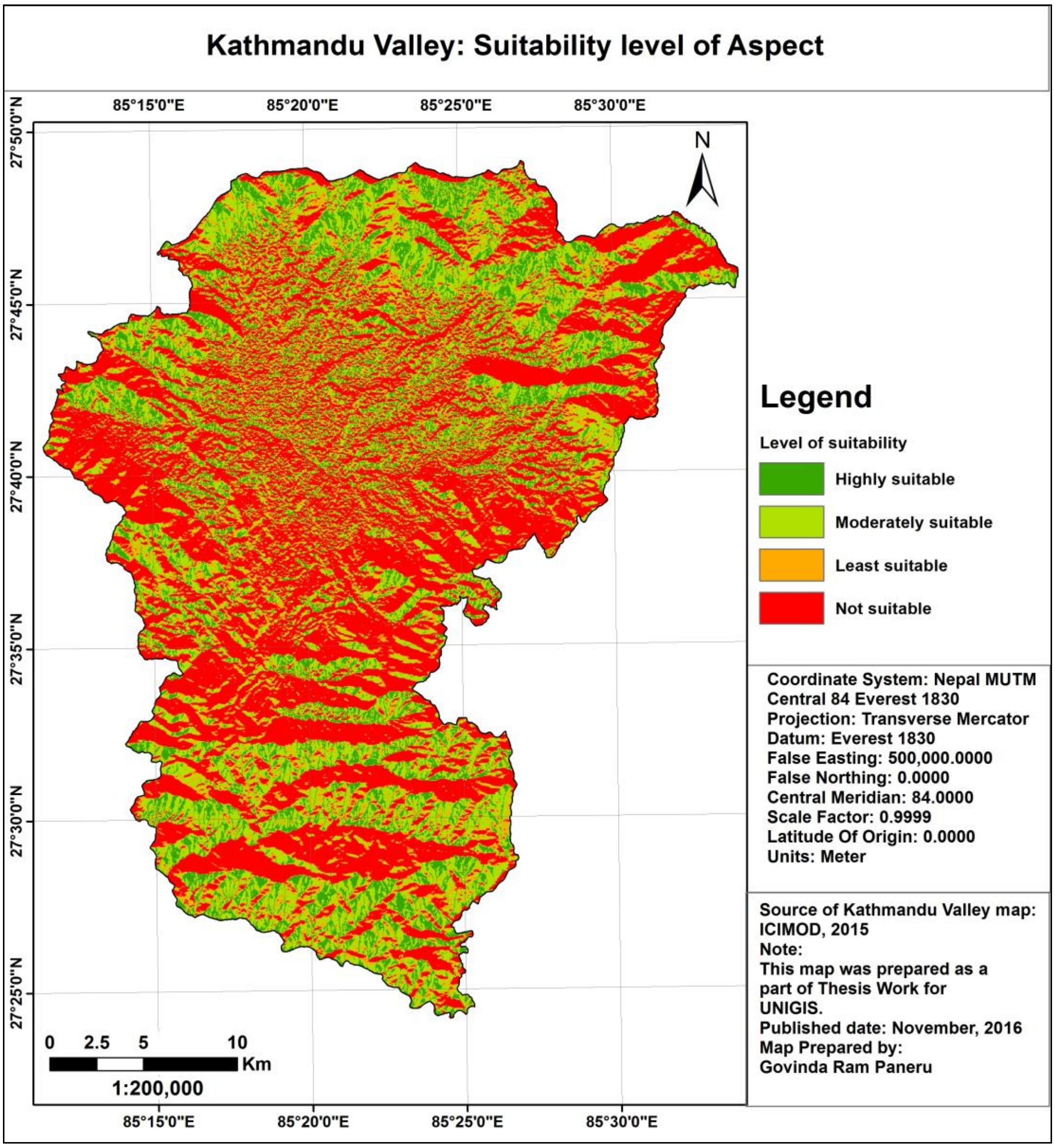


Figure 10: Aspect showing the degree of differences and suitability

The following map shows the Aspect map of Kathmandu Valley after performing the reclassification according to the above table.

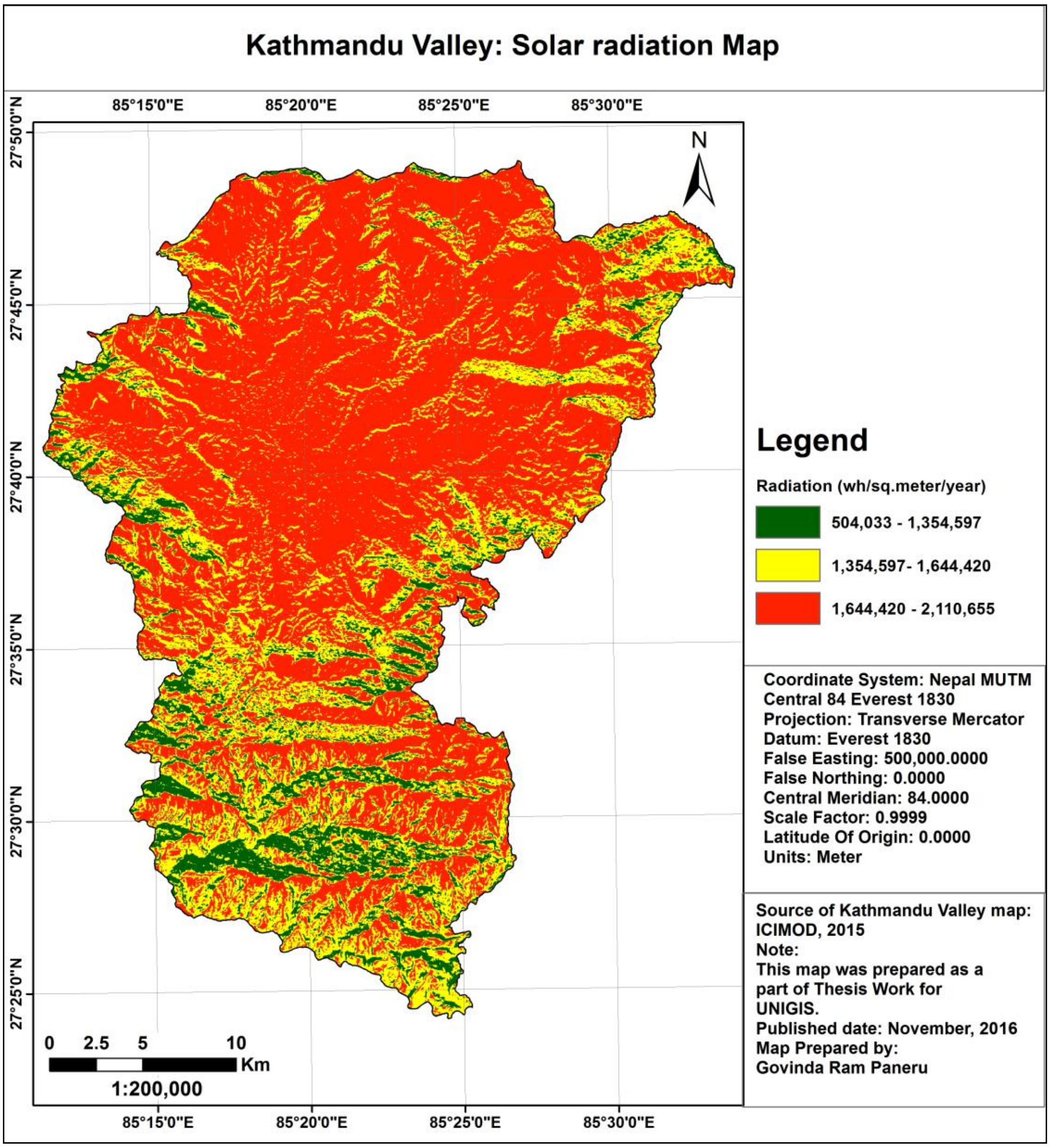


Map 6: Aspect suitability map of Kathmandu valley

3.5. Solar Radiation

The suitability of site for installing solar PV is highly determined by the amount of solar radiation that is received by that site. In case of Nepal, the national average solar insolation is found to be 4.66 kWh/m^2 per day (Adhikari, Gurung & Bhattarai, 2014) i.e. 1,70,00,900 wH/m^2 per year which indicates that Kathmandu valley is one of the potential sites for installing solar energy power plant. The Kathmandu Valley

DEM was used to derive solar radiation raster data for Kathmandu valley. **Area Solar Radiation** tool in ArcMap was used to create the solar radiation raster data.



