Addis Ababa Institute of Technology (AAiT)

School of Civil and Environmental Engineering

SOLAR FARM SITE SELECTION USING SPATIAL MULTI CRITERIA EVALUATION METHOD: A CASE STUDY OF KEWET WEREDA, NORTH-CENTER ETHIOPIA.

By:

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Addis Ababa, Ethiopia

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A Thesis Submitted to the Graduate School of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geodesy and Geomatics (Specialization in Geomatics).

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Declaration

I hereby declare that this thesis, entitled "**Solar farm site selection using spatial multi criteria evaluation method case study of Kewet wereda, North-Center Ethiopia**" Which, I submit to school of civil and environmental Engineering of Addis Ababa University Institute of Technology in partial fulfillments of the requirement of the degree of master of science in Geodesy and Geomatics (Specialization in Geomatics), is my original work carried out under the supervision of Dr.Binyam Tesfaw (Asst. professor). It has not been presented for a degree in any other universities and all sources of materials used for the thesis work have been properly acknowledged.

Gashaw Kibret Goshem Signature _______________ Date____________

School of Civil and Environmental Engineering

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This is certified that the thesis entitled "**Solar farm site selection using spatial multi criteria evaluation method case study of Kewet wereda, North-Center Ethiopia**" is the original work of Mr.Gashaw Kibret Goshem for the partial fulfillment of the Degree of Master of Science in Geodesy and Geomatics (Specialization in Geomatics) from Addis Ababa University under my guidance and supervision.

Dr.Binyam Tesfaw (Asst. professor) Signature_______________Date______________

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This is to certify the thesis Prepared by Gashaw Kibret Goshem entitled as "**Solar farm site selection using spatial multi criteria evaluation method case study of Kewet wereda, North-Center Ethiopia**" is submitted in partial fulfillment of the requirements for the degree of Master of Science in Geodesy and Geomatics (Specialization in Geomatics) compiles with the regulation of the university and meets the accepted standards with its originality and quality.

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Abstract

Solar energy can provide a great opportunity for alternative energy source and development of the nation of the country. It can access freely throughout earth surface so, solar energy is good alternative energy source for solving limitation of power especially when there is drought. Therefore, this thesis aims to select suitable solar farm sites by using spatial multi criteria evaluation method in Kewet Wereda. Different spatial and non-spatial data such as solar radiation, slope, aspect, LULC, proximity distance to road, proximity distance to sub-station site, proximity distance to river, proximity distance to railway and proximity distance to town have been used to identify and map area. Some parameter data are taken from 30 meter resolution of DEM such as solar radiation, slope, aspect and river streams. Analytical Hierarchy process (AHP) was used for calculation of the criteria weighted overlay to produce a suitable solar farm site map.

The result shows that solar radiation has the highest weight and distance to river has the lowest weight with 36.6% and 3.4%, respectively. In addition, optimal solar farm sites were identified and highly suitable area found in the south, southeast and northeast part of the study area and covers 35988.71 hectare area. This potential zone contributes to fill the energy gap between the demand and supply of the country when there is a shortage of railfall through the country and shortage of water at the dam. It is also used as bridge for energy gap between rural and urban communities.

KEY words: Solar radiation, Spatial Multi criteria Evaluation Method, Solar farm site selection, Kewet wereda.

List of abbreviations

AHP	Analytic Hierarchy Process
DEM	Digital Elevation Models
CI	Constancy index
CR	Constancy Ratio
EMR	Electromagnetic energy Radiation
ENMA	Ethiopian national meteorological agency
EPCO	Ethiopian Electric Power Corporation
ERA	Ethiopian Roads Authority
ERSDC	Earth Remote Sensing Data Analysis Center
ESRI	Environmental System Research Institute
FAO	Food and Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
GIS	Geographic Information Systems
GDP	Growth Domestic Product
GPS	Global Positioning System
GTP	Growth and transformation plan
GW	Giga Watt
IEA	International Energy Agency
KWh	Kilowatt hour
Km	Kilometer
Km2	Square Kilometer
LULC	Land Use land cover

m.a.s.l	mean sea level
MCDM	Multi criteria Decision Makin
MWh	Megawatt hour
NA	Non Adjust
NASA	National Aeronautics and Space Administration
PV	Photovoltaic
RI	Random Index
RS	Remote Sensing
SMCEM	Spatial Multi Criteria Evaluation Method
SRTM	Shuttle Radar Topography Mission
TW	Tetra Watt
UN	United Nation
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
Wh/m2	Watt hours per square meter.
WGS	World Geodetic System

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Solar energy is vast, free, clean and renewable power source that is available everywhere on the planet(Mohtasham, 2015). The earth receives about 99.9 percent of energy from the sun(Dickinson & Cheremisinoff, 1980). The energy stored in the fossil fuels which we burn originated from the sun when they formed(Piirisaar, 2019). Using directly the sun's energy for electricity generation delivers several benefits. However, the extent of insolation reached on the earth surface shows great spatial and temporal variation at the local and on global(Teshome, 2014).

Energy is a critical part of modern life almost all human activities are strongly connected with it(Kereush & Perovych, 2017). The accessibility and secure source of energy is a key element for modernity life and prosperity of the society and the country(Caruso, Fantozzi, & Leccese, 2013). Although in the current economic situation, the rational use of the available resources and the need to overcome the undesirable environmental effects and other problems associated with fossil fuels have forced many countries to enquired into and change to more environmentally friendly alternatives which are renewable in order to sustain the increase energy demand(Georgiou & Skarlatos, 2016). The potential availability of solar energy differs from region to region in the world because of geographical location and world climate zones(Creutzig et al., 2017). For Built a solar energy it needs, knowing the presents of solar radiation, the angle of the sun and the suitability of geographical locations(Noorollahi, Fadai, Akbarpour Shirazi, & Ghodsipour, 2016).

The increased energy demand and the environmental consequences of conservatory gas emissions have driven the world to support a considerable increase in renewable energy sources as replacing fossil fuels with renewable energy source is regarded as a significant measure for satisfying the increased demand for energy while reducing global carbon emission(Uyan, 2013). Full use of renewable energy source can help to mitigate global warming in environmental terms and also meet energy needs in economic terms(Zhang, 2015).

According to UN (2020), more than 940 million people of the world's population, 600 million people of Africa and 55% of the Ethiopian population have not access sufficient energy.

Above 110 million people living in Ethiopia, among those population 45 % of the population were used daily consummation of electric energy(Getie, 2020). However the country has bulk electric power resource potential in nonrenewable and renewable energy resources, it utilized insignificant amount of resource potential. The electricity generation capacity approximately 90% of the installed generation of electricity is from hydropower while the remaining 8% and 2% are from wind and thermal sources respectively(Lakew, Hailu, Hailu, & Carter, 2017).

Ethiopia is a country which found in sub Saharan Africa those highly awarded with an abundant solar energy, in fact 'thirteen months of sunshine' is the motto of the Federal Democratic Republic of Ethiopia (FDRE) Ministry of Culture and Tourism (2015). But the energy sector is the least developed in the world and mostly dependent on traditional sources of energy such as wood, crop residues and animal waste(Nebey, Taye, & Workineh, 2020).

GIS is a powerful tool for recognizing suitable site selection, for consulting, for editing data, for analyzing and reduce risk costs of large solar energy investments(Otgonbayar et al., 2017). In this era, GIS-based SMCE had become gradually popular as a tool for different site selection studies, especially in the energy planning(Abdelrazek, 2017).

1.2 Statement of the problem

Ethiopia is located in the horn of Africa and among one of the fastest developing nations on the continent. In terms of population, the country is home to over 110 million people, which makes it the second most populous country in Africa behind Nigeria and just ahead of Egypt. As a result of Ethiopia's rapid population over the past decade, the electricity demand has also been increasing gradually. Even if the country has bulk electric power resource potential in nonrenewable and renewable energy resources, these have inadequate access to all the Ethiopian regions, zones and other administrative areas(Getie, 2020). Most remote areas such as Kewet wereda where there is drought or the amount of dam water is become decline impossible to get adequate electric energy.

The use of renewable energy sources such as solar energy use as electricity is new in the developing nations different scholars was written about the solar energy production with different methods and data types. (Bayou & Assefa, 1989) was estimated the solar radiation from six stations measured data by using interpolating methods and mapped the Ethiopian solar energy distribution. (Bayou & Assefa, 1989; Tucho, Weesie, & Nonhebel, 2014) was estimated the solar radiation from 17 stations measured data by interpolating to know the solar energy potential of Ethiopia. Unlike temperature and rainfall, solar radiation cannot be measured at sample meteorological stations and interpolated for the surrounding areas(Kumar, Skidmore, & Knowles, 1997). This is mostly since incoming solar radiation was extremely dependent on landscape structure and surface characteristics(Gastli & Charabi, 2010). In addition, (Teshome, 2014) was selected solar energy potential sites in Ethiopia with 90 Meter resolution of DEM using GIS and AHP method.

The above two studies were trying to interpolate the solar radiation over with wide area from a limited number of stations. But, recent studies indicated that from wide area solar radiation cannot be interpolated. In addition, estimation of solar radiation with higher resolution is more accurate than lower resolution DEM data(Lingfors et al., 2017).

Therefore, the study aimed to select solar farm sites by determining solar radiation from 30 meter resolution DEM using spatial multi criteria evaluation method. The finding of this study will fill the gaps of energy by identifying the potential solar farm sites in Kewet wereda.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study was to evaluate the suitable solar farm site selection using spatial multi criteria evaluation method.

1.3.2 Specific Objectives

The specific objectives of the study were:

- ✓ To estimate solar radiation from digital elevation model.
- ✓ To identify the parameters of solar farm site suitability analysis.
- ✓ To select optimal solar farm sites in the study area.

1. 4 Research Questions

1. How to estimate the solar radiation using digital elevation method?
2. What are the parameters of solar farm site suitability analysis?
3. How to select optimal solar farm sites?

1.5 Significance of the Study

Use solar energy as a source of electric energy was new in Ethiopia. For the reason that there are a few scholar articles that conducted about the renewable solar energy in Ethiopia. So, the study provides to comprehensive information on the solar energy in addition, it could be considered as a reference for any solar energy utilization technology. Therefore, the main significance of this study was to fill or bridge the shortage of energy by selecting suitable solar farm sites in Kewet wereda.

1. 6 Scope of the Study

This paper was focused on solar farm site selection in the case of Kewet wereda by using spatial multi criteria evaluation Method, estimating the solar radiation using 30 meter resolution DEM, identifying the parameters of site suitability analysis and selecting optimal solar farm sites in the study area.

1.7 Limitation of the Study

Because of lack of pyranometer instrument through the study area, the study have some limitations for acquiring primary data such as solar radiation. Also, the current Covid-19 pandemic have great challenge for gathering and offering different primary and secondary data from different organization and to acquire advisor face to face. And the current situation of our country has high challenge to get enough internet access. And also, the absence of specific standards in the development of solar farm site selection criteria in our country has a high challenge in this study to choose weights. Additionally, lack of high advanced processor computer challenged to use high resolution satellite image to estimate better solar radiation value.

1.8 Thesis Structure

This thesis is organized into six chapters. Chapter one covers: introduction, background of the study area, statements of the problem, objective, research question, scope, limitation and significance of the study. Chapter two covers: literature review which used to develop and grasp information from different articles. Chapter three focused on: description of the study area, study area materials and general methodology. Chapter four discuses on data analysis and results. Chapter five focuses on discussion part and the last chapter covers conclusions and recommendations.

CHAPTER TWO

2. Literature Review

2.1 Site Selection

Site selection is a method of land evaluation, which measures the degree of correctness of land for a certain use and also, aims at identifying the most appropriate spatial pattern of future land uses according to specify requirements, preferences, or predictors of some activity(Collins, Steiner, & Rushman, 2001).

Selection of appropriate location was deepened with different measures such as on the local conditions of its surrounding environment. The incoming radiation which reach on the ground as well as the absorbed and scattered radiation can be affected by the atmospheric particles(Hofierka & Cebecauer, 2008).

Alternative energy sources like geothermal, solar, and wind power are defined as a clean source of renewable energy which has a less harmful impact on the environment than other energy sources such as coal, natural gas and oil(Kereush & Perovych, 2017).

Our country is awarded with vast amount of solar, geothermal, wind, and hydropower energy potentials. Yet, irrespective of its huge capacities the energy organization reliant on the customary energy sources such as fossil fuels and only about 45% of the population get electric energy. Given this fact the country has engaged itself in unmatched multimillion dollar energy projects in recent years, however, some of the projects and the construction of huge dams have raised controversy over sustainability issue(Bekele & Palm, 2010).

2.2 Solar Energy

Our primary source of clean, abundant energy is the sun. The sun deposits 120, 00 TW of radiation on the ground surface, far exceeding human needs even in the most aggressive energy demand scenarios. The sun is earth's natural power source, driving the circulation of global wind and ocean currents. Solar energy would afford 20 Terra Watt of energy power which is closely two times the world's energy consumptions, giving an energy flow more effective than current advanced technology supply(Nattan & George, 2005).

The sun is the energy source for almost all the processes that happened on the surface of our planet(Carlisle, Kane, Solan, Bowman, & Joe, 2015). Solar energy generated from radiation of sun which is unpolluted, renewable source of energy and harnessed by solar collection methods such as solar cells and changed into usable energy such as electricity. Solar energy can be for different purposes such as for transportation, solar ventilation, ware treatment architecture, heating water, electricity production, and horticulture(Mohtasham, 2015).

Wind is a result of temperature differences in the atmosphere induced by solar radiation, and rain initially formed by the evaporation of water due to sunlight. More than 99.9 % of the energy source which have flow on the ground surface in case of incoming solar radiation and the rest is from gravitational (tidal), nuclear sources and geothermal(Dickinson & Cheremisinoff, 1980).

Solar radiation is transmitted to the earth in the form of EMR, that is comprised of photons(Caruso et al., 2013).

The solar radiance which consist global daily direct radiation measured by the pyranometers and the other alternative method of measuring solar radiation, which is less accurate, however also less expensive is sunshine recorders, if both of does not access the solar radiation can be estimated from the satellite data(Katiyar & Pandey, 2013).

2.3 Solar Energy potential in Ethiopia

Ethiopia located in the tropical region which have a high abundance of solar resources through the country, the annual direct normal solar irradiance is estimated to range from 1168 to 2337 KWh/m^2 and the daily direct normal solar irradiance is estimated to range from 3.2 to 6.4 KWh/m^2.

