Site suitability analysis of Solar PV Power generation in South Gonder, Amhara Region

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Abstract

Currently, Ethiopian government looked towards renewable energy resources to generate electrical power for the country needs. 85% of the total population of the country live in rural areas and use wood and fossil fuel for their domestic uses. Using wood and fossil fuel is danger for users and the environment. And the government of Ethiopia planned to electrify 85% rural community with abundantly available renewable resources around the community. Therefore, identifying potential locations for solar Photovoltaic with geographic information system is a decision support tool for proposing the suitable sites to stakeholder. The solar Photovoltaic suitability analysis provides optimal locations to solar Photovoltaic power plant installations. To find suitable locations for Solar Photovoltaic , factors that affect the suitability were identified and weighted by using Analytical Hierarchy processes. Then the weighted values and reclassified values were multiplied together to produce the final suitability map to solar Photovoltaic. Due to site unsuitability, solar Photovoltaic the efficiency drops and may malfunction. By identifying the most suitable locations, solar PV power plant was optimally located. Therefore, the objective of this study was to find the most suitable sites in South Gonder Zone for generating power from solar Photovoltaic . The suitability of the study area for solar Photovoltaic power plant was 86.5%. Eighty six (86%) of the criteria considered in the study area was found to fulfill all the criteria to be suitable for solar Photovoltaic power plant. Most of the suitable areas were found in the western part of the zone. Nature topography is a key factor in generating solar energy; it affects the solar irradiance coming to the solar Photovoltaic panel surface.

1. Introduction

Renewable Energy is derived from natural process constantly. It is economically feasible, easy to use, less pollution, and abundant in nature. Therefore, renewable energy is more important than none renewable sources of energy. Using renewable energy maintains the environment and does not contribute to global warming[1, 2]. In the context of Ethiopia, it is not good condition, since most of the families use wood and fossil fuel for their domestic uses. This will affect development of country and health of community. The development of country depends on exploiting renewable energy resources, and to use it optimally. Ethiopia is blessed with an abundance renewable energy resource like solar, wind, hydro, and others. Amahara is the region, where these renewable energies are available throughout the year[3, 4].

Ethiopia has a higher potential to exploit renewable energies for domestic applications. This vast renewable energy resources potential is not exploited sufficiently in the country, primarily due to the lack of scientific and methodological know-how in regards of planning, site selection, and technical implementation. A further constraint prohibiting their utilization is that the real potential of these resources locations are not well-known, because of the lack of research emphasis[3, 4].

Even though the government of Ethiopia recently, took steps towards renewable energy resources, there is problem in identifying the exact resources locations. The efforts were not organized and this is due low number of researches to explore locations in Ethiopia .Therefore, the aim of this study was to find suitable locations for solar PV in four districts (Dera,Estie, Farta,and Foger) of South Gonder Zone Amhara region, Ethiopia(Fig. 1).

2. Study Area And Data Settings

A suitability analysis for solar power installation was conducted in South Gonder Zone, Amhara region. Amhara region is located the north-western parts of Ethiopia between $9^{\circ}20'$ and $14^{\circ}20'$ North latitude $36^{\circ}20'$ and $40^{\circ}20'$ East longitude. Its area is estimated about 170000 square kilometres[5]. The region has twelve zones, and there was no more electricity access to town and the surrounding community in these zones.

South Gondar is one of Zone in the Amhara Regional state. Shouth Gonder zone is located at $11^{\circ} 50' 19''$ N latitude and $38^{\circ} 5' 58''$ E longitude[5].

In locating suitable areas for solar power plants ArcGIS10.4.1 was used. To analysis site suitability, none suitable sites were excluded like towns, water bodies, schools/protected areas and the weight of criteria was formulated for decision making[6–8]. Data set rasterizing and reclassifying have been conducted on vectors and raster layers like solar irradiance, distance from roads, towns, soil, slope, land use land cover, forest, stream and distance from school areas respectively. Finally, reclassified data were combined by using ArcGIS overlay tool[9–11].

The datasets were obtained from different sources in vector formats and then vector data were converted to raster with conventional tool of ArcGIS10.4.1. Thus the raster outputs of data sets were reclassified and finally overweighed to show results for finding suitable sites[12–14].

There are three tasks, in finding the suitable areas for solar power plant installations.

1. Data preparation and criteria formulation as the nature of the study areas, then insert the data into ArcGIS10.4.1 software as layers.
2. Reclassify the data sets
3. Overlaid the reclassified data

2.1 Analytic Hierarchy Process (AHP) for criteria Evaluation

Analytic Hierarchy Process (AHP) is one of multi criteria decision making method. Thus a pairwise comparison method was used to make complex decision problems in this paper. The input was obtained from subjective opinion like satisfaction feelings and preference. The pairwise comparison of the attributes makes it easy to decisions for complex problems. It compares the importance of the two the attributes at one time (Table 1).

Table 1
Fundamental Scale for Pairwise Comparisons[13, 15]

Degree importance	Definition	Explanation
1	Equal importance	Criteria equally important to the objective
3	Moderate importance	One criteria slightly importance over another
5	Strong importance	One criteria strongly importance than another
7	Very strong importance	One criteria very strongly importance than another
9	Extreme importance	One criteria extreme importance than another
2,4,6,8	Intermediate values	A compromise is needed

2.2 Selecting criteria for solar Photovoltaic installation

In finding the potential sites for solar power plant, site selection is depending on the weights of each layer. Opinions of experts were used to determine each site selection criterion for locating solar PV[10, 11, 16]. Solar Irradiance, roads, town, soil, slope, land use, land cover, forest, stream and schools were used to create a model to identify suitable locations for solar PV as per nature of the study area (Table 2).