Map 7: Kathmandu valley area solar radiation map

The solar radiation map of Kathmandu valley in the above figure shows the maximum of 2110665 wh/m^2/year and minimum of 504032 wh/m^2/year of solar radiation that is received.

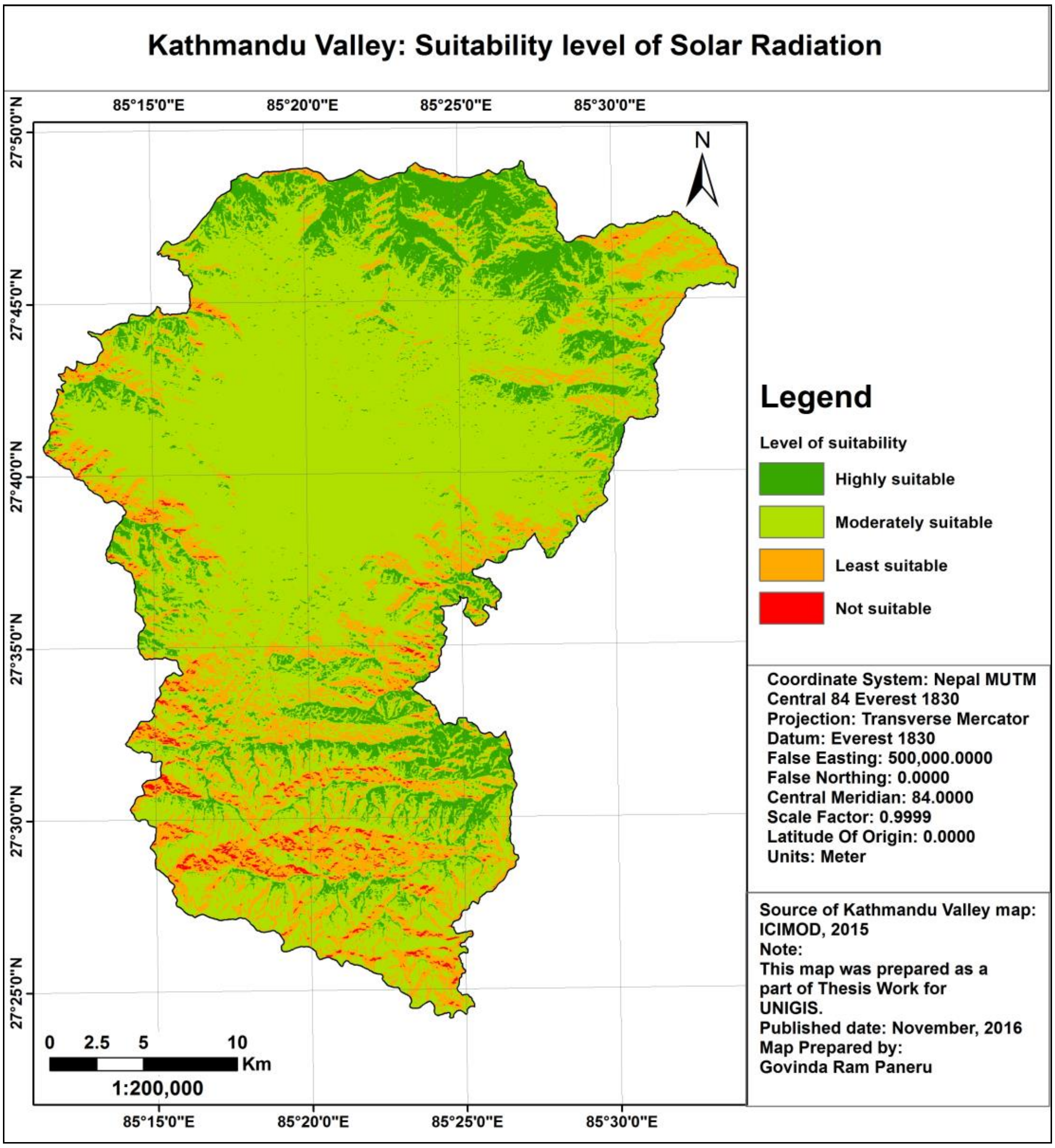
Reclassification of Solar Radiation

The solar radiation data was reclassified into four rankings for their suitability. The following table shows the reclassified values along with the suitability ranking.

S.N	Solar radiation (wh/m²/year)	Reclassified values	Suitability ranking
1	1800000 - 2200000	4	4 - Highly suitable
2	1500000 - 1800000	3	3 - Moderately suitable
3	1000000 - 1500000	2	2 - Least suitable
4	500000-1000000	1	1 - Not suitable

Table 8: Reclassification of Solar radiation values

The following map shows the Solar Radiation map of Kathmandu Valley after performing the reclassification according to the above table.

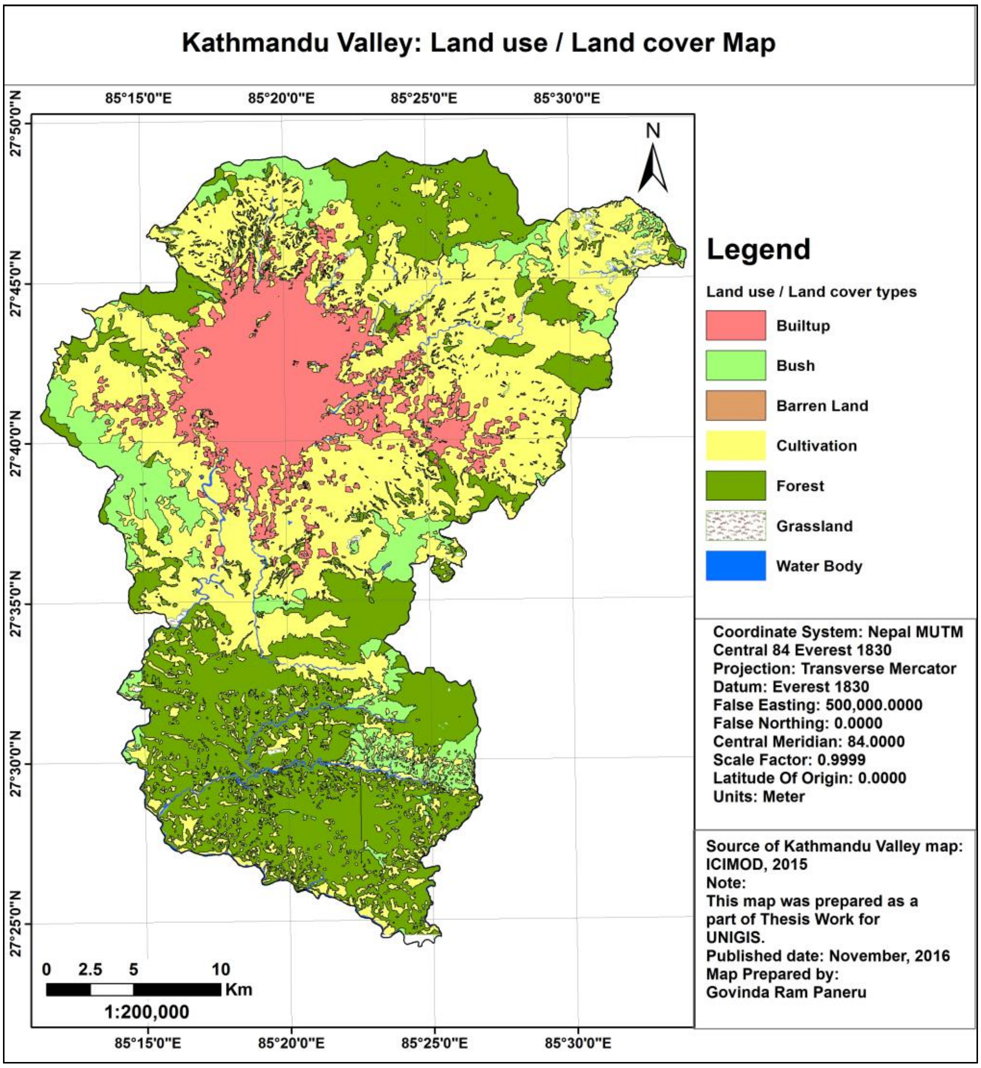


Map 8: Kathmandu valley solar radiation suitability map

3.6. Land use / Land Change (LULC)

To locate a Solar power plant, according to IEA (International Energy Agency) and NREL (National Renewable Energy Limited, USA), that location which we identify needs to have some Topographic elements. They are a) Plain Area. b) Without shadow c) Non Agriculture land such as Waste land or Barren land.