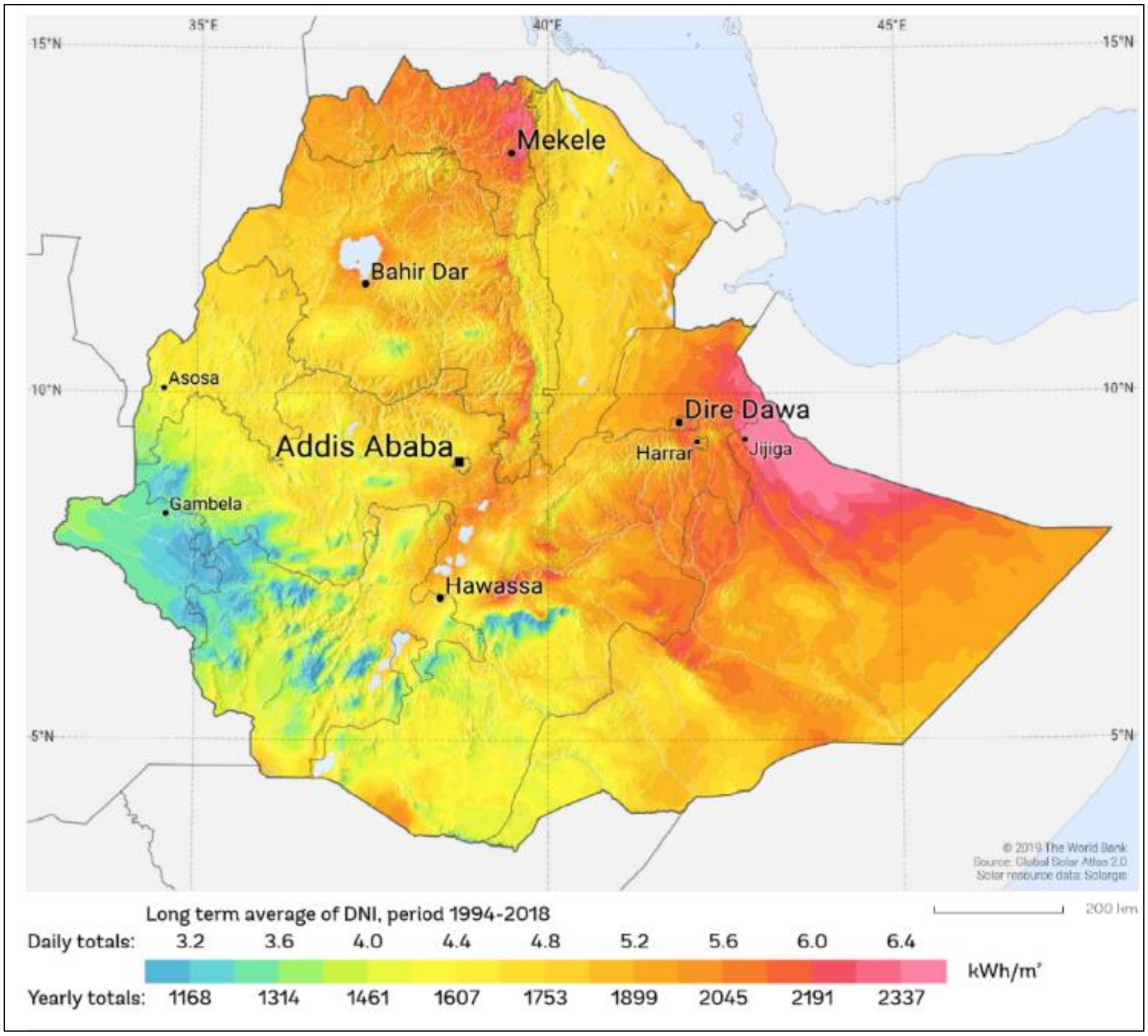

Figure2. 1The direct normal irradiation of Ethiopia

Source of data Global solar atlas period (1994-2018)

2.4 Solar farms

A solar farm is an installation of multiple solar panels, generally on small towers covering an area of ground, it is abundant, non-polluting and does not emit greenhouse responsible for global warming. Unlike the solar panels on roofs, these panels can be placed away from the shade and moved so, they are at the optimum angle to harvest solar rays throughout the day and throughout the seasons(Carlisle et al., 2015).

2.5 Solar Analyst

Solar analyst extension for ArcGIS has been designed by(Fu & Rich, 1999) for showing solar radiation with different measures. Solar analyst enables the calculation of global, diffuse and direct insolation separately. It has high different advantages for developed model such as for versatile output (calculating global radiation, diffuse, direct during, sun maps and sky maps, and view sheds(Fu & Rich, 2000).

2.6 History of Emerging GIS in the site selection

There are three periods in the modern era that were divided emerging the GIS technology in the planning field the first one is called “the GIS research frontier period” that referred to the innovative stage in 1950-1970s.The second is called “the development of general purpose GIS systems “that referred to the integration stage in the 1980s, and the last period is called “the proliferation stage “which was mainly focused on the development the users deal with GIS technology(Malczewski, 2004).

Environmental management is directly linked to the geographic context and therefore has been the main reason of progresses in GIS throughout its history. GIS become an important software in the nowadays environmental management, it plays a dominant role in the improvement of environmental policy and in environmental decision making(Goodchild, 2003).

2.7 Previous works

Different scholar's article was available throughout the world using different approaches to select a suitable site for solar farm potential .The following studies conducted at different scales from developed and developing countries.

(Watson & Hudson, 2015)were used a GIS-assisted multi-criteria evaluation method to assess suitability for solar and wind energy developments in southern England. The study was conducted in three stages. First, a binary variables layer were formed to exclude unsuitable locations and a factor layer developed to indicate high and low suitability for solar farm development. AHP was applied to produce the weightings for factor variables from the pairwise comparisons. Secondly, suitability layers for the whole region were created. Last, a sensitivity analysis was performed to check the reliability of the suitability model. The results revealed good suitability for solar farm improvements trough the country.

It shows the probable of solar energy in the closest neighboring country and offers an example of how and to what extent solar farms could be deployed.

(Uyan, 2013)was determined suitable site selection of solar farms by using GIS and AHP, Turkey.

He considered the quality of terrain, local weathering factors, proximity to high transmission capacity lines, agricultural facilities and environmental conservation issues in the selection process. Generally he found that 13.92 percent of the study (840.07 km2) as highly suitable for solar farms.

(Michal and Beta, 2017) were determined suitable site selection of solar farms by using **(**AHP) Warsaw, Poland. They measured the quality the investigation was distributed into two steps. In the first one, the areas anywhere the location of solar farms was not possible were removed. In the 2nd, the best sites conforming all environmental and economic standards were selected. The study was done for the Legionowo District, nearly sixty percent of the study area was excluded.

(Tahri, Hakdaoui, & Maanan, 2015)Assessed solar farm suitability in Morocco. In 2009 the Moroccan agency for solar energy launched the improvement of the 500 MW ouarzazate plant for PV and CSP technologies. The study combined MCDM and AHP methods. In this study four factors were used in the selection process such as climate, LULC, location and orography. The analysis showed high suitability for implementing solar power generation projects whereby the majority of the best suitable locations were found to be on flat grounds and oriented towards the south.

(Effat, 2013)Recognize best sites for building solar farm sites in Ismailia area Egypt, to achieve this, research two stages was applied in her research. The RS data was used to drive the LULC map of the study area. Also SRTM and elevation model were used to calculate the aspect map and the solar radiation. AHP was used for calculation of the criteria weights.

She concludes that Spatial Multi-criteria evaluation, analysis managed to solve the site selection problem and fulfill the objective of the study. It's considered the most effective criteria, i.e.

Climate and orography, and their relative importance in the decision making. Such decision support tool studied need more attention from both researchers and decision makers.

Teshom (2014) was applied to calculate available solar energy resources and map the sites which is suitable for large-scale PV installations in Ethiopia. He has done his research by computing the annual and monthly solar radiations from 90m resolution ASTER DEM using the solar radiation analyst tool in the ARCGIS software. He took so many factors for Scale PV solar farms in the study area taking into account various topography, economic, social and environmental factors. For his research he consider, population density, land cover, slope, aspect, distance to road network and distance to water source was consider into account in the GIS-based MCA for large scale solar farms in Ethiopia. The factors used in his study have more of an effect on eliminating non-suitable areas for large-scale solar farms. He concludes that there was a very high potential of solar power generation in extensive areas of Ethiopia throughout the year.

(Bayou & Assefa, 1989; Tucho et al., 2014)were applied interpolation methods with inputs of various meteorological data to predict the monthly average global radiation in Ethiopia for 17 and 6 stations. Maximum and minimum, precipitation, relative humidity, temperature and surface pressure data were used in this study. The monthly average results for Ethiopia, which ranges from 19.5MJ m^{-2} day^{-1} to 20 MJ m^{-2} day^{-1} are observed by using interpolation from these stations. He concluded that Ethiopia is characterized on average, by relatively high daily global irradiance rates and a high percentage of clear days.

CHAPTER THREE

3. Materials and Methodology

3.1 Description of Study Area

Kewet is one of the wereda at the North-Center part of Ethiopia. It is located at 225 km northeast of Addis Ababa in the northern Shewa Zone Amhara Region. Shewa Robit is one of it's the major town, it has an altitude of about 1,280 meters above sea level (m.a.s.l).The Wereda lies at a longitude and latitude of 39.744°E,10.167°N. It is bounded on the north by Efratana Gidim, on the northwest by MenzMamMidir, on the east by afar Region and on the southwest by Termaber. It has total area 785.85 square kilometers and population number was based on 2007 national censuses it have over 118,381population.

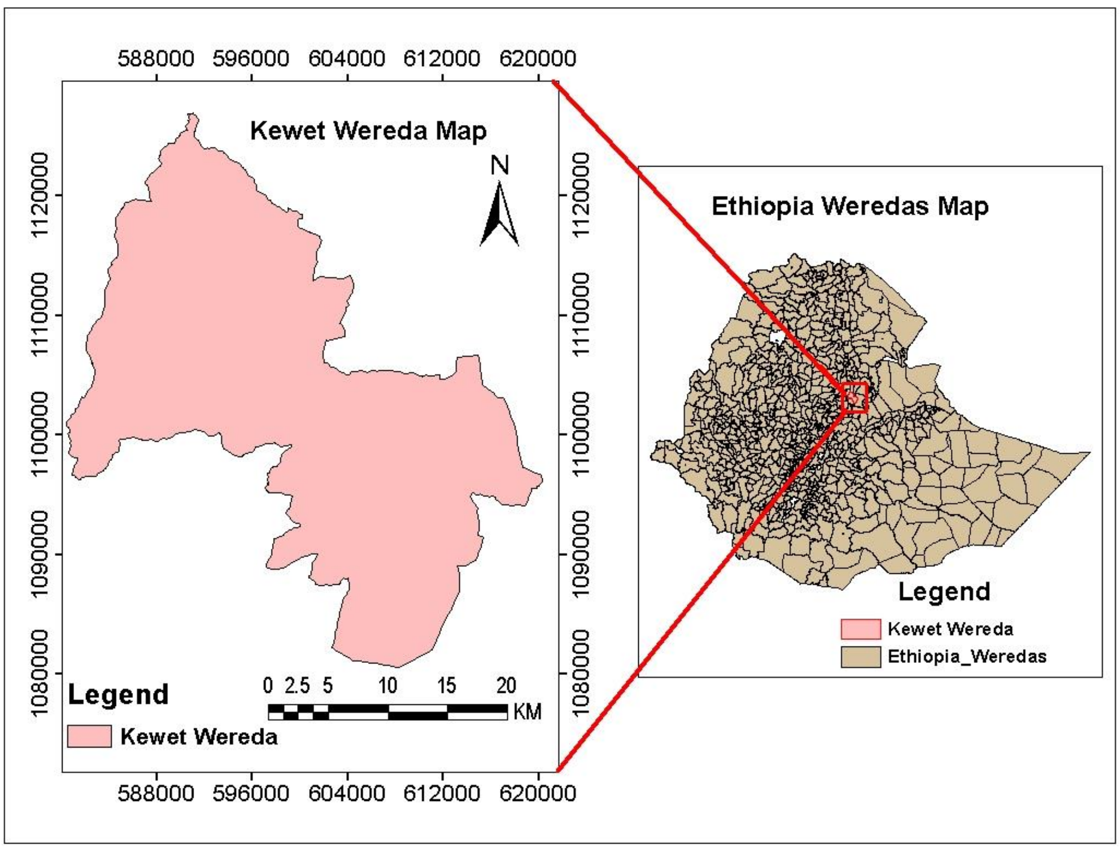

Figure3. 1Study Area

3.2 Topographic structure of the study area

3.2.1 Slope

The landscape of the earth was very a significant factor in deciding suitable solar farm site selection through the study area. Nearly spaced lines symbolize sharper slopes and scarce contours display gentle slope while in the altitude output raster each cell has a slope value. In general lower slope indicate the flatter terrain and higher slope shows the steepness of the terrain. The altitude of the earth affects the receiving radiation of the sun. Most of the radiation receives by the flat earth's surface and can produce high energy from the solar(Umer et al., 2019).

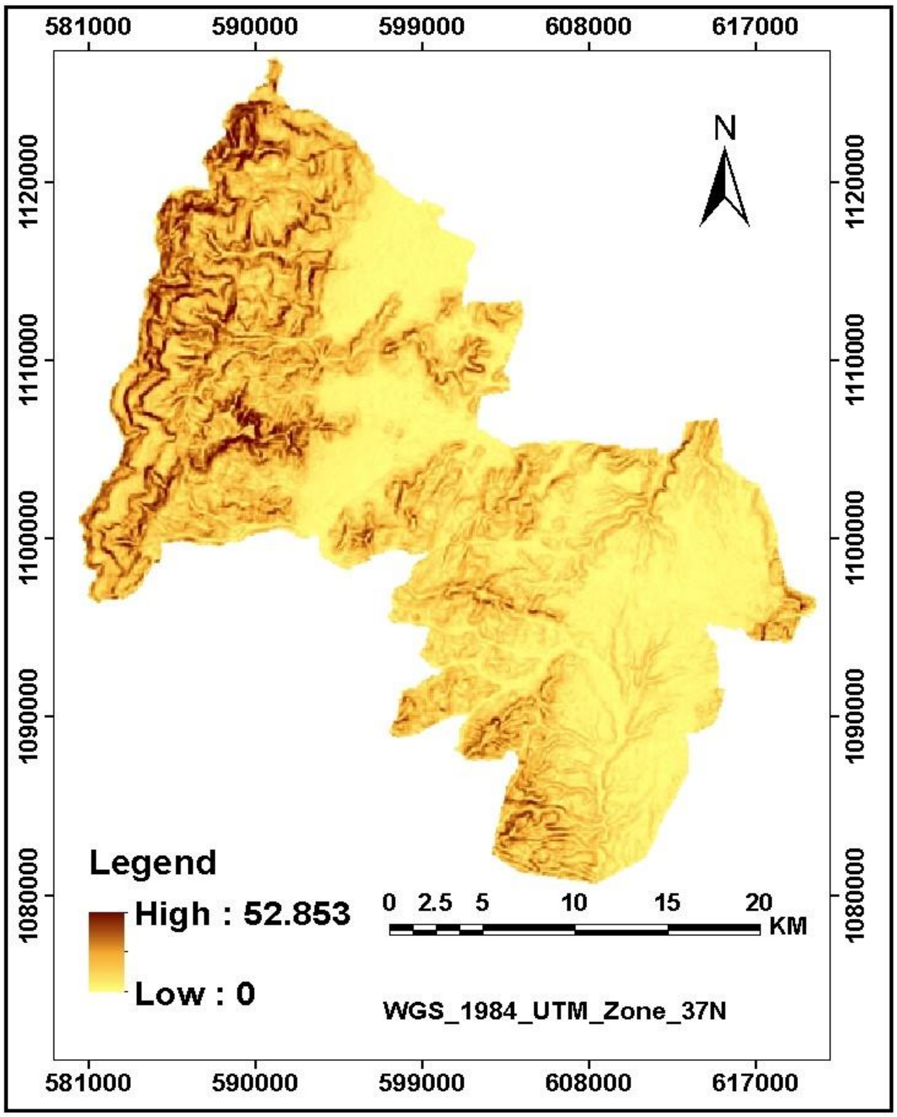

Figure3. 2The slope of the study area

3.2.2 Aspect

The aspect of the study area was driven from the digital elevation model. It shows the slope direction and measured azimuthal direction as shown in the following figure3.3 the solar energy depends on the suitable solar farm site orientation and tilt angle, both have high factors to change the level of solar energy received by the target(piirisarr, 2019).

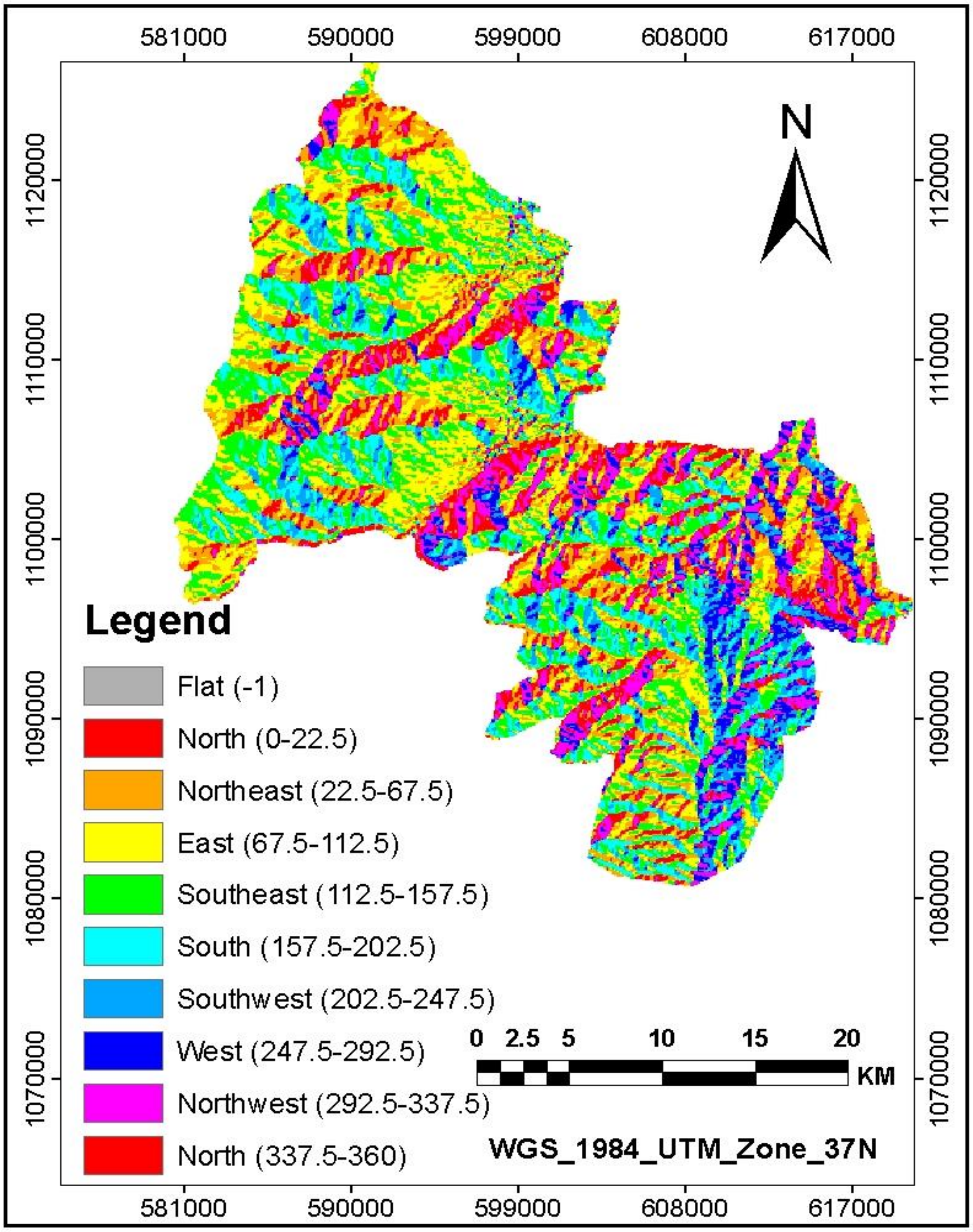

Figure3. 3 Aspect of the Study Area

3.3 Climate of the study area

3.3.1 Temperature

The climatic data gathered from Ethiopian national meteorological agencies such as monthly minimum temperature, monthly maximum temperature and rainfall data. According to the Ethiopian national meteorological agency (NMA), the mean minimum and the mean maximum monthly temperature is ranges between (11. 2 -17.1) °C and (28.4 -35.5) °C as shown in the following table 3.1 and figure 3.4.

Table3. 1 Mean monthly, maxi, min and mean temperature (°C) of Kewet wereda (2006 -2019)

Months	1	2	3	4	5	6	7	8	9	10	11	12
Mean monthly Mini T°	12.8	14.2	14.2	14.3	15.9	17.1	16.9	15.9	14.1	13.6	10.3	11.2
Mean T°	20.3	20.9	23.1	22.8	27.1	29.2	24.5	23.9	23.8	20.9	21.7	20.1
Mean monthly max T°	28.4	29.5	32	30.7	34.2	35.5	32.5	32.1	32.6	30.6	30.8	29.9

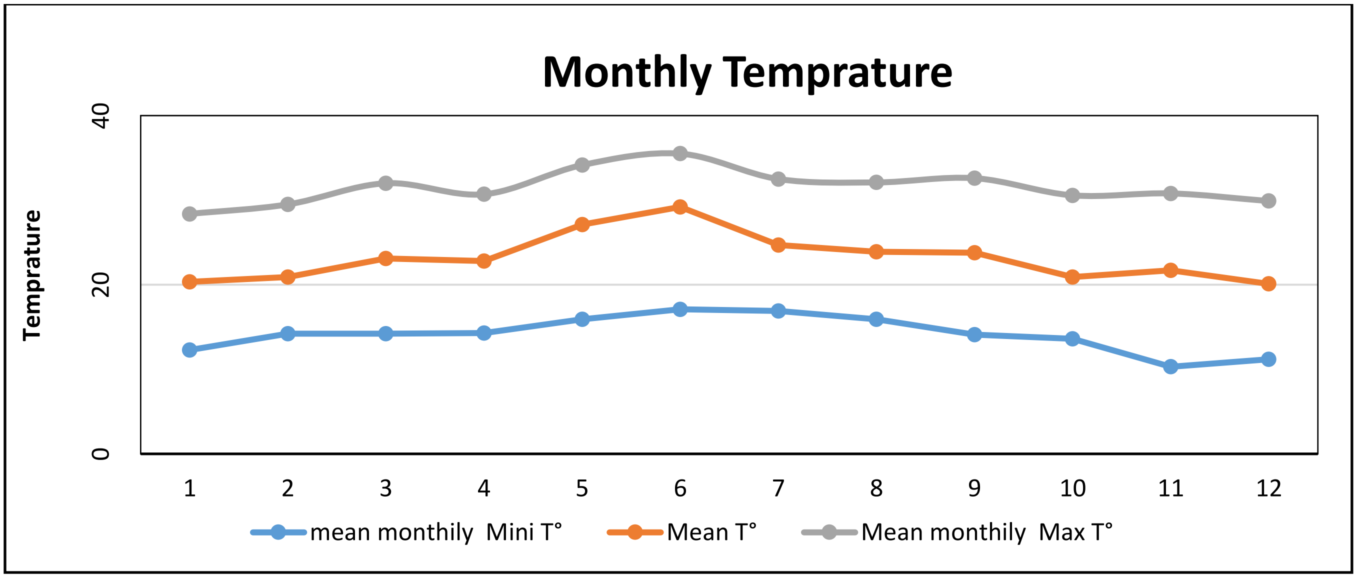

Figure3. 4 Mean monthly, mean maximum and mean minimum Kewet wereda (2006 -2019)

Source: NMA

3.3.2 Rainfall

The rainfall data gathered from national meteorological agency of Ethiopia, the mean monthly rainfall ranged between12. 8 mm up to 221.2mm as shown in the following table 3.2 and figure 3.5 also, the study area gets its most precipitation at months of July and August.

Table3. 2 Average monthly rain fall

Rainfall at Shewa Robit Station												
Months	1	2	3	4	5	6	7	8	9	10	11	12
Rainfall (mm)	15.3	38.8	50.5	92.2	66	25.5	193	221.2	94.1	17.3	20.3	12.8

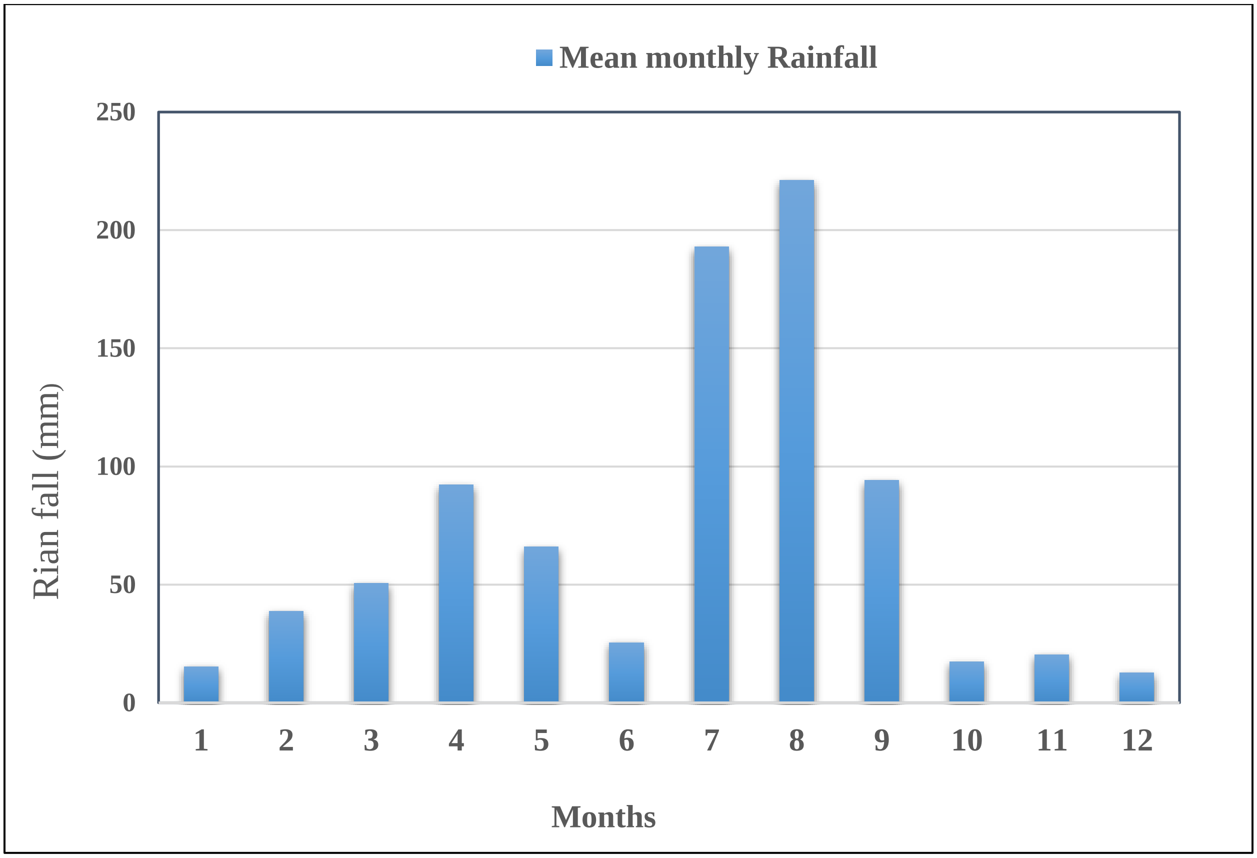

Figure3. 5 Monthly Rain Fall (2006-2019)

Source: NMA

3.4 Hydrological units of the study area

3.4.1 Delineation of river network from DEM

Kewet wereda is one of the most severely affected by flood in the southeast Amhara region; particularly Robit Catchment was affected by flood(Asefa & Mindahun, 2019). In case of the flood availability through the study, generating and knowing river streams in study area is mandatory for locating optimal solar energy sites.

The river /stream networks was delineated from DEM using ArcGIS spatial analysis hydrology tools. Then the flow direction was derived from DEM, which was used to calculate the flow accumulation. Finally, from the stream network was extracted from flow accumulation. Figure 3.6 shows the extracted stream networks of the study area.