In case of our project, we have used Kathmandu valley LULC raster in which land types are classified into eight different categories as shown in the figure below.



Map 9: Kathmandu valley LULC map

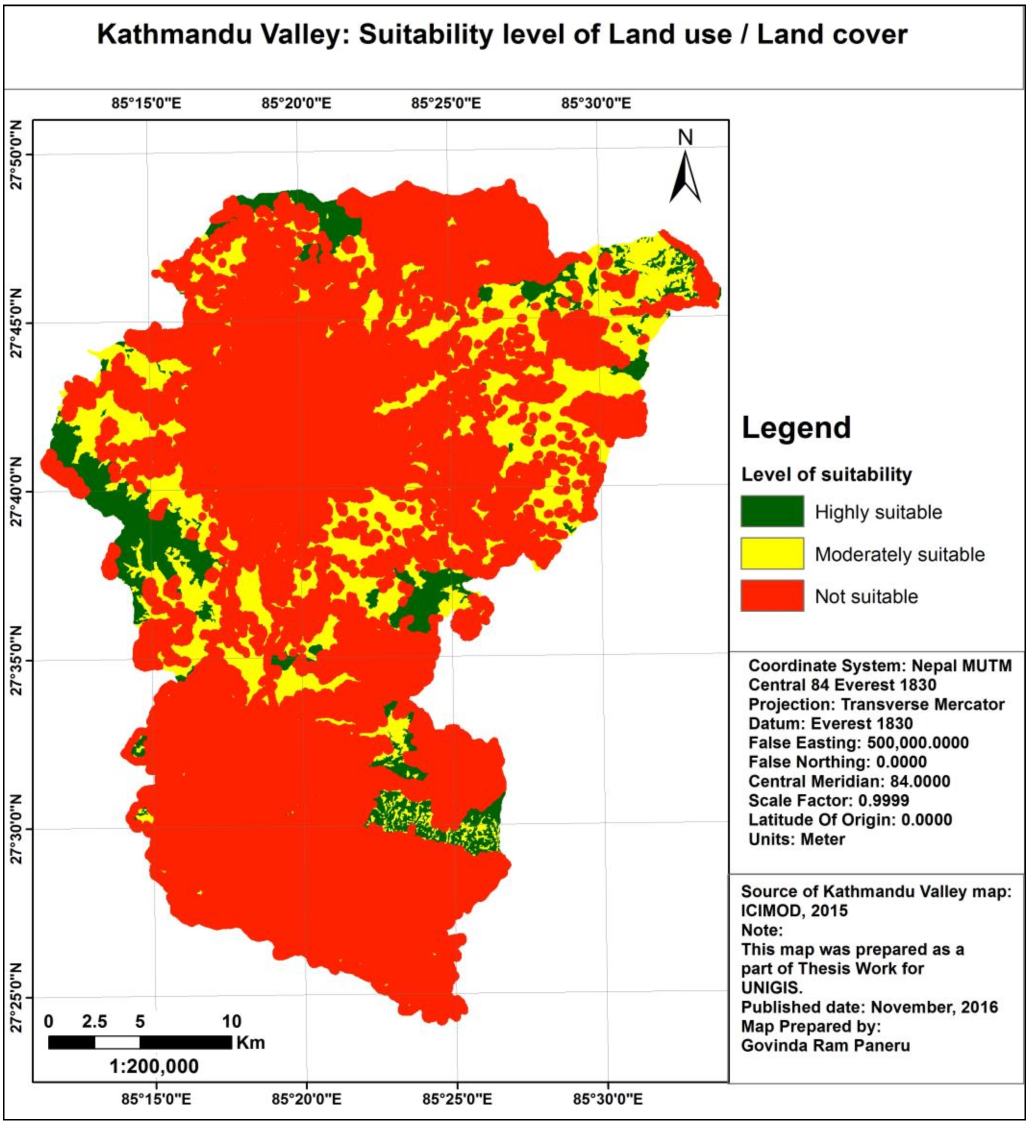
The map shows that the outer area of valley and most of the areas of Lalitpur district is covered by forest. The central part of valley is mostly built-up area while the outskirt of built-up or residential area is mostly cultivation land.

Reclassification of LULC

Out of the seven different land-use types, we have classified them into four categories according to their suitability for the construction of solar energy collection plant. In the case of Water bodies, built-up areas and forest, a 200 meter buffer zone was also calculated and classified it as not suitable area.

S.N	Land-use types	Reclassified values	Suitability ranking
1	Bush, Barren land, grassland	4	4 - Highly suitable 3 - Moderately suitable 2 - Least suitable 1 - Not suitable
2	Cultivation	3	
3	Water bodies, built-up areas, Forest (along with 200 meters buffer zone)	1	

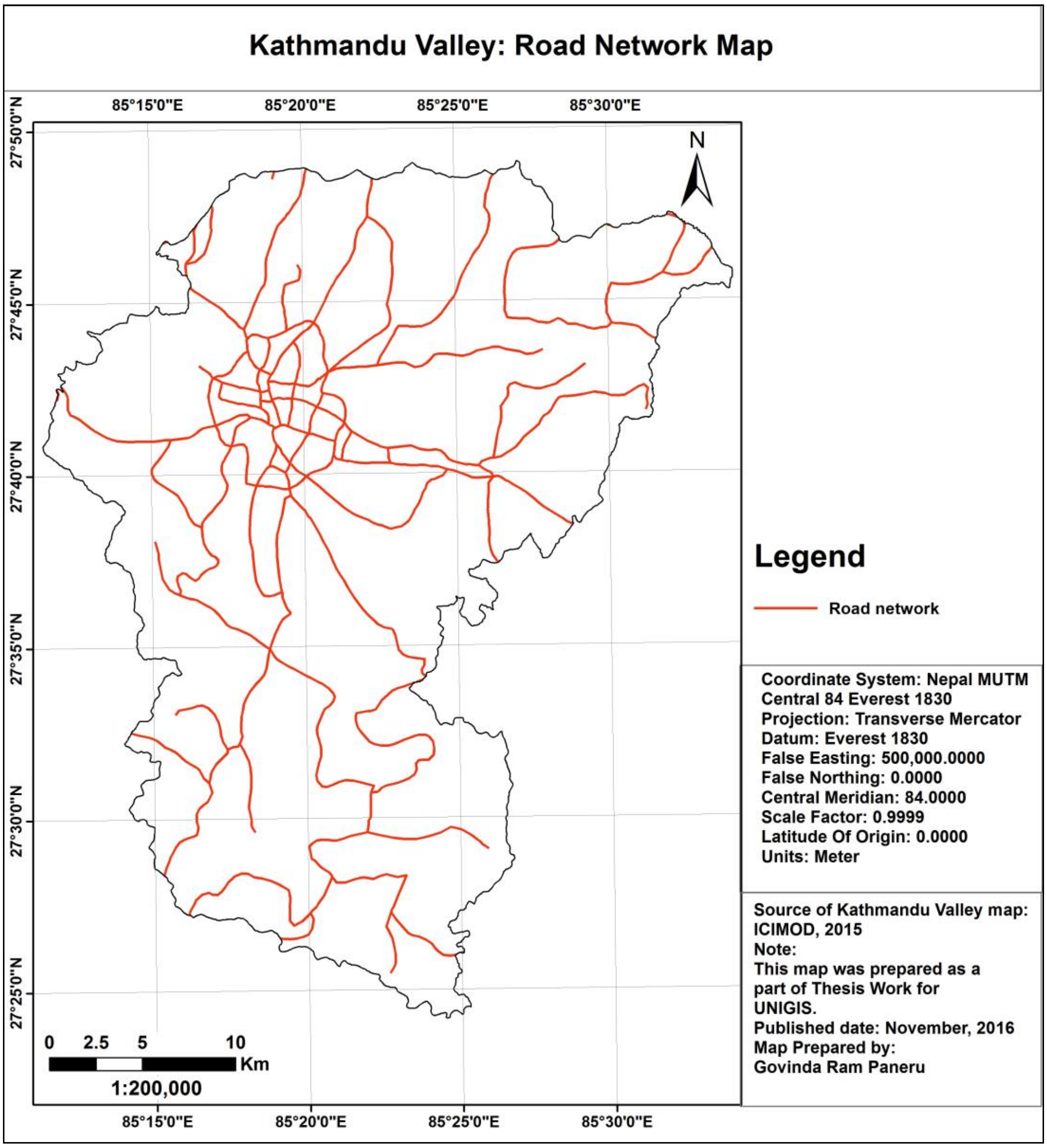
Table 9: Reclassification of Land use/ Land cover values



Map 10: Kathmandu valley LULC suitability map

3.7. Road

Road is yet another important criteria that is taken into account while selecting suitable site for construction. Road plays an important role in the construction of solar power collection plant in terms of the transportation of equipment, access to the site, regular maintenance and monitoring. But it has been considered that the construction site should be outside the certain buffer zone of road. The following map shows the road network in the Kathmandu valley.