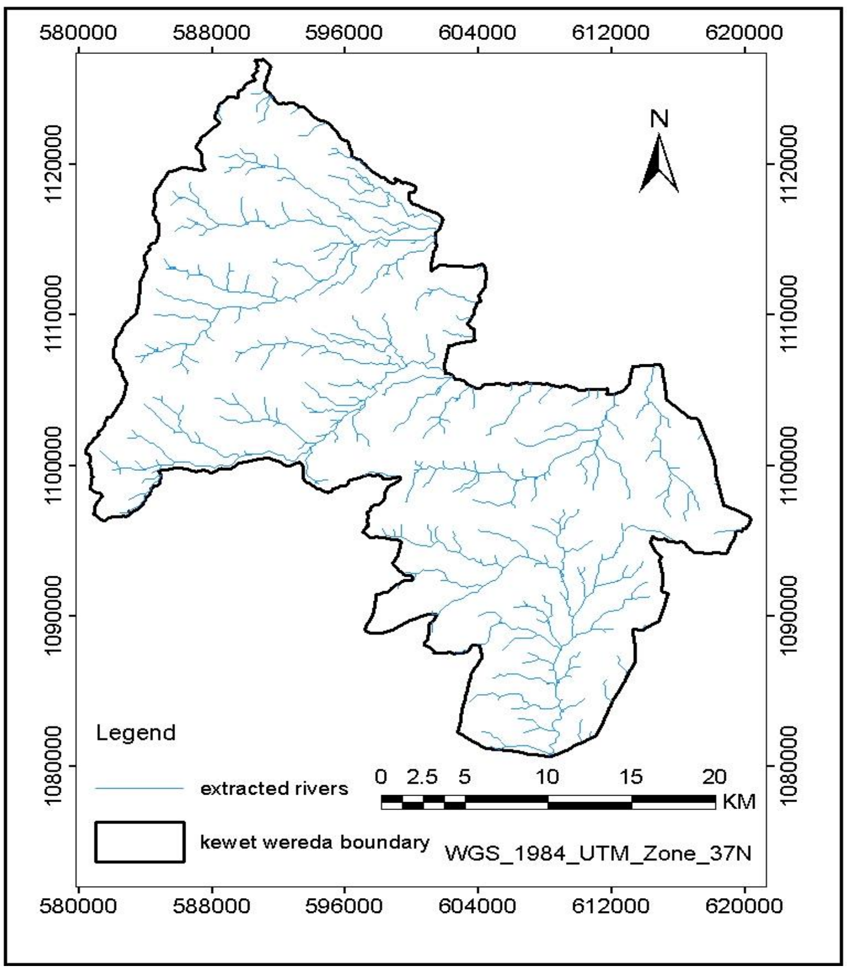

Figure3. 6 Delineated river streams

3.5 Data Description and material used

3.5.1 Data Description

Different data were gathered from different organizations and field observation. GPS data is one of the primary data which collected from field and SRTM data, landsat8 satellite data, road network data, sub-station site, boundary shape files data, railway data and recorded meteorological data are secondary data.

Table3. 3 data source

SN.	Dataset	Format	Sources	Resolution
1	SRTM	Raster	(https://earthdata.nasa.gov/)	30 M
2	Solar radiation	Raster	DEM	30 M
3	Landsat8	Raster	https://earthdata.nasa.gov	30 M
4	Meteorological data	Float	National meteorological agency	NA
5	Road network	Vector	The FDRE Ethiopian Roads Authority	NA
6	Boundary shape file& Ethio,Town	Vector	The FDRE Geospatial Information institute	NA
7	Railway	Vector	Ethiopian Railway Corporation	NA
8	Sub-station site	Vector	The FDRE EPCo.	NA
9	River	Raster	By delineating DEM	30 M
10	GPS data	Float	Field survey	NA

3.6 Software used

Table3. 4 Software

Software	Utilization
ARCGIS10.5	To prepare all map layouts, to calculate weight using AHP and overlay spatial data.
ERDAS IMAGINE 2014	Preprocessing data and Classification of LULC.

3.7 Estimated Solar Radiation

As previously mentioned, solar radiation can be measured by pyranometer instrument. But, here in the study area there is no any instruments which used for measuring solar radiation. In case of this we use satellite (DEM) data to estimate the study area solar radiation. The ESRI toolset solar analyst extension in ArcGIS is used for calculating solar radiation for this thesis. The main input in this thesis is DEM with 30 meter resolution. The user determines a number of conditions for the remaining tool parameters.Table3.5below shows the input parameters for creating the solar surface of for the study area.

Table3. 5 the input parameters for creating the solar surface of for the study area.

Input	Description	Value
DEM	From the surface raster layer	30 meter resolution
Latitude	Latitude of Study area	9.85°(Automatic input from raster)
Sky size	Resolution of the viewshed, upward looking representation of the sky.	200
Time configuration	Time used for calculating solar radiation	Whole year 2020
Day interval	The day interval through the year	(Monthly)
Hour interval	The hour interval through the year	0.5
Z factor	Number of ground x, y units in the surface Z unit	1
Calculation Directions	Number of azimuth directions, multiple of 8, 32 is default.	32
Zenith Divisions	Default is 8 divisions relative to the zenith	8

Azimuth divisions	Number of divisions used to create sky map default 8.	8
Diffuse Model type	Type of diffuse model uniform sky.	Standard overcast sky
Diffuse proportion	Global normal radiation	0.3
Transmissivity	Relates to cloud cover	0.5

Source: Description from Esri 2013 a desktop Help.

3.8 Land Use /Land Cover of the Study Area

3.8.1 Image pre-processing

Landsat 8 image was downloaded from USGS Earth explorer website with a path and row of 168 and 053. This Landsat8 data has spatial resolution of 30 meter and less than 0.3 % cloud cover Feb, 2020 for the classification of LULC of the study area. The Landsat was corrected and projected to WGS _84datum and Universal Transverse Mercator Zone 37 North coordinate system. All pre-processing done with ERAS IMAGINE 2014 Software, from stacked satellite image the study area was extracted using ArcGIS10.5 software.

Table3. 6 Details of Landsat 8 image

Satellite	Sensor -ID	Path/row	Bands	Date of acquisition	Grid cell Size (M)
Landsat8 OLI/TIS	LC08-L1TP-168053-20200220	168/053	11	20 February 2020	30M

3.8.2 Atmospheric Correction

In remote sensing data atmospheric correction is a critical pre-processing technique (Liang, 2005). EM energy signals gathered by visual satellite in the solar range which influenced by absorption and scattering of gases and aerosols while travelling through it from the earth surface to the sensor(Cui et al., 2014). The main atmospheric effects scattering by molecules and aerosols, absorption by carbon dioxide, water vapor, oxygen, clouds and other particles in the atmosphere.

The atmospheric error were corrected by applying dark pixel subtraction method using ERDAS IMAGINE 2014 Software.

3.8.3 Geometric Correction

It adjusts RS data for the shifts and confirms that features are properly positioned on the image. But for Landsat8 satellite image no applied correction because USGS provided geometrically corrected images.

3.8.4 Radiometric Correction

Radiometric correction of RS data generally involves the processing of digital image to improve the fidelity of the brightness value magnitude(Chrysoulakis, Abrams, Feidas, & Arai, 2010). Radiometric correction was applied to minimize the impact of errors in image brightness values.

1^{st} convert the digital number values to radiance, which was converted the DN recorded by the sensor back to the actual energy units that the digital number represents. Radiance can be calculated by the following formula:

$Radiance\lambda = Bias\lambda + (Gain\lambda \times DN\lambda)$

Where λ = ETM/TM band number.

The gain and bias for all bands were considered from the lower (Lmin) & upper (Lmax) stage of the post-calibration spectral radiance range. The gain can be calculated from Lmin

Lmax with this equation: Gain = (Lmax - Lmin)/255

Then converting radiance to reflectance by using ERDAS IMAGINE 2014 Software.

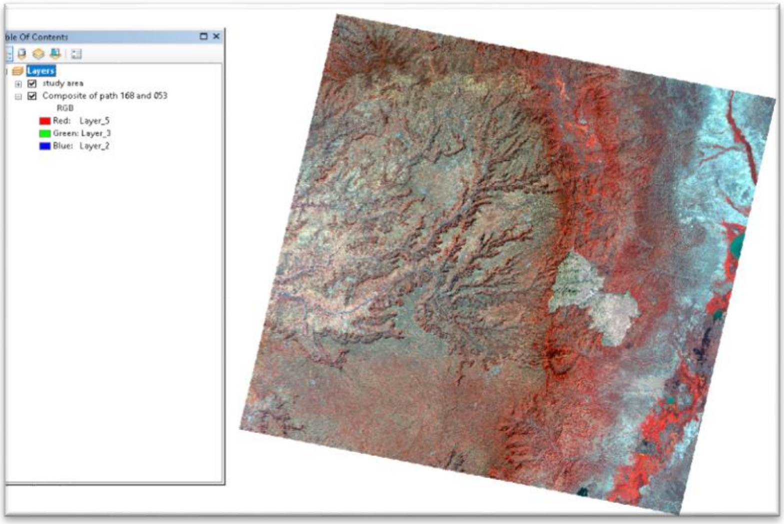

Figure3. 7Original Composite image of path 168 and 053

3.8.5 Land use land cover classification

For this study the classification method was performed by supervised classification with maximum likelihood algorithm. The LULC was divided into six classes, these are mixed forest, water body, built-up areas, shrubs, agriculture and bare land.

Table3. 7 Land use /land Cover Classification

Land cover	Description
Water body	Streams, rivers, swamps, Lakes
Built up areas	All other Buildings and man-made structures. Residential, commercial services, Industrial area, mixed urban area or built uplands and all rural building houses.
Bare land	Land which has occupied with exposed soil, sand or rocks and which never has more than 10% vegetation coverage.
Shrubs	Lands with vegetation less than 2 meters tall.
Mixed forest	Land which covered by trees greater than 60% and height exceeding two meters.
Agriculture	Lands which covered by temporary crops, crop fields and pastures.

3.8.6 Classification Accuracy Assessments

Accuracy assessments or validation is an important phase in the classification procedure(Congalton, 1991). The objective of the accuracy assessment is to give the comparison value between the ground truth which derived from the field investigation, google earth and google map and the classified pixels which derived from land sat. A total of 351 points (locations) were created thought out the study area as shown figure 3.8.

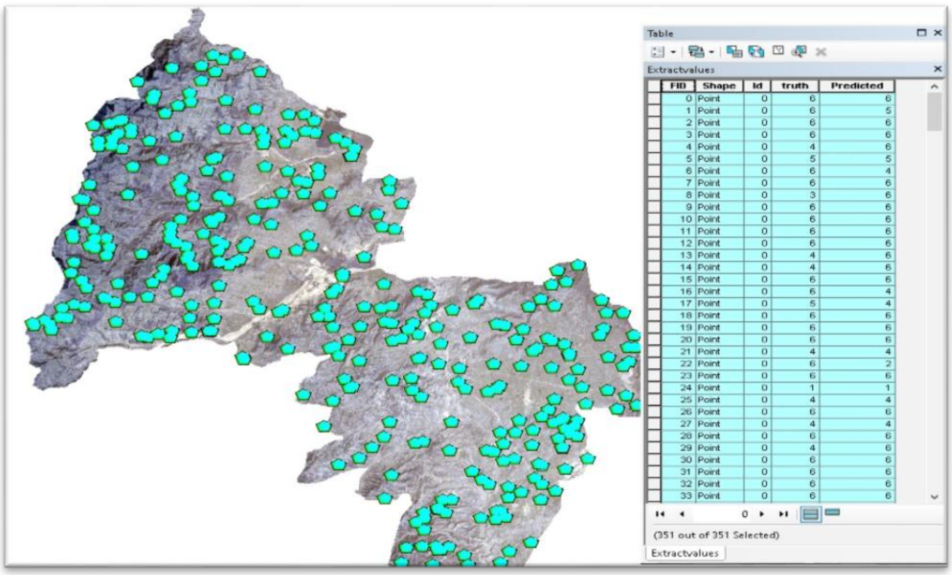

Figure3. 8 Landsat image of the study area and sample points

Kappa analysis is a discrete multivariate method used in accuracy assessments(Rwanga & Ndambuki, 2017). Kappa value varies from zero up to one, which means that zero value indicts no agreement and one value which shows the perfect agreement. A kappa value less than zero indicts poor agreements, kappa value from 0 up to 0.2 shows slight agreements, kappa value from 0.21 up to 0.4 indicts fair agreements .Kappa value from 0.41 up to 0.6 shows moderate agreements. Kappa value from 0.61 up to 0.80 has substantial agreements and kappa value 0.81 up to one indicts almost has perfect agreements(Pontius Jr & Millones, 2011).

K=Observed accuracy –chance agreement /1-chance agreement

- Observed accuracy determined by diagonal in error matrix
- Chance agreement incorporates off-diagonal

3.9 Methodology

As previously mentioned, the aim of this study was to select most suitable solar farm site of kewet wereda using spatial multi-criteria evaluation method. During the selection of suitable solar farm site, GIS 10.5 software package was used. The analysis was done based on different vector and raster layers like LULC, solar radiation, aspect, slope, proximity to roads, proximity to sub-station, proximity to train line, proximity distance to town and proximity to river.

3.9.1 Spatial multi criteria evaluation method

This method can be thought of as a process that combines and transforms a number of geospatial data (input) into a resulting decision(Malczewski, 2004). This methods provide us a set of tools for spatial decision making processes in order to help to find the solutions for multiple choice alternatives. Since this deals with evaluating locational choice alternatives on the beginning of suitability criteria much effort has been made in integrating spatial multi criteria evaluation method with GIS software(Eldrandaly, Eldin, Sui, Shouman, & Nawara, 2005).

3.9.2 GIS-AHP based approach for suitable solar farm site selection

Nowadays, analysis of land-use suitability requires consideration of different criteria including not only the natural/physical capacity of a land unit but also socio-economic and environmental effects(Noorollahi et al., 2016).

AHP has specific application in group decision making, and was used all over the world in different decision situations, in fields such as, industry area, government sector, healthcare sector, business area, shipbuilding, site suitability selection and education(T. L. Saaty, 2013). Somewhat recommending a "precise" judgement, AHP aids for decision makers delivering best generation for their goals and their understanding of the problem(Madurika & Hemakumara, 2017). The essentials of the order be able to join to any feature of the conclusion difficult touchable or intangible, wisely dignified or approximately expected, fit or unwell assumed everything at totally that applies to the choice(Kim et al., 2018).

3.9.3 Methodology used for Analysis of Factors

Numerous literatures have shown that site suitability for solar farm influenced by solar radiation, aspect, land use land cover, sub-station site, road, slope and railway, especially solar radiation is the major limiting factors for solar farm site selection(Effat, 2013).

Table3. 8 Mapping factors and their Importance

Mapping factors	Importance for Mapping
Solar radiation	For identifying the surrounding area average daily receiving solar energy in Kwh/m^2.
Land use/cover	To know types of land covering through the study area.
Sub-station site	For identifying its economical distance from the sub-station site
Road network	For identifying its economical distance from the roads.
River	For identifying its proximity from the rivers.
Railway	For identifying its economical distance from the railway
Slope	For identifying the land surface of the area
Aspect	For identifying the direction /azimuths
Town	For identifying its proximity distance from the town.

3.9.4 The Criteria on Weighting

All criteria were ranked according to their significance expert opinions and literatures. Weights of criteria used for suitability evaluation were obtained using professional experiences of local experts in Kewet wereda and supported by different scientific literatures through pairwise comparisons method following AHP(R. W. Saaty, 1987) a widely accepted decision making method. This method is a mathematical and a flexible for evaluating and making complex decisions to decompose into specific elements by using pairwise comparison(Kim et al., 2018).

3.9.5 Pairwise comparison matrix

It is a method which has commonly used to challenge the individual and unbiased decisions around qualitative and quantitative measures in multi-criteria decision making, especially in the Analytical Hierarchy Process (AHP) denoted as pairwise comparison matrices(Kou, Ergu, Lin, & Chen, 2016).

3.9.6 Evaluation of Matrix Consistency

The consistency ratio was calculated by the following formulas.

$$CI = (\lambda\text{-}n) / (n-1) \text{ -------------------- } (1)$$

The CI stand for Constancy Index, deliver a measure of departure from constancy, to determine the goodness of CI, AHP compares with it by using the random index.

$$CR=CI/RI\text{------------------------------ } (2)$$

CR means constancy ration and Random index (RI) the CI of a randomly created pairwise comparison matrix of order 1to 10 obtained by approximating random indices using a sample size 0f 500(R. W. Saaty, 1987), table 3.9 shows the value of RI sorted by the order of the matrix.

Table3. 9 Random index

Order Matrix	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

The AHP method explained in the following steps:

1. The goal of AHP is locating the top hierarchy criteria, the lower and the sub-criteria by creating ordered problem model for decision making.

2. At each hierarchy, comparison the decision maker expressed the preferences by using saaty scale. It contains 5 level and 4 sub levels, which describe the corresponding numeric standards in the range of 1 to 9.

Table3. 10 The fundamental Scale(R. W. Saaty, 1987)

Importance	Definition	Explanation
1	Equally important	Both activities have equal contribution.
3	Moderately important	Experience and judgment strongly favor one activity over the other.
5	Strong important	Experience and judgment Strongly favor one element over the other.
7	Very strong and important	An activity is strongly important and has dominated in practice compared to the other.
9	Extreme importance	One element has extreme importance in comparison with the highest possible order of affirmation.
2,4,6,8	Inter-values between the two Adjacent judgements	When compromise is needed

3. The assessment was for applying a calculation for individual such as the local criteria, sub-criteria and alternatives are synthesized. The total priority of each alternative is calculated with sum of local priorities that are weighted with weights of elements from higher levels.

4. Then the sensitivity analysis was conducted.

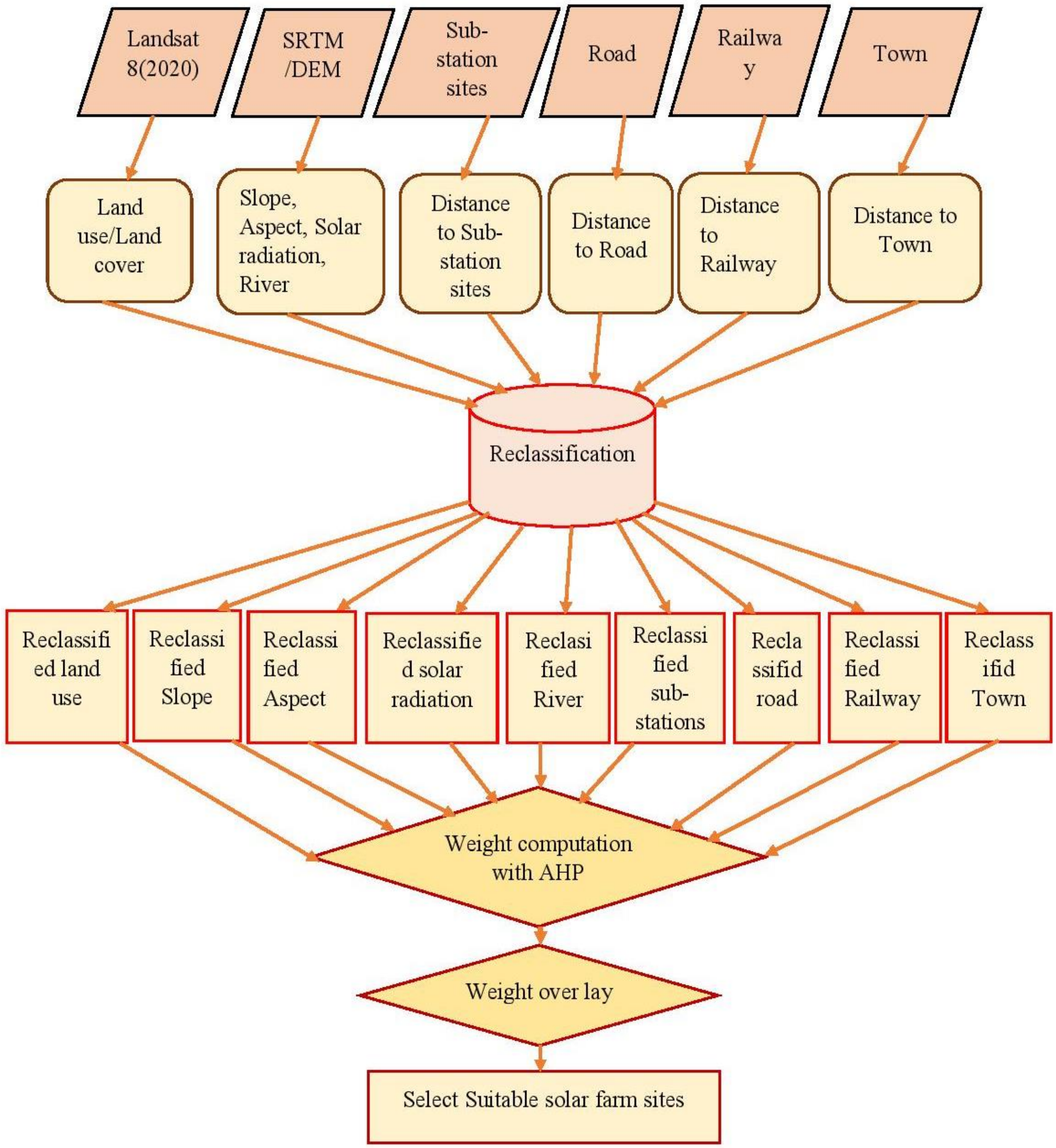

Figure3. 9 Flow chart of the methodology

CHAPTER FOUR

4. RESULTS

This section shows all the results of the study such as, the LULC, the estimated value of solar radiation, parameters of the study and Optimal solar farm sites in Kewet wereda.

4.1 land use /land cover Classification

The LULC of the study area is covered by the agriculture 45%, shrubs 16%, mixed forest 6%, built-up areas 21%, barely lands 9%and 3% water body.

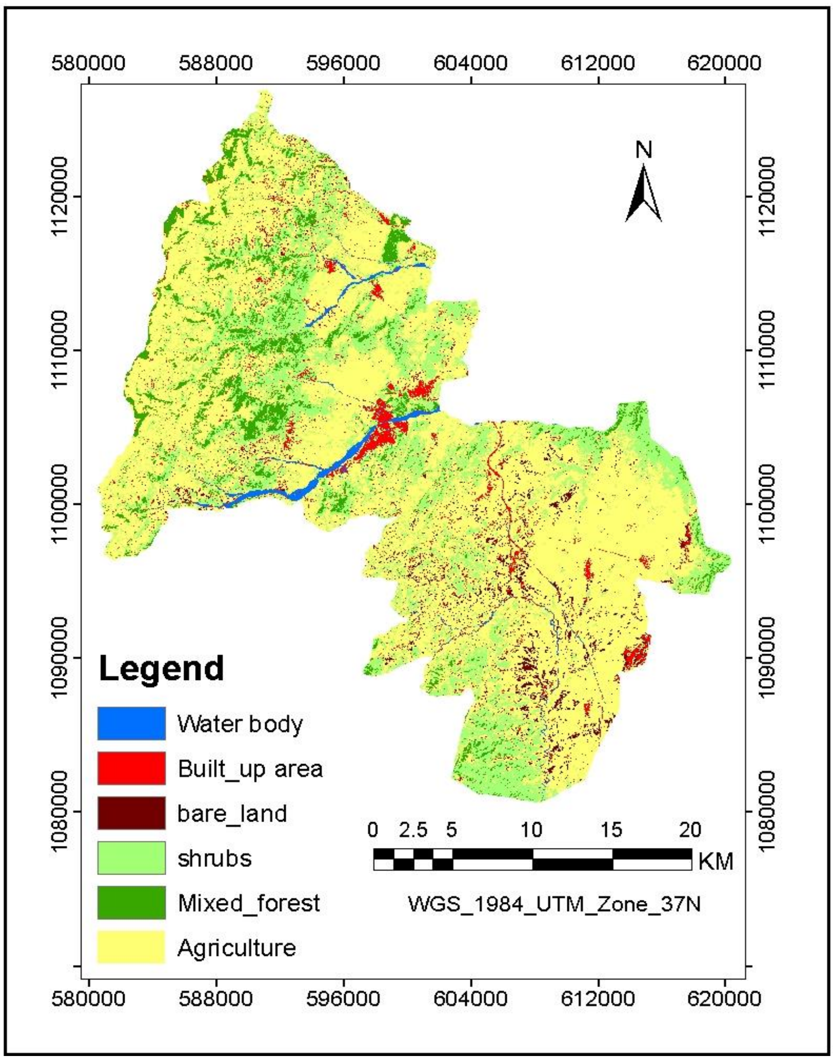

Figure4. 1 Study area land use/ land cover classification

Table4. 1 Area coverage of classified LULC map

Land cover classes	Area in Km2	Area Percentage (%)
Water Body	22.550	3
Built up areas	167.517	21
Bare land	68.670	9
Shrubs	124.783	16
Mixed forest	51.520	6
Agriculture	350.800	45
Total	785.84	100

4.2 Classification Accuracy Assessments

The classified LULC map of Kewet Wereda has an overall classification accuracy of 87.7 % and kappa value of 81%.

Table4. 2 Error Matrix of LULC Classification

Classified	Water Body	Built up Areas	Bare Land	Shrubs	Mixed Forest	Agriculture	Total	Correct sampled	User accuracy (%)	Commission error (%)
Water body	**33**	0	0	0	0	1	**34**	33	97.1	2.9
Built up areas	1	**81**	10	1	3	2	**98**	81	82.7	17.3
Bare land	0	0	**18**	0	0	0	**18**	18	100	0
Shrubs	0	0	5	**31**	1	3	**40**	33	82.5	22.5
Mixed Forest	0	0	3	3	**35**	2	**43**	35	83.4	18.6
Agriculture	2	3	2	1	2	**108**	**118**	108	91.5	8.5
Total	**36**	**84**	**38**	**38**	**41**	**116**	**351**	**308**		

producer Accuracy (%)	**91.7**	**96.4**	47.4	**81.6**	85.4	93.1	Over all accuracy =87.7%
Omission Error (%)	**8.3**	**3.6**	52.6	**13.2**	14.6	6.9	Kappa=81%

4.3 Estimated solar radiation of the study area

The international energy agency (2010) nominated that, any surface with different climatic condition which have the estimated solar radiation greater than 1300kWh/m2 have potential for produce solar energy. The study area solar radiation was estimated by using DEM its value range from 1,179 up to 2,458 KWh/m2 as shown in the following figure 4.2.

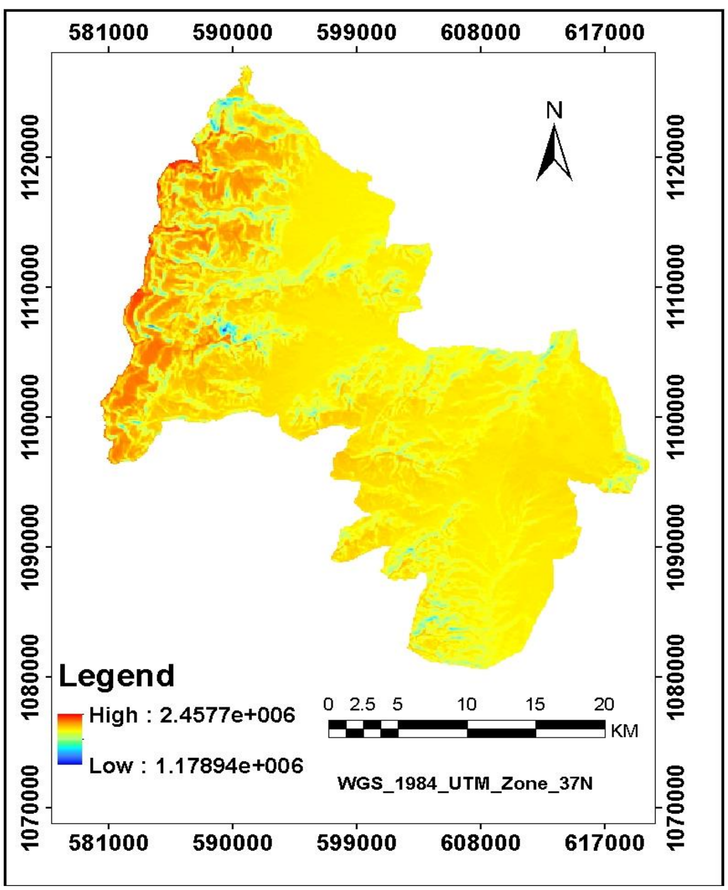

Figure4. 2 Estimated solar radiation of the study area

4.4 Parameters of solar farm site suitability analysis

4.4.1 Reclassified Slope

The slope is one of the factors for selecting optimal solar farm sites. There are high relations between slope and solar farm site selection which indicate that the slope less than 15degre were good such that <3 degree is highly suitable, from3 up to 5 degrees is suitable, from 5 to15 degrees is less suitable but greater than 15 degrees taken as unsuitable because of its economic factors(Yousefi, Javadzadeh, Noorollahi, & Yousefi-Sahzabi, 2018). The study areas which have less than 3 degree gradient were reclassified as highly suitable and greater than 15 degree gradient taken as unsuitable .This study areas suitability ranges show as the following table4.3.