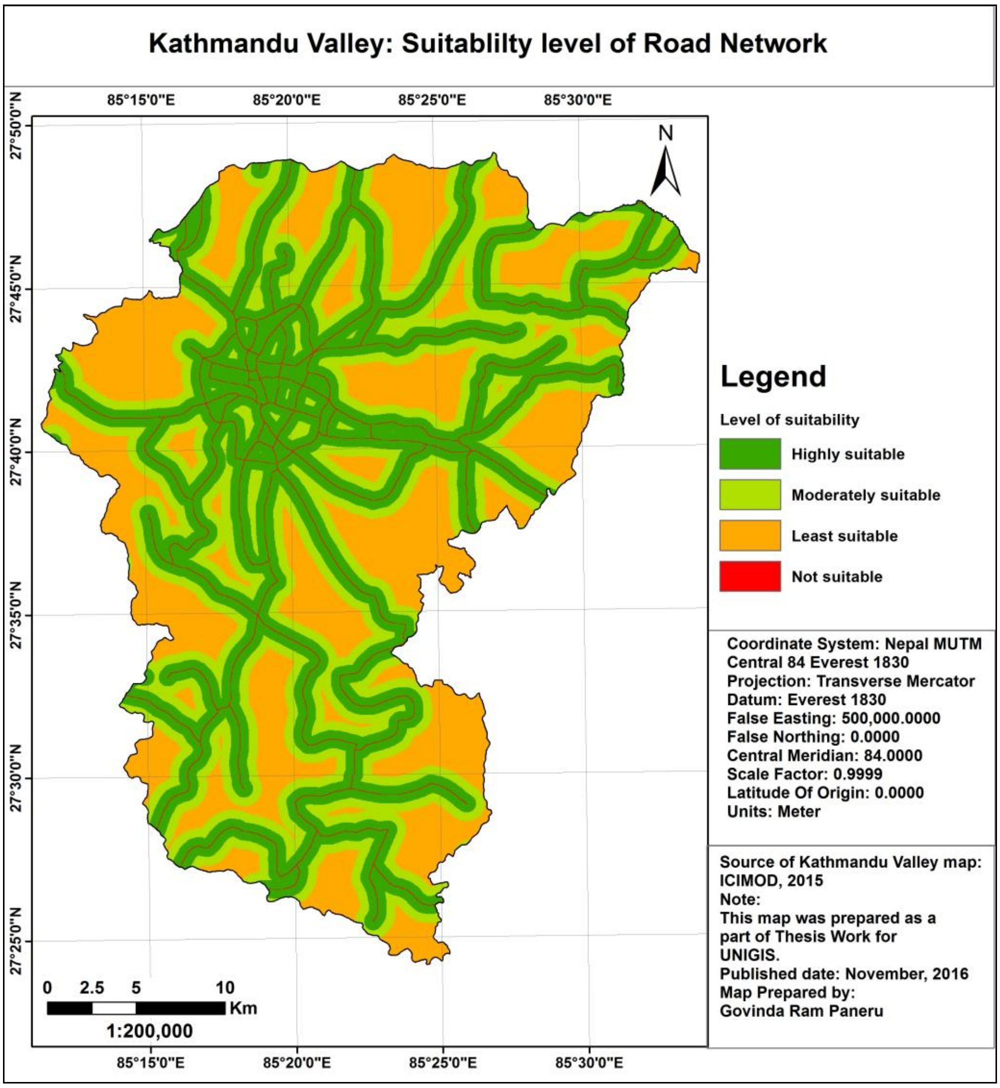
Map 11: Kathmandu valley road map

Reclassification of Roads

Previous researches and literatures have considered that the solar energy collection plant should be nearer to the road for easy access. So I have classified the Euclidean distance of road into four categories according to their suitability ranking.

S.N	Euclidean distance (meters) from road data	Reclassified values	Suitability ranking
1	0 – 15 and 2000 - 5000	1	4 - Highly suitable 3 - Moderately suitable 2 - Least suitable 1 - Not suitable
2	15 - 500	4	
3	500 - 1000	3	
4	1000 - 2000	2	

Table 10: Reclassification of road values



Map 12: Kathmandu valley road network suitability map

Road network have been categorised in which the highly suitable site is 15 to 500 meters from road. Similarly, 0 to 15 meter buffer for the road has been classified as not suitable in order to prevent the site from being falling into the road.

3.8. Pairwise comparison matrix

The AHP considers a set of evaluation criteria, and a set of alternative options among which the best decision is to be made. A pairwise comparison of the criteria is a process that is conducted in order to generate weight for each evaluation criteria according to the decision maker's observation. The higher the weight, the more important the corresponding criterion is.

After reclassification of all criteria, a pairwise comparison matrix was prepared. For the preparation of the matrix, a desktop application program AHP version 2.0 (http://www.hig.se/~sab) was used.

The validity of the weights for criteria was confirmed by looking at the resulting consistency ratio. As discussed in the literature review section of this study, the consistency ration less than 0.1 is considered valid for the pairwise comparison. In our case, the consistency ration obtained was 0.032 which is considered valid for further processing.

The relative weights obtained in this case is high for solar radiation which is 39% and low for road which is only 4%. For LULC, slope and aspect, it is 9%, 21% and 27% respectively.

The following screenshot shows the criteria features compared with each other. The relative weights were obtained for each criteria.