Table4. 3 Reclassified Slope values

Old values (degree)	New Values	Suitability range
0-3	1	Highly suitable
3-5	2	Suitable
5-15	3	Less suitable
15-53	4	Unsuitable

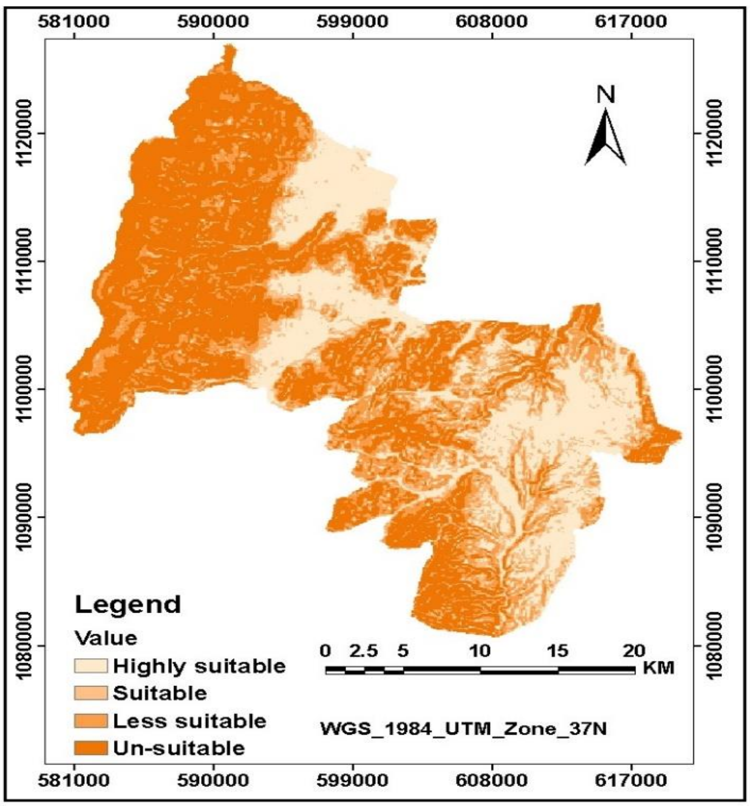

Figure4. 3Suitability map of slop

4.4.2 Reclassified Aspect

The suitability aspect of for solar farm site selection high radiation received in orientation of respectively south, southeast, southwest and flat area taken as high potential solar radiation, east – face and west-face are medium potential and north, northeast and northwest taken low potential Southeast, southwest azimuthal directions are considered suitable to produce the most solar energy (Effat, 2013; Mierzwiak & Calka, 2017; Teshome, 2014). The study area suitability rang shows as the following table 4.4.

Table4. 4 Reclassified values for Aspect dataset

Orientation (degrees)	Suitability range	Suitability
Flat, South	1	High suitability
Southeast, Southwest	2	Suitable
East, West	3	Less suitability
North, Northeast, Northwest,	4	Unsuitable

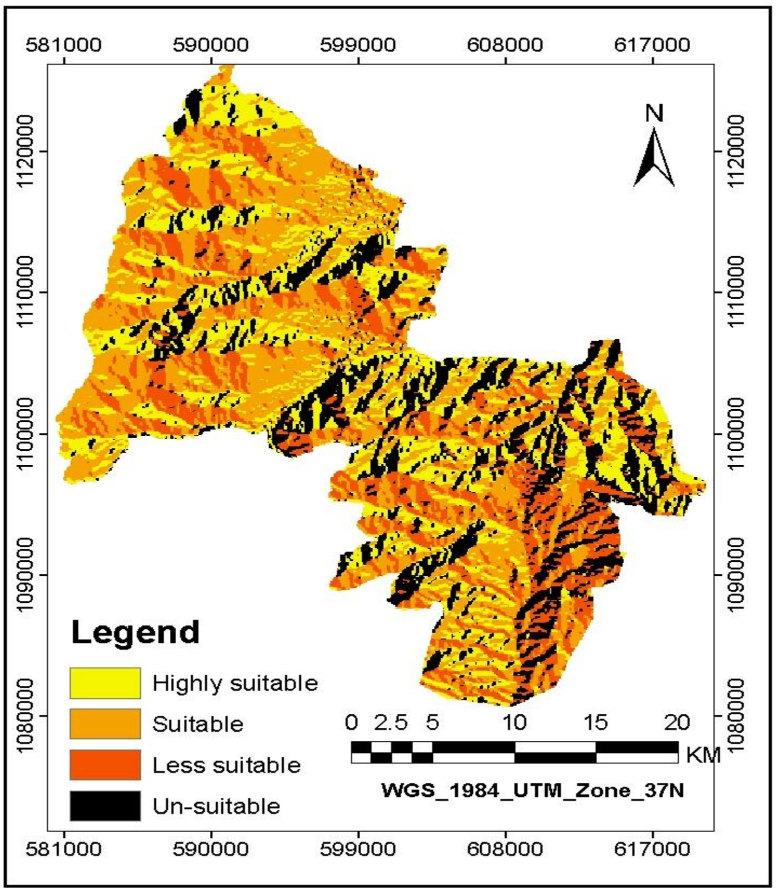

Figure4. 4 Suitability map of aspect.

4.4.3 Distance to Road

The road proximity to the solar farm site is divided based on its economical factor, so <500 meter was taken as highly suitable, 500-1000m taken as suitable, 1000-1500m taken as less suitable and >1500 meter taken as unsuitable(Effat, 2013; Kereush & Perovych, 2017; Nebey et al., 2020). The following table 4.5 shows the reclassified value and the suitability map of the road.

Table4. 5 Reclassified distances of roads

Old values in meters	New values	Suitable Range
0-500	1	Highly suitable
500-1000	2	Suitable
1000-1500	3	Less suitable
>1500	4	Unsuitable

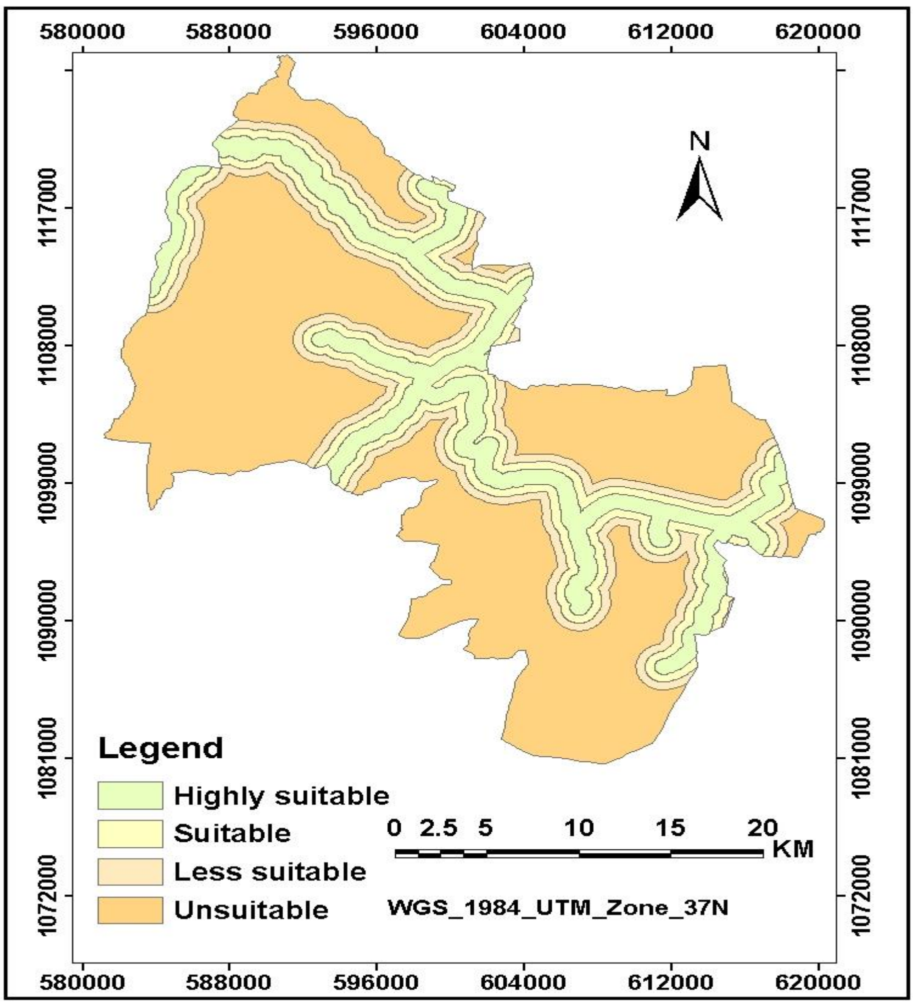

Figure4. 5 Suitability distance of the roads.

4.4.4 Distance to Sub-station

The proximity distance from sub-station is determined based on their distance to the desired site distance from 0 to 500 taken as high potential, from 500-1500 taken as medium potential and greater than 1500 taken as low potential(Mierzwiak & Calka, 2017).The nearest distance to sub-station is very important in order to transport the produced energy to sub-station, so the proximity of the sub-station is taken 0-500 highly suitable area, 500-1500 suitable, 1500-2500 less suitable and >2500 taken as unsuitable area as shown in the following table4.6.

Table4. 6 Reclassified distance of sub-station

Old values in meters	New values	Suitability Range
0-500	1	Highly suitable
500-1500	2	Suitable
1500-2500	3	Less suitable
>2500	4	Unsuitable

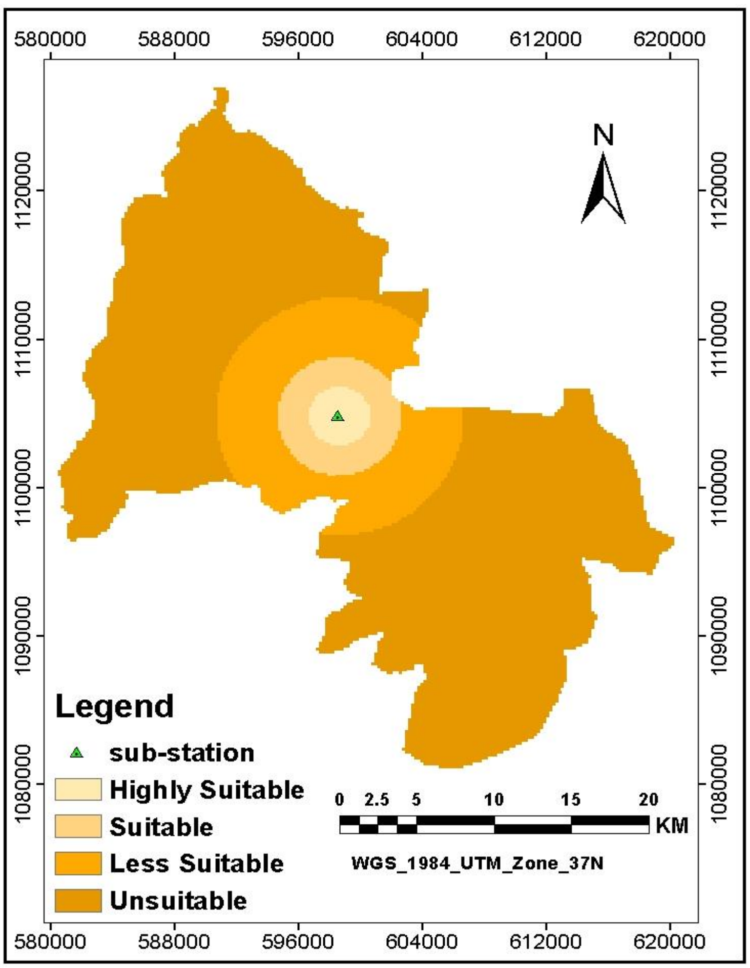

Figure4. 6 Suitability map of sub-station

4.4.5 Distance to River

The proximity of distance from the river is determined based on their distance to the desired site distance from >1500 taken as a high potential, from 1000-1500 taken as medium potential, 500-1000 less potential and less than 500 taken as low potential(Mohamed, 2020). In this study area the water body found only river so, for selecting a suitable site of a solar farm through the study area and to determine the suitability range we use as the following table 4.7.

Table4. 7 Reclassified Distance of River

Old values in meters	New values	Suitability range
0-500	1	Unsuitable
500-1000	2	Less suitable
1000-1500	3	Suitable
>1500	4	Highly suitable

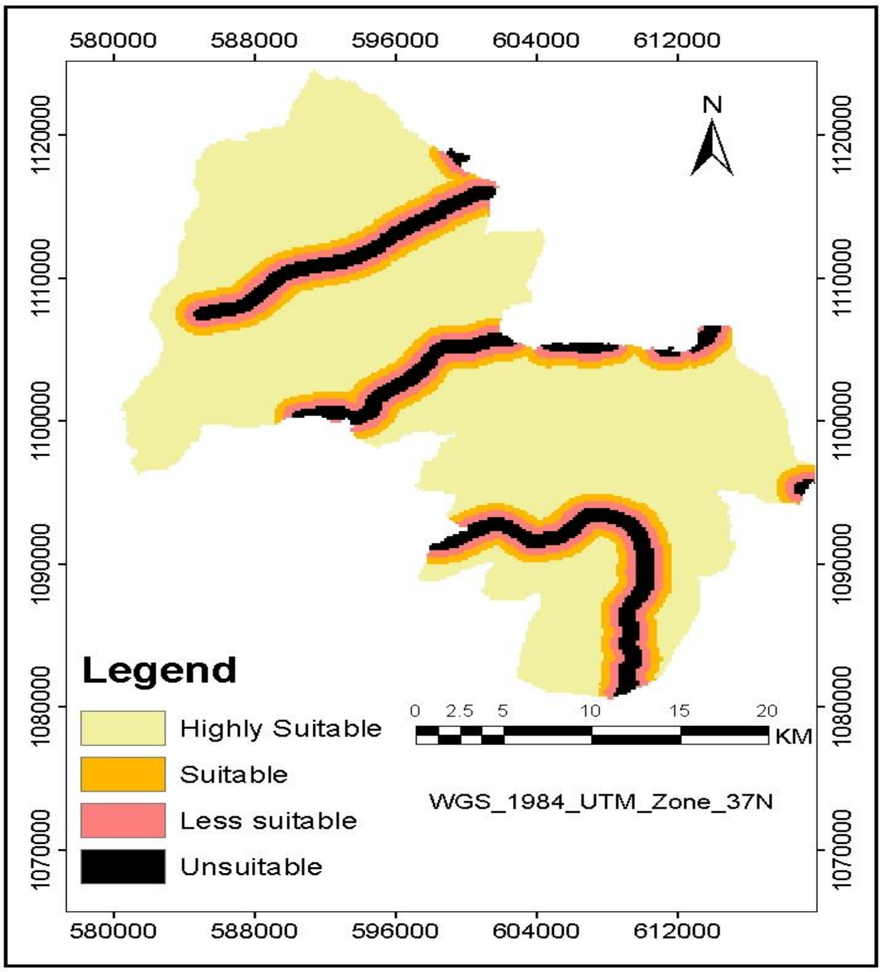

Figure4. 7 Suitability distance of river.