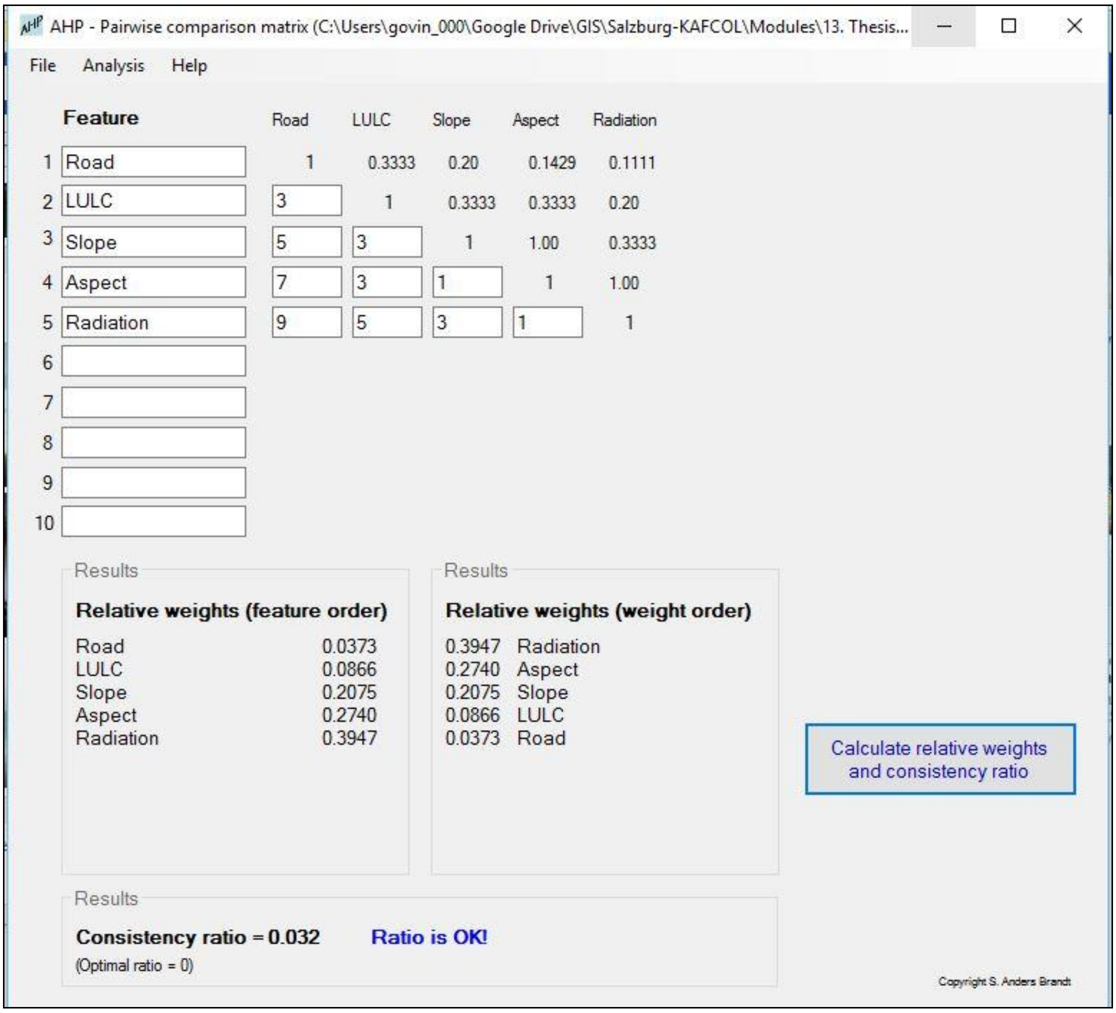


Figure 11: AHP pairwise comparison matrix showing consistency ratio

The relative weights for each criteria are given below:

a. Slope : 0.2075

b. Aspect : 0.2740

c. Radiation: 0.3947

d. Road: 0.0373

e. LULC: 0.0866

Now, as the relative weights for each criteria were identified, weighted overlay operation was performed which is described in the following section.

3.9. Weighted overlay

The weighted overlay tool provided in the ArcMap is one of the approaches that is used to solve multicriteria problems such as site selection in this research. An integrated analysis is performed using this technique where a common scale of values are applied to diverse and dissimilar inputs.

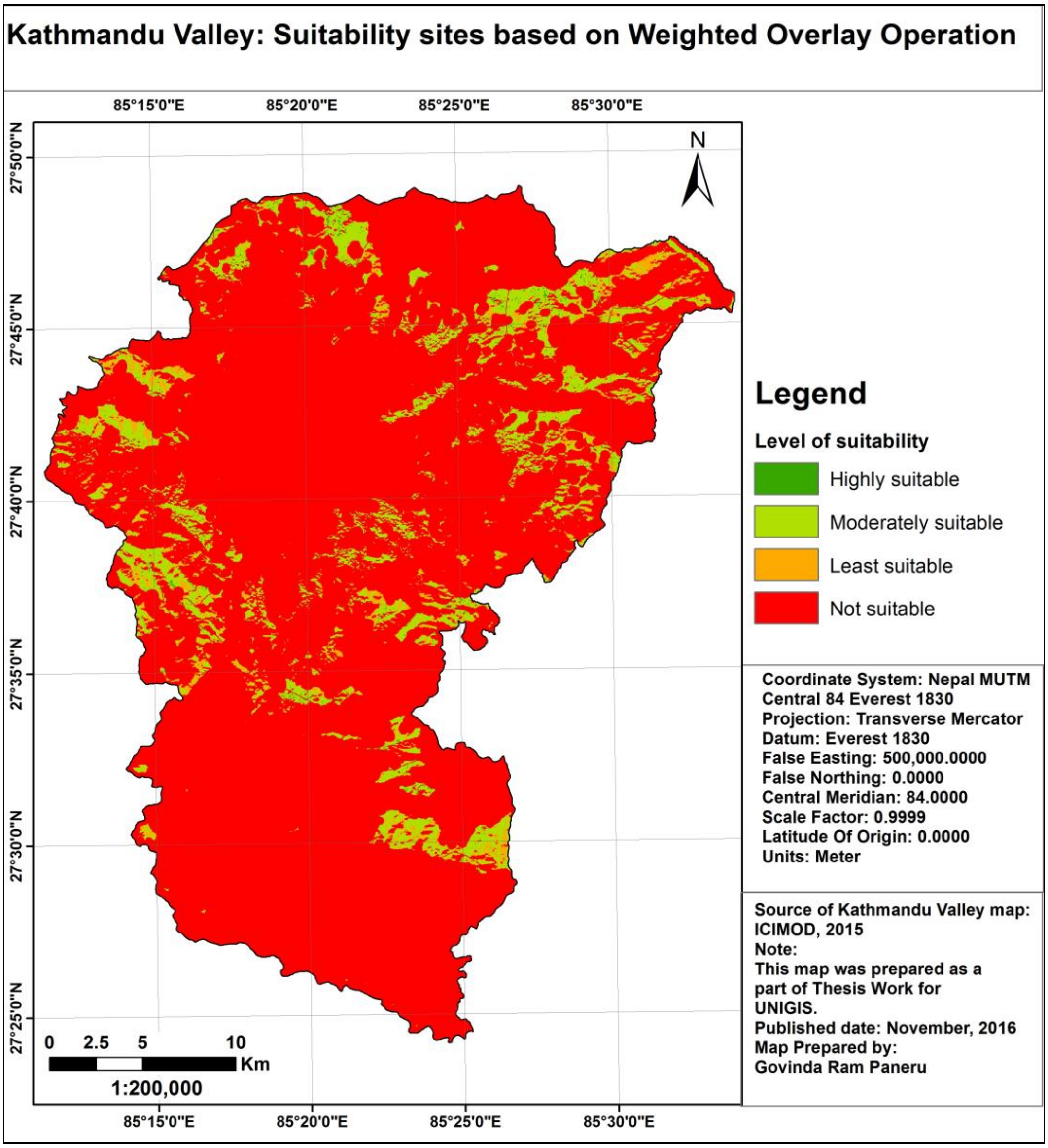
For the purpose of this research work, weighted overlay tool in the ArcMap was used.

The following screenshot shows the weighted overlay table showing the field values and scale values along with the restricted values.

Raster	% Influence	Field	Scale Value
Reclass_Slope	21	Value	
		1	Restricted
		2	2
		3	3
		4	4
		NODATA	NODATA
Reclass_aspect	27	Value	
		1	Restricted
		2	2
		3	3
		4	4
		NODATA	NODATA
Reclass_Radiation	39	Value	
		1	Restricted
		2	2
		3	3
		4	4
		NODATA	NODATA
Reclass_LULC	9	Value	
		1	Restricted
		2	2
		4	4
		NODATA	NODATA
Reclass_road	4	Value	
		1	Restricted
		2	2
		3	3
		4	4
		NODATA	NODATA

Figure 12: Weighted overlay table showing the field values and scale values

The output map produced from the weighted overlay is shown below:



Map 13: Suitable sites in Kathmandu valley for solar energy collection plant

3.10. Potential Sites for Installing Solar Energy Collection Plants

The output map obtained after the weighted overlay operation identifies the potential sites for the installation of solar energy collection plants in Kathmandu valley. The identified sites have been classified according to the suitability based on considered criteria. The complete workflow process that has been followed in order to get the final result has been depicted in figure 7 and 8.

3.11. Result analysis

The methodology and data used for this study has resulted into a maps showing locations ranging from highly suitable to least suitable location for installing solar energy collection plants. Individual maps for four different suitability classes were also prepared. Finally, the area falling under different classes were determined.

3.12. Finalized sites and their characteristics

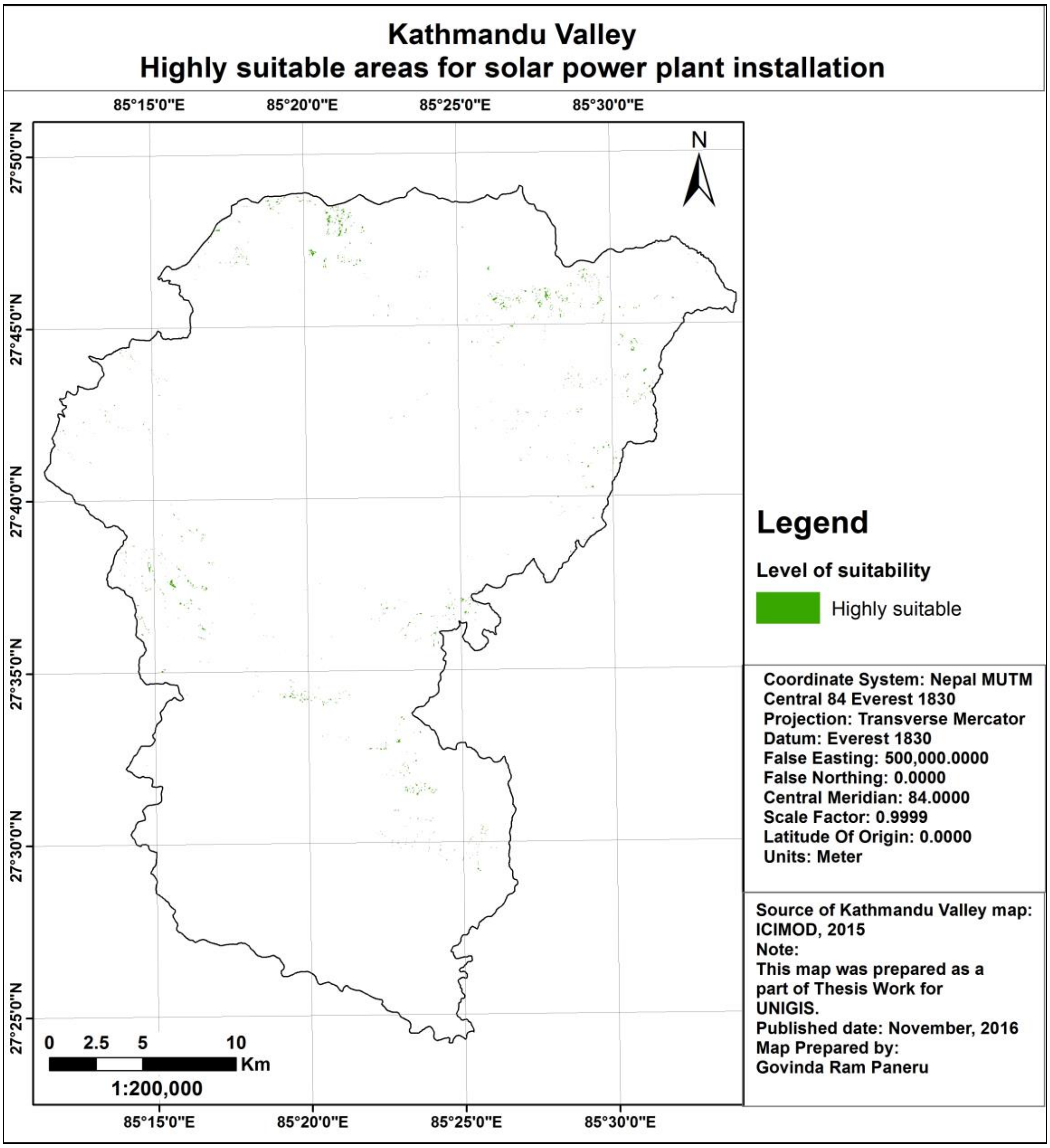
3.12.1. Highly suitable areas

Highly suitable areas are those areas solar energy collection plant would yield the highest possible solar electricity. Solar radiation, aspect, slope, road access and LULC were considered in this study for the selection of suitable site for the construction of solar energy collection plant. Though Kathmandu valley receives considerable amount of solar radiation, other factors such as LULC, aspect, slope and road seems to create constraints in suitable site selection.

The result obtained from this operation shows a very small area of land that is highly suitable for our purpose. The map shows few dots of scattered areas in Kathmandu valley that falls under this category. This result seems realistic since these areas consists of steep slopes (higher than 15 degrees). Other factors such as restricted area (forest, built-up area and water bodies) has also attributed to this result.

The total area of Kathmandu valley covered by this category of land is 2.19 Sq.Km.

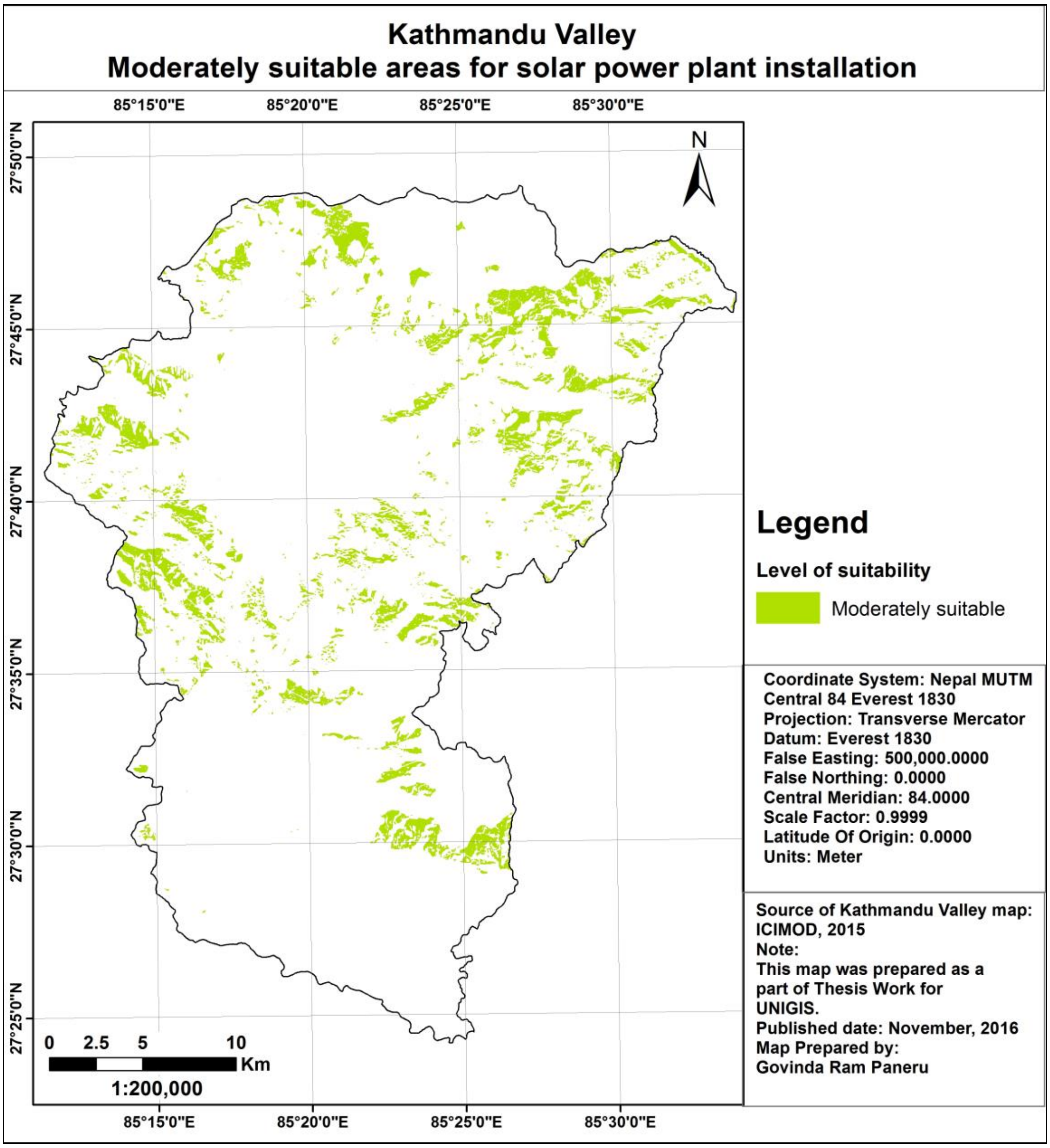
Based on the considered criteria, the area that is highly suitable sites for installation of solar energy collection plant was identified which is shown in the map below.