4.4.6 Distance to Railway

Distance to railway and distance to road have equal factor for determining suitable site for solar farm site selection in the case of this proximity of distance to railway is <500 meter high suitable,500-1000 meter suitable, from 1000-1500 less suitable and >1500m unsuitable distances to railway(Bahaidarah, Rehman, Subhan, Gandhidasan, & Baig, 2015; Collins et al., 2001; Effat, 2013). Distance to railway was reclassified as the following table 4.8.

Table4. 8 Reclassified Distance to Railway

Old values in meters	New values	Suitability range
0-500	1	Highly suitable
500-1000	2	Suitable
1000-1500	3	Less Suitable
>1500	4	Unsuitable

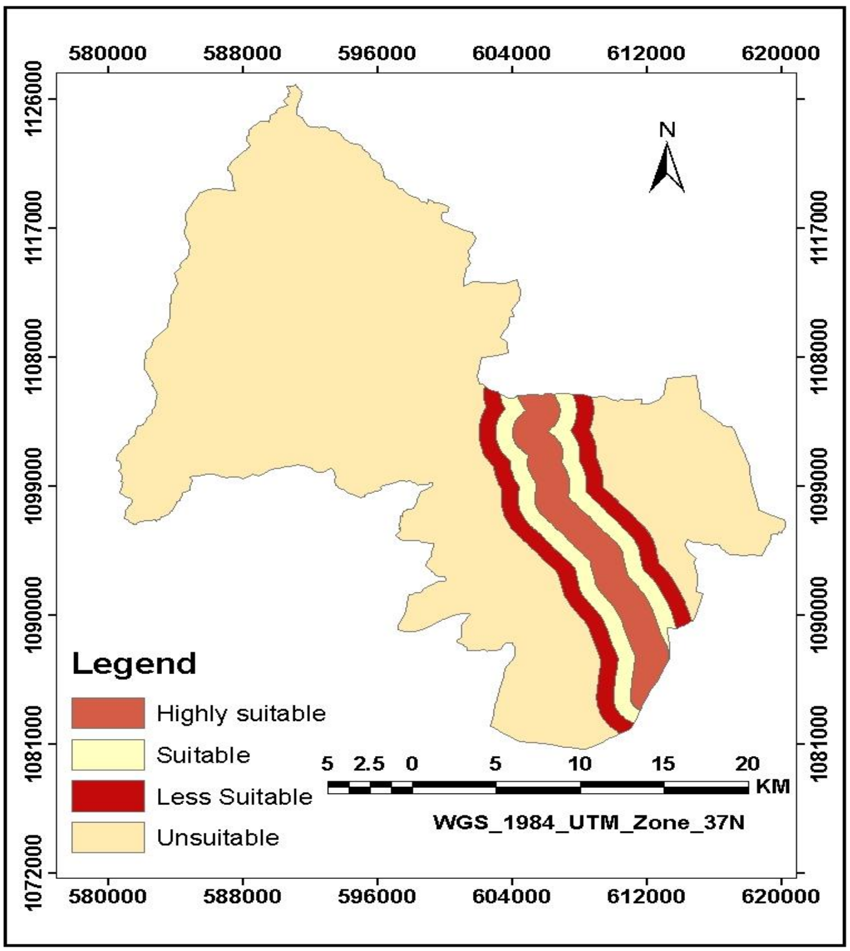

Figure4. 8 Suitability map of railway.

4.4.7 Distance to Town

Distance to town was the main necessary factor to select suitable solar farm site, they categorized the farthest distance from the town as highly suitable and the shortest distance to the town taken as unsuitable they reclassified as highly suitable (>6km),suitable(4-6km),moderately suitable (2-4km)and unsuitable (<2km)(Hsueh; Kereush & Perovych, 2017; Nebey et al., 2020).The study area's suitability range were reclassified as highly suitable when the distance is greater than 6km, suitable (4-6km),less suitable when the distance is (2-4)km and unsuitable(<2km) as shown in table 4.9.

Table4. 9 Reclassified Distance to Town

Old values in meters	New values	Suitability range
0-2000	1	Unsuitable
2000-4000	2	Less suitable
4000-6000	3	Suitable
>6000	4	Highly suitable

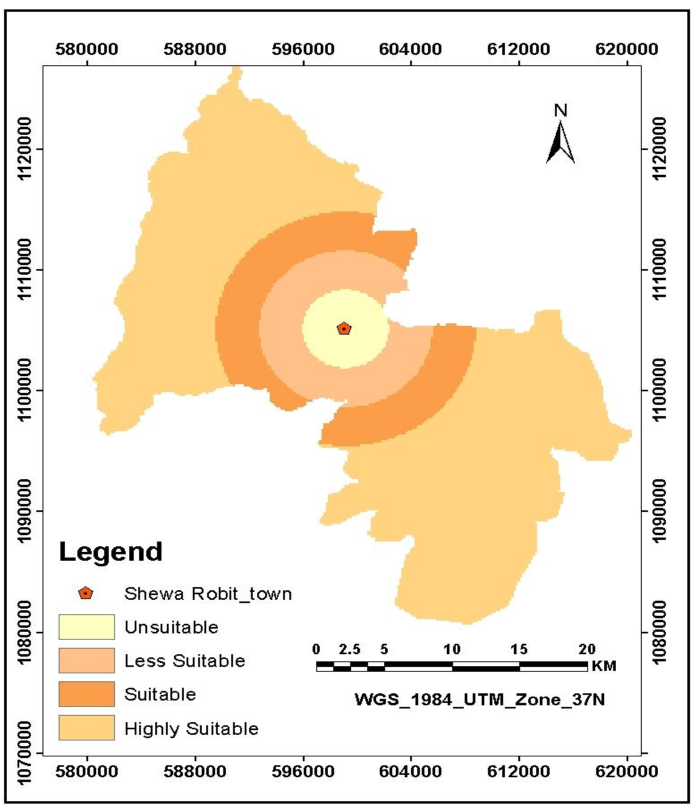

Figure 4. 9 Suitability map of town.

4.4.8 Reclassified Solar Radiation

Selecting the best site for solar farm depend on the abundance of solar radiation. The solar radiation greater than 1900 kWh/m2/year reclassified as highly suitable, suitable (1600-1900KWh/m2/year), less suitable (1300-1600KWh/m2/year) and unsuitable less than 1300 kWh/m2/year(Effat, 2013; Piirisaar, 2019; Tahri et al., 2015). The following table 4.10 shows suitability range of this study.

Table4. 10 Reclassified Values of Solar Radiation

Old values in kWh/m2 per year	New values	Suitability range
>1900	1	Highly suitable
1600 -1900	2	Suitable
1300-1600	3	Less suitable
<1300	4	Unsuitable

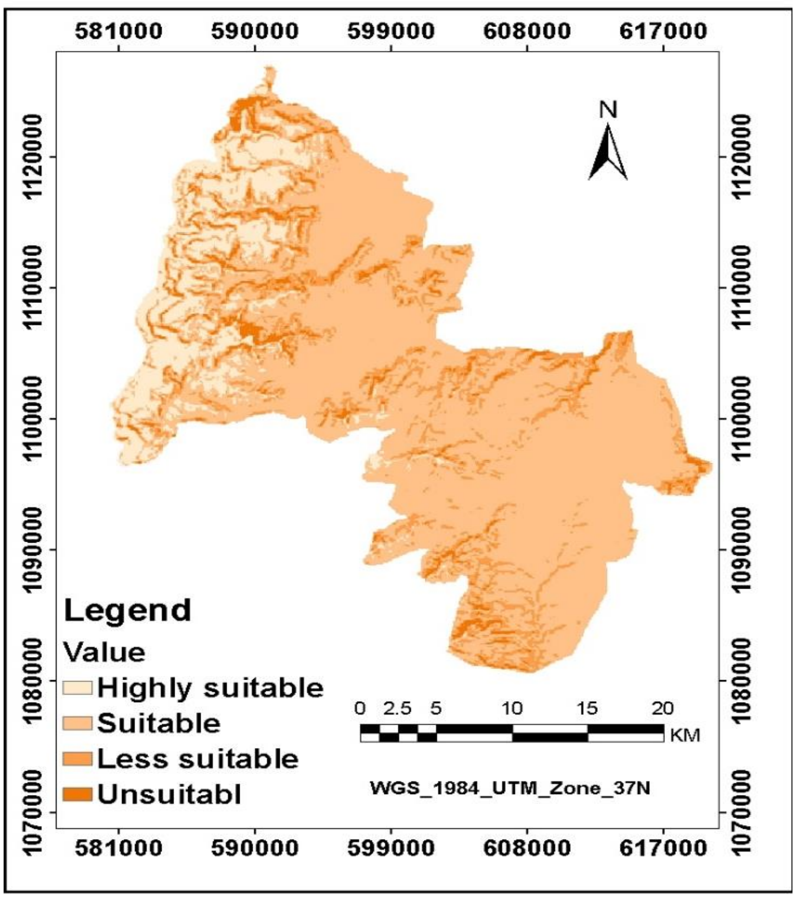

Figure4. 10 Suitability map of solar radiation

4.4.9 Classified Land use land cover

The land use land cover of this study areas suitability range was reclassified into four. bare land and shrub's was taken as high suitable area, agriculture was taken suitable, mixed forest land was taken as less suitable and water body and built up areas taken as unsuitable(Effat, 2013; Latham, He, Alinovi, DiGregorio, & Kalensky, 2002; Mohamed, 2020).

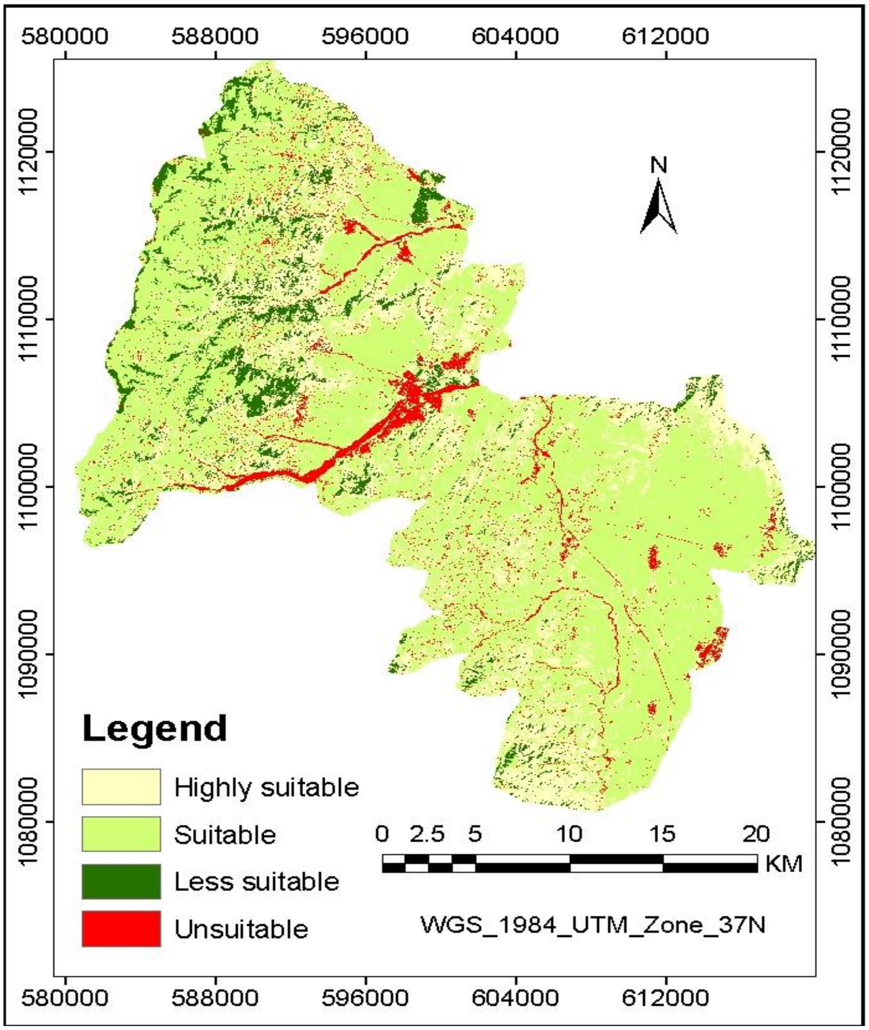

Figure4. 11 Suitability map of land use land cover

4.5 Optimal solar farm sites in the study area.

The study area optimal solar farm sites derived by using the parameters and calculating their weights using pairwise comparison then doing weight overlay by using ArcGIS10.5.

4.5.1 Weight derivation using pairwise comparison matrices

The nine criteria such as solar radiation, aspect, slope, sub-station site, road, railway, land use land cover, town and river. These nine criteria pairwise comparisons calculate priorities using Analytic Hierarchy Process. The constancy ration of this pairwise comparison result is 7%, which is less than 10% and acceptable so we can use this driving weight for next step software work.