Map 14: Highly suitable areas for solar power plant installation

3.12.2. Moderately suitable areas

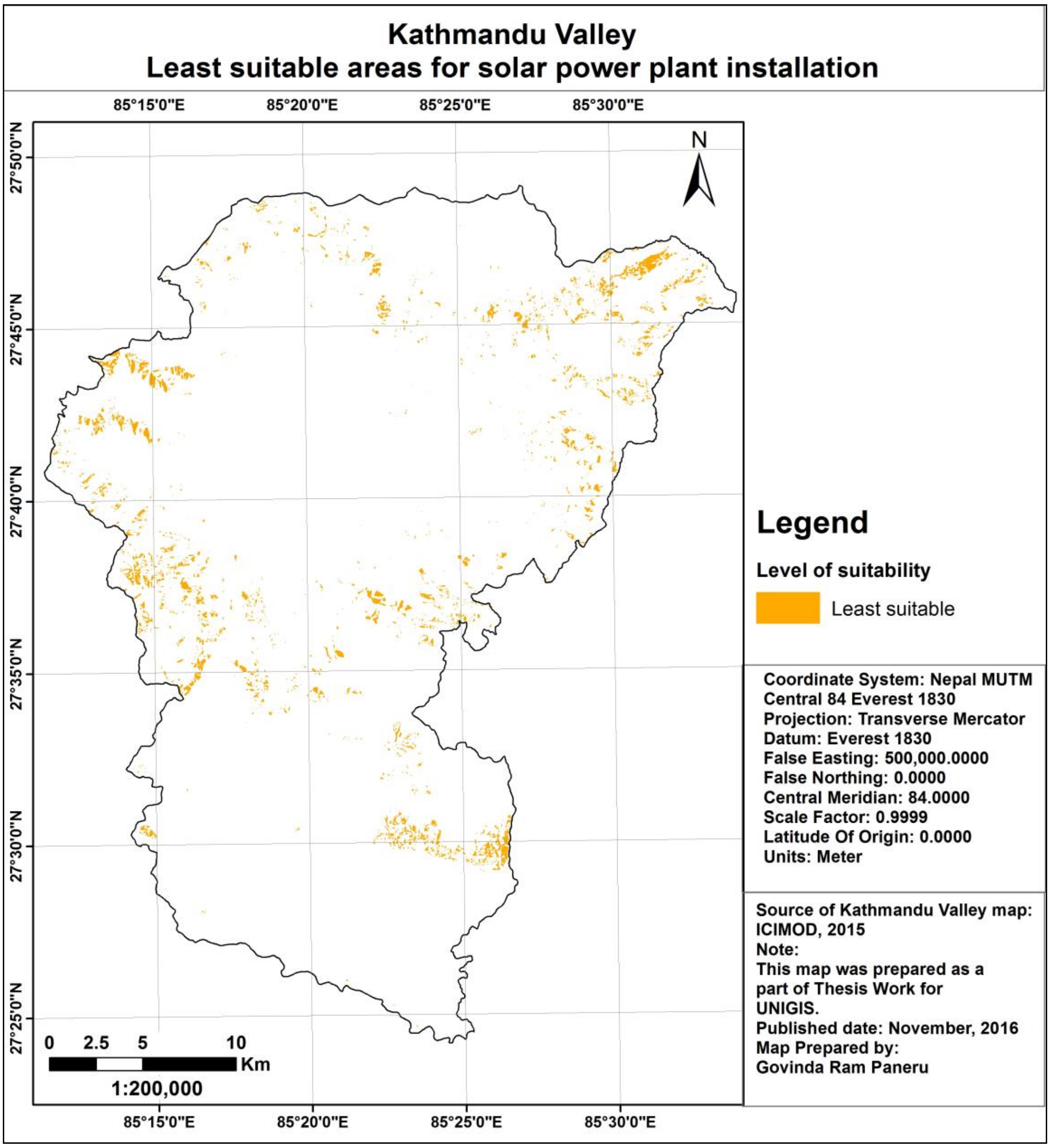
This category of land is also highly scattered over the study area. These sites are available at the outskirts of major built-up areas of Kathmandu valley. It is almost unavailable in the southern part of valley (Lalitpur district) due to its hilly land type. The total area of Kathmandu valley covered by this category of land is 83.83Sq.Km. The moderately suitable areas can be seen in the following map.



Map 15: Least suitable areas for solar power plant installation

3.12.3. Least suitable areas

This category of area is also scattered mainly around Kathmandu district. The identified area is also suitable in terms of land availability. The total area of the least suitable land that has been shown by this research is 23.27 Sq. Km. The map below shows suitable areas for the installation of solar energy collection plants.



Map 16: Least suitable areas for solar power plant installation

Summary

As the solar power plant with capacity 680.4 kWp which is in operation in Sundarighat in Kathmandu valley has occupied 0.006105 Sq.Km of land, with this reference, I can make a projection that we require at-least 0.006105 Sq.Km of land to install solar energy collection plant having equivalent capacity.

The result has shown that there are 1711 polygons having area greater than 0.006105 Sq.Km in all category. Among that, 48 such polygons are in highly suitable area. Similarly, there are 803 polygons having area greater than 0.006105 Sq.Km in moderately suitable category and 674 polygons are having area greater than 0.006105 Sq.Km in least suitable category.

The research process resulted into four different categories of sites that ranges from *not suitable* to *highly suitable* for the purpose of building solar energy collection plant. According to the result, most of the areas on the outskirts of densely populated Kathmandu city area is suitable for the considered purpose. But the result is optimistic in the sense that it has identified 1711 potential area where solar power plant having capacity of at least 680kWp can be installed. The result shows that there are still suitable lands available in Kathmandu valley for the construction of commercial grade solar energy collection plant which can power the households Kathmandu valley. The following charts summarises the area covered by each site categories.

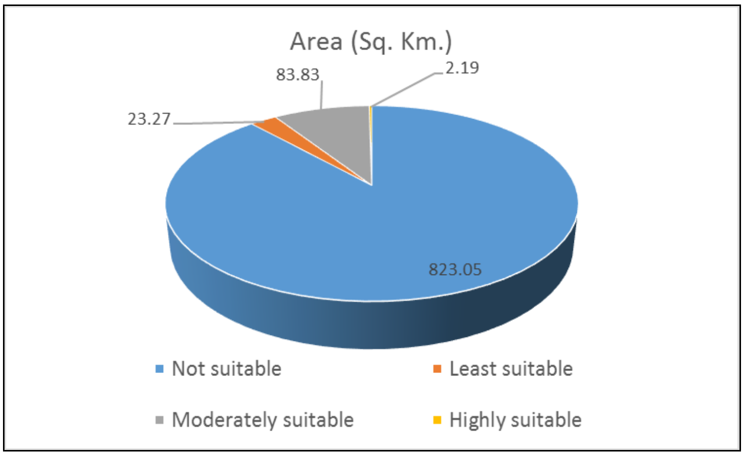


Figure 13: Pie chart showing different categories of sites with their areas

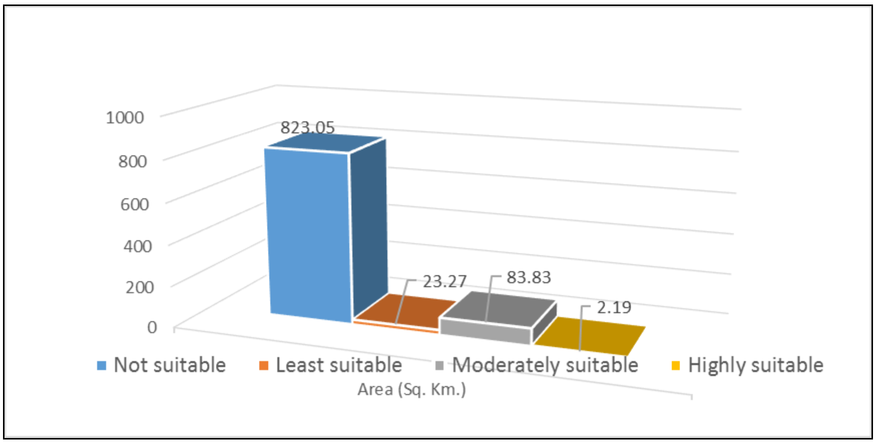


Figure 14 Bar chart showing different categories of sites with their areas

Chapter 4. Conclusions and Recommendation

4.1. Conclusions

Nepal is a country where the demand for electricity is increasing at an alarming rate. Higher use of electric appliances, industrialization and rapid urbanization has aided in the increased demand. A timely approach by concerned authority has become urgent to address current hiked demand as well as the prevailing load shedding problem mainly in Kathmandu valley and other parts of Nepal as well. In this scenario, research on the construction and operation of alternative energy can become a milestone. The research findings can be used by investors, policy makers, traders and other stakeholders to achieve a sustainable alternative for current problems.

In this current research, economic feasibility has not been evaluated. Since the construction of solar energy collection plant requires a huge investment, economic feasibility needs to be considered together with environmental fitness in order to achieve sustainable energy generation.

This research work involves Geographic Information System (GIS) to select highly suitable sites for solar energy collection plant system, based on environmental and geographical aspect. The result showed that although there is very less area available for constructing solar energy collection plant in Kathmandu valley, among the suitable sites, some places in Kathmandu and Lalitpur districts look to be the best sites for building solar energy collection plant.