Table4. 11 The weight result for the criteria based on our pairwise comparisons

S.NO.	Criteria	Priority	Rank
1	Solar radiation	36.6%	1
2	Aspect	17.3%	2
3	Slope	13.1%	3
4	LULC	8.2%	4
5	Railway	5.9%	5
6	Sub-station site	5.7%	6
7	Town	5%	7
8	Road	4.8%	8
9	River	3.4%	9

Table4. 12 The weight result of decision matrix based on the principal Eigenvector

S.NO	Criteria	1	2	3	4	5	6	7	8	9
1	S.radiation	**1**	5.00	3.00	3.00	9.00	7.00	7.00	3.00	9.00
2	Aspect	0.20	**1**	2.00	4.00	5.00	3.00	3.00	3.00	3.00
3	Slope	0.33	0.50	**1**	2.00	5.00	3.00	2.00	3.00	2.00
4	LULC	0.33	0.25	0.50	**1**	2.00	2.00	2.00	2.00	2.00
5	Railway	0.11	0.20	0.20	0.50	**1**	2.00	2.00	2.00	2.00
6	Sub-station	0.14	0.33	0.33	0.50	0.50	**1**	1.00	2.00	4.00
7	Town	0.14	0.33	0.50	0.50	0.50	1.00	**1**	1.00	2.00
8	Road	0.33	0.33	0.33	0.50	0.50	0.50	1.00	**1**	2.00
9	River	0.11	0.33	0.50	0.50	0.50	0.25	0.50	0.50	**1**

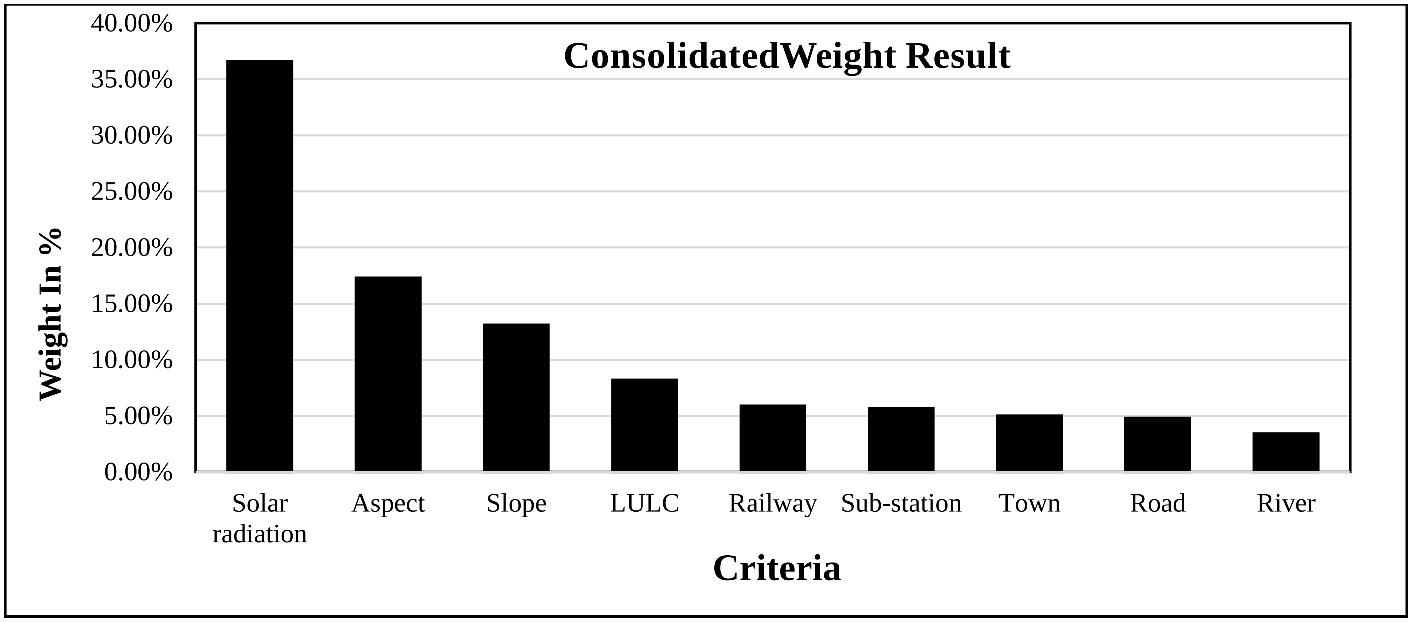

Figure4. 12 The output of the criteria weighted using by pairwise comparison matrix methods

4.5.2 Weighted overlay analysis

The weighted overly analysis was done by using ArcGIS 10.5 Spatial analyst tool. The final step was aggregate all reclassified raster datasets that include solar radiation, aspect, slope, road, railway, sub-station, river, land use land cover. All these raster data sets were aggregate based on their weighted level. The below table 4.13 generalized the weights of all criteria, all factor value and assigned in the weight overlay tool.

Table4. 13 The criteria used in the solar farm suitability analysis

Sn	Criteria	Weight%	Factors	Suitability	Reference
1	Solar radiation	36.6	>1900 kWh/m2 per year	Highly suitable	(Effat, 2013; Piirisaar, 2019; Tahri et al., 2015).
			1600 -1900	Suitable	
			1300-1600	Less Suitable	
			<1300	Unsuitable	
2	Aspect	17.3	Flat, south	Highly suitable	(Mierzwiak & Calka, 2017; Teshome, 2014).
			South east, southwest	suitable	
			West, east	Less suitable	
			North, northeast/west	Unsuitable	

3	Slope	13.1	<3% 3-5% 5-10% >10%	Highly suitable Suitable Less suitable Unsuitable	(Jaugsch & Löwner, 2016; Yousefi et al., 2018).
4	Distance to sub-stations	5.7	<500 meter 500-1500 1500-2500 >2500	Highly suitable Suitable Less suitable Unsuitable	(Effat, 2013; Mierzwiak & Calka, 2017) .
5	Distance to Road	4.8	<500 meter 500-1000 1000-1500 >1500	Highly suitable Suitable Less suitable Unsuitable	(Effat, 2013; Kereush & Perovych, 2017; Nebey et al., 2020).
6	Distance to Railway	5.9	<500 meter 500-1000 1000-1500 >1500	Highly suitable Suitable Less suitable Unsuitable	(Kereush & Perovych, 2017; Nebey et al., 2020).
7	Distance to River	3.4	<500 meter 500-1000 1000-1500 >1500	Unsuitable Less suitable Suitable Highly suitable	(Abdelrazek, 2019, Piirisaar, 2019).
8	Distance to Town	5	<2000 meter 2000-4000 4000-6000 >6000	Unsuitable Less suitable Suitable Highly suitable	(Mierzwiak & Calka, 2017; Mohamed, 2020).
9	Land use land cover	8.2	Bare land, shrub Agriculture Mixed forest Water body, built up	Highly suitable Suitable Less suitable Unsuitable	(Effat, 2013; Latham et al., 2002; Mohamed, 2020).

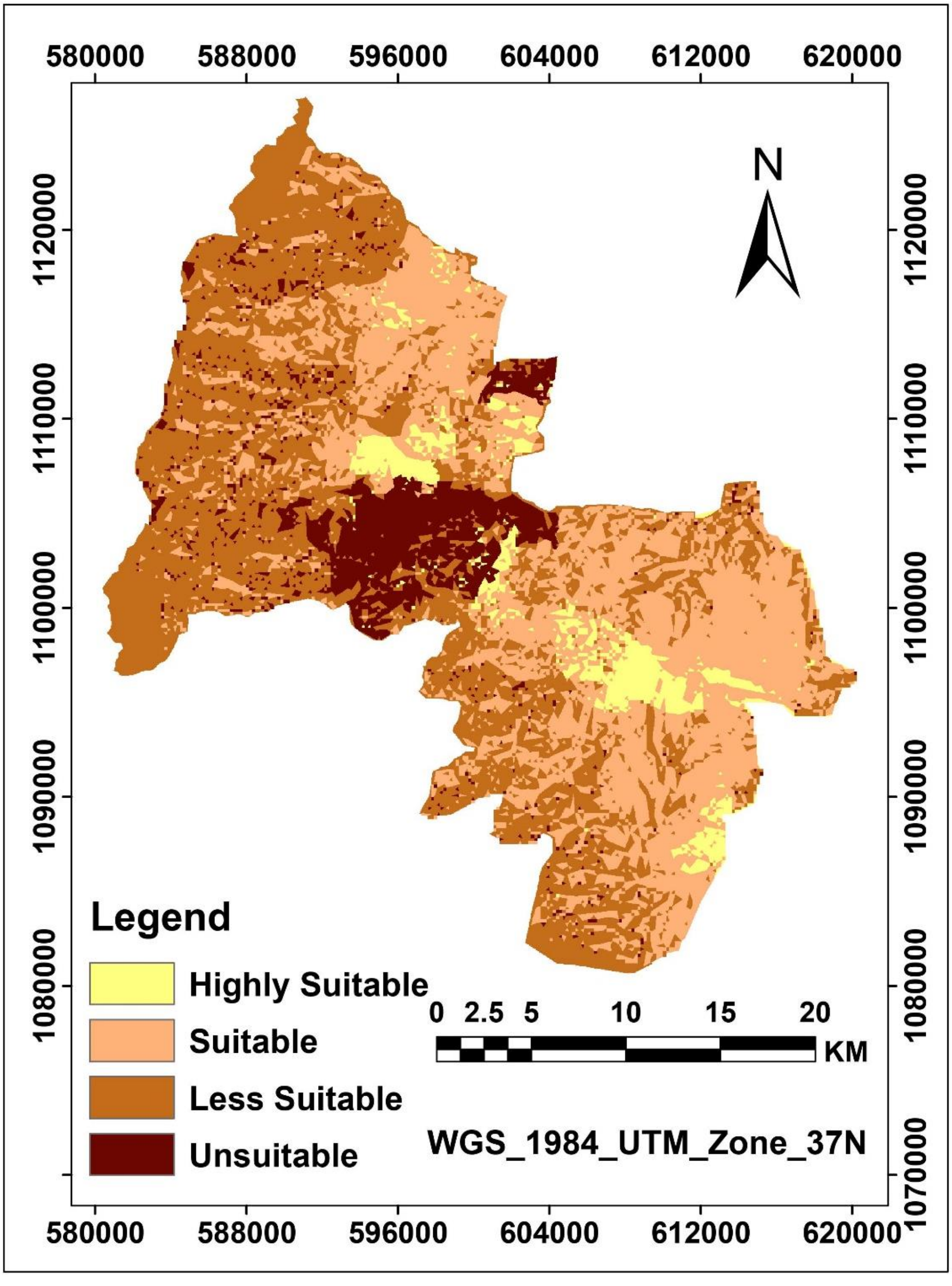

Figure4. 13 Suitable Map of the Study Area

CHAPTER FIVE

5. Discussions

GIS and different geospatial technology are used for analysis and combination of different features that are used to indicate suitable solar farm sites. In doing this study, we have used different vector and raster data format such as Landsat data, road, sub-station, railway and digital elevation model. DEM has great factor in this study to estimate the study areas solar radiation and almost all the environmental factors are drive from it, such as slope, aspect, solar radiation and river streams. The estimated solar radiation depended on the resolution of DEM as well as the parameters such as time interval and sky size resolution(Mierzwiak & Calka, 2017). Higher resolution with smaller time interval and bigger sky size results more accurate output, but also increases considerable calculation time.

GIS-based spatial multi criteria evolution method was applied to select the ideal location for selecting a suitable solar farm site at kewet wereda. In addition to solar radiation potential, various topography, economic and environmental factors were taken into considering in the site selection process. As environmental (solar radiation, aspect, slope), economical (proximity to road, proximity to sub-station, proximity to the railway, proximity to the river and proximity to town). The accuracy assessments and the weighted of the study area were both have acceptable values.

(Pontius Jr & Millones, 2011) Kappa value 0.81 up to one indicts almost has perfect agreements. The study area accuracy assessment was done with 351 points based on this points the accuracy, verify by field survey, google earth and google map and we generate 87.7 % of overall accuracy and kappa value 81% which match with our study area so, it was acceptable to do further analysis. According to (R. W. Saaty, 1987), the AHP pairwise comparison CR value less than 0.1 is acceptable. So, this study weight was derived from the AHP pairwise comparison method its CR value was 0.07 which is less than 0.1 and the weight was acceptable.

The solar farm suitability analysis result tells that, the most suitable area found in the south, southeast, northeast direction and the approximately coverage area is 4465.31 hectares of the study area highly suitable with 6% of the study area, 31523.4 hectares area covered with suitable represented by 40%, 34729.93 hectares area less suitable represents by 44% of the study area and 7723.52 hectares unsuitable represents 10% of the study area.

In the same title (Teshome, 2014) was also used a multi-criteria approach in his GIS analysis to select suitable solar farm site throughout Ethiopia. By using six criteria and with low resolution satellite image and his study area coverage was very large. Which included all Ethiopian area so, in case of wide area coverage the researcher was verified the accuracy assessments with google earth and google map. Because of this, the researcher have poor accuracy classification and less accurate result, but in this study which differ from Teshome the coverage of the study area was limited and which have done with nine criteria and with 30 meter resolution of satellite image and the accuracy of the study area classification was verified by field trip, high resolution satellite image, google earth and google map which have acceptable classification and good result.

(Bayou & Assefa, 1989) was estimated the solar radiation from six stations measured data by using interpolation methods and mapped the Ethiopian solar energy distribution, in addition (Tucho et al., 2014) was estimated the solar radiation from 17 stations measured data by interpolating to know the solar energy potential of Ethiopia. (Kumar et al., 1997) unlike temperature and rainfall, solar radiation cannot be measured at sample meteorological stations and cannot be interpolated for the surrounding areas. This is mostly since incoming solar radiation is extremely dependent on landscape and geographical structure(Gastli & Charabi, 2010). Tesfay and Sharew was identified and mapped the solar energy of Ethiopian with a few stations by interpolation with all Ethiopia's topography features from the lowest depression (-125 meter) to the highest elevation (4550 meter), because of this, their result is less necessary. But this study differ from both of them with methods, coverage area and data usage, this thesis was cover less area and done with determining solar radiation by using 30 meter resolution satellite data which contain all the topography of the study area and determine good solar radiation value with using nine criteria such as based on economic factors (road, sub-station, railway, river, town, LULC) and environmental factors (solar radiation, slope, aspect) were used to do this study.

CHAPTER SIX

6. Conclusions and Recommendations

6.1 Conclusions

This study assesses suitable solar farm sites of Kewet wereda based on spatial multi criteria evaluation methods by ArcGIS software using different type of spatial and non-spatial data. The obtained results show that there was high potential of solar farm sites in Kewet wereda. However the geographical location of the country has a high advantage for acquiring high potential zone of the solar farm site in the study area, because it found at sub Saharan African countries. The 35988.71 hectares area was selected as an optimal location for selecting solar farm sites. The analysis was done with the account of various topographic, economic, social and environmental factors such as solar radiation, aspect, slope, land use land cover, proximity distance to road, proximity distance to sub-station, proximity distance to railway, proximity distance to river, proximity distance to town.

The result shows that solar radiation has the highest weight and distance to river has the lowest weight with 36.6% and 3.4%. Also highly suitable, suitable, less suitable and unsuitable areas were cover in the study area with 6%, 40%, 44%and10 % respectively. Highly suitable or the most potential of solar farm sites were found in the south, southeast and northeast parts of the study area. This potential zone contributes to fill the energy gap between the demand and supply of the country when there was a shortage of rainfall through the country and shortage of water at the dam. It was also used as bridge for energy gap between rural and urban communities. If the country starts to use this high green solar potential the community's energy gap will be eliminated and people live high standard life with easily accessing energy.

6.2 Recommendations

Majority of the local residence that live in study area don't get enough water supply, clinical service and telecommunication, service, good school environments because of lack of electric energy so, the government of Ethiopia must be see different alternative energy source, such as solar energy for addressing the shortage of energy for the local residence.

There is high lack of accessible organized spatial and non-spatial data through the study area so, the concern body such as Ethiopian EPCo, they must convert their sub-station data in digital form to access easily, Ethiopian metrological data must be gathered and measure the solar radiation with instrument which have more advantage for more analysis in the future studies. In addition, I recommended for Ethiopian space science and technology institute, they must organize and archive all geospatial information data and deliver high resolution data for the user to doing better analysis throughout the country. In addition I want to recommend to the government and private business sector to use this study paper for minimizing the shortage of energy and achieving the prosperity goal of the country. Lastly, I recommended to spread future studies throughout the country related to suitable solar farm site selection with additional data sets to solve the shortage of energy in rural and urban society.

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