The approach and methodology applied in this research has resulted in the identification of different category of sites for solar energy power plant. Currently, there are no large scale solar power plant that exist in Kathmandu valley. It is beneficial for country like Nepal to utilize the current approach in the selection of suitable site for building solar energy collection plant.

4.2. Recommendation and future work

GIS-based analysis for the selection of suitable site combines spatial and non-spatial data to construct visualized information that can be easily understood and analysed by decision makers. By using illustrative maps obtained from the GIS-based multi criteria analysis, decision makers can obtain very accurate solutions for problems. In this study, the optimal site for solar energy collection plant were identified and the result were visually interpreted which proves that the result from GIS method is, relatively accurate and practical.

For the establishment of solar power plant in urban areas like Kathmandu valley, it is necessary to prepare a comprehensive guidelines, laws and regulations on such site selection. Factors such as settlement, roads and LULC were also crucial in making decision on site selection process.

The followings things needs to be considered during the site selection process for the purpose of constructing solar energy collection plant:

a. It is recommended to use up-to-date data especially in the case of LULC, road and settlement in these kinds of research works which helps in yielding realistic result.

b. The types or category of road is also key in determining the suitable location. So, it is recommended to use road data with classified road types.

c. Solar radiation has been calculated using the DEM in this research due to unavailability of radiation sensor data for Kathmandu valley. It is therefore recommended to use data from NASA or similar data providers which could help in achieving high precision results.

d. Use of multiple criteria gives accurate result in MCA analysis. In this research, I have considered five criteria. There are lots of other factors that can alter the current result. It is therefore recommended to use as much criteria as possible for better result.

e. Making decision about the size of power plant can be studied as a part of future work.

f. A comprehensive study on the amount of land available as well as amount of land that would be demanded in future is also important research work that can be carried out in future.

The limitations for this research work has been already discussed in the first chapter. Few limitations have been discussed above as well. So, improved data sources and consideration of multiple criteria can improve site selection process for solar panel mounting.

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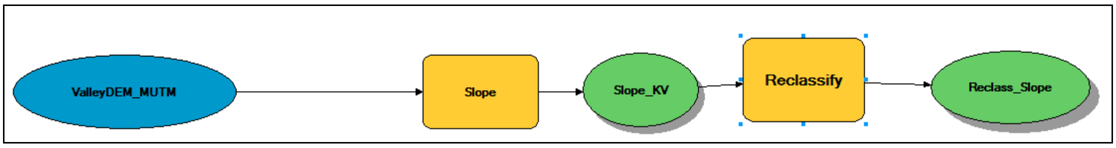
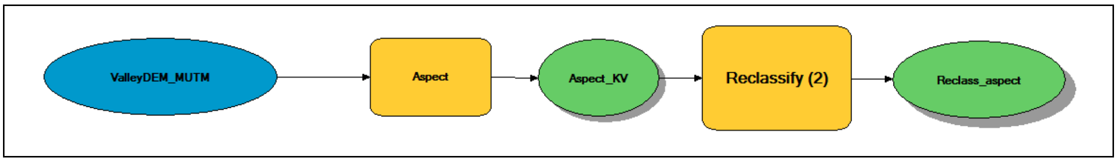
Appendix I: Models for creating the MCA criteria layers

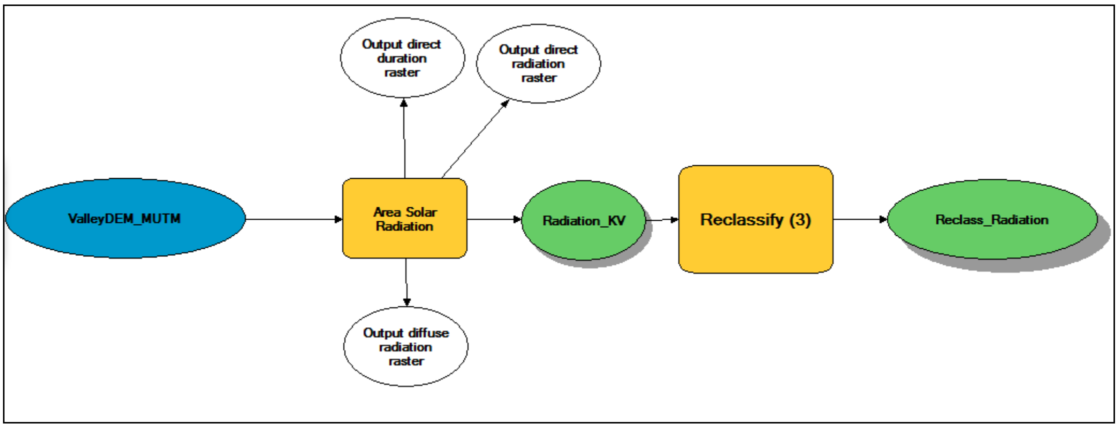
A. Slope



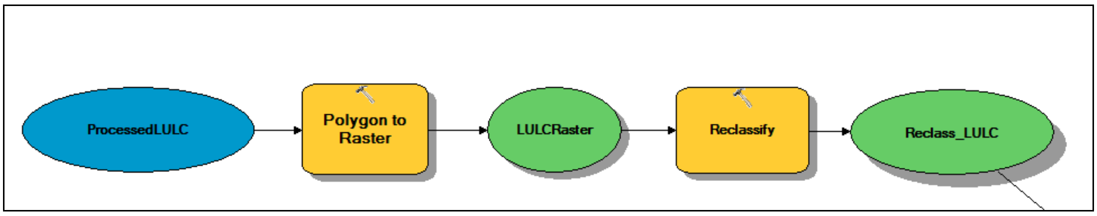
B. Aspect



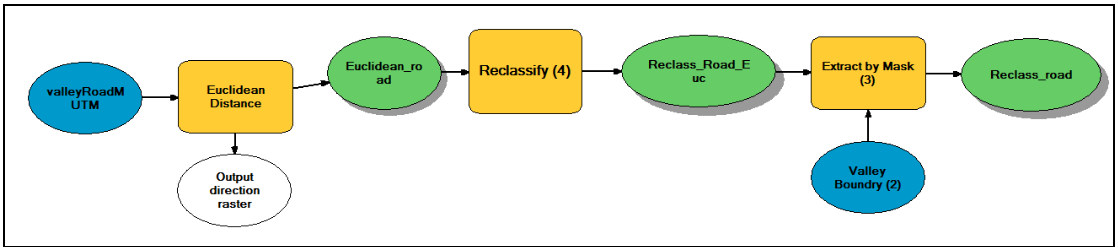
C. Radiation



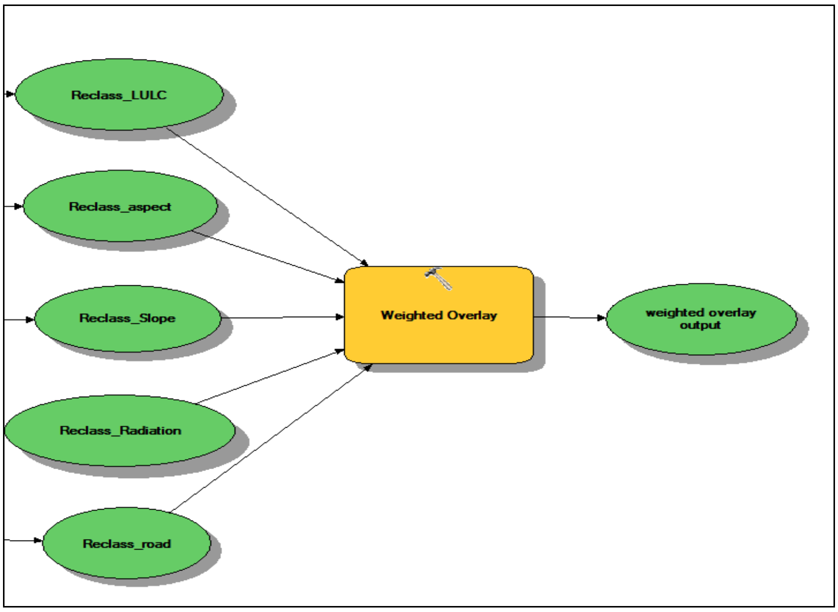
D. LULC



E. Road



F. Weighted overlay



G. Complete model for creating the MCA criteria layers