Table 2
Decision maker matrix of solar PV power plant

Criteria		1	2	3	4	5	6	7	8	9
		Irradiance	Roads	Town	Soil	Slope	Land	Forest	stream	school
1	Irradiance	1	5	6	9	8	9	3	9	9
2	Roads	1/5	1	2	2	3	1/3	1/4	2	2
3	Town	1/6	½	1	3	7	1	3	1	1
4	Soil	1/9	½	1/3	1	2	3	2	4	4
5	Slope	1/8	1/3	1/7	1/2	1	3	1	2	3
6	Land use	1/9	3	1	1/3	1/3	1	4	2	3
7	Forest	1/3	4	1/3	1/2	1	1/4	1	5	5
8	stream	1/9	½	1	1/4	1/2	1/2	1/5	1	1
9	school	1/9	½	1	1/4	1/3	1/3	1/5	1	1

The normalized decision matrix of solar PV power plant was obtained by summing up the column and divides it to each cell value (Table 3). The normalized values were calculated from the decision making matrix (A_{ij}) as:

$$N = \frac{\sum j}{c} \quad (1)$$

Where

N is normalize value

J is the column of the matrix

C is the values of column of the decision

In identify the potential sites for solar PV power plant; site selection was depending on the weights of each layer (Table 4). The weights of the criteria were calculated from normalized matrix (A_{nm}) as:

$$W = \frac{\sum n}{x} \quad (2)$$

Where

W is weights of the criteria

n is the row values of normalized matrix

x is the number of criteria for suitability analysis

Table 3
Normalized decision matrix of solar PV power plant

		1	2	3	4	5	6	7	8	9
Criteria		Irradiance	Roads	Town	Soil	Slope	Land	Forest	Stream	schools
1	Irradiance	0.44	0.25	0.47	0.53	0.35	0.49	0.20	0.33	0.31
2	Roads	0.09	0.05	0.16	0.12	0.13	0.02	0.02	0.07	0.07
3	Town	0.07	0.25	0.08	0.18	0.30	0.05	0.20	0.04	0.03
4	Soil	0.05	0.03	0.03	0.06	0.09	0.16	0.14	0.15	0.14
5	Slope	0.06	0.02	0.01	0.03	0.04	0.16	0.07	0.07	0.10
6	Land	0.05	0.15	0.08	0.02	0.01	0.05	0.27	0.07	0.10
7	Forest	0.15	0.20	0.03	0.03	0.04	0.01	0.07	0.19	0.17
8	Stream	0.05	0.03	0.08	0.01	0.02	0.03	0.01	0.04	0.03
9	Schools	0.05	0.03	0.08	0.01	0.01	0.02	0.01	0.04	0.03

Table 4
Eigenvector and weights of the criteria solar attributes

Criteria for suitability analysis		Eigenvector	Weight
1	Solar Irradiance	3.38	0.38
2	Roads	0.72	0.08
3	Town	1.22	0.14
4	Soil	0.83	0.09
5	Slope	0.57	0.07
6	Land use land cover	0.82	0.09
7	Forest	0.89	0.09
8	Stream	0.30	0.03
9	School	0.27	0.03

2.3 Site suitability analysis of solar Photovoltaic

Geographic information system (GIS) and ArcGIS were used to indicate the appropriate sites for solar PV power plant. ArcGIS can prioritize the site to determine the most suitable sites. GIS Was modeled to store data, analyze data and display spatial data on the map[3, 17, 18].

To determine the most suitable areas for solar Photovoltaic(PV) placement nine data sets were taken as a layer. Thus dataset were solar irradiance, roads, forest, stream, schools, town, soil, slope and land use land cover. The study area was ranked to determine the most suitable sites, and the potential sites for solar Photovoltaic Placement were prioritized, as highly suitable, suitable, moderately suitable, and unsuitable.

2.3.1 Solar irradiance reclassification

The solar irradiance was the most dominance factors to find the most suitable location for solar power plant. The solar irradiance dataset was taken from National aeronautics and space (NASA) surface metrology which represents the average of daily totals of global horizontal solar irradiance in kWh/m²[7, 19–21].

The Twenty years, yearly average solar irradiance layer was downloaded from NASA.

As the national renewable energy laboratory report[22]. Areas with 3.56Kwh/m² solar irradiance per day are economically feasible. Therefore, areas less than 3.56Kwh/m² solar irradiance per day was considered as unsuitable in the study (Table 5). The raster solar irradiance was reclassified to unsuitable (< 5), moderately suitable (5-5.5), suitable (5.5-6), and highly suitable (> 6) Kwh/m² per day respectively (Fig. 2).

Table 5
solar irradiance reclassification

Old values in Kwh/m ²	New values
< 5	1
5-5.5	2
5.5-6	3
> 6	4

2.3.2 Roads reclassification

Transportation cost was the dominant factor for any power plant installations. Thus the areas far from roads are economically infeasible and unsuitable. Therefore, areas less distance than 500 m was selected as highly suitable sites for solar[12, 21, 23]. Areas with distance (500-1000m) suitable, (1000-5000m) moderately suitable and greater (1500 m) unsuitable were prioritized respectively (Fig. 3).

The Euclidean distance was used for road data reclassifications in ArcGIS tool and the Euclidean distance were reclassified as below (Table 6).

Table 6
Road reclassification

Old values(meter)	New values
< 500 m	1
5000-1000m	2
1000-1500m	3
> 1500 m	4

2.3.3 Reclassification of slope

The surface of the earth was an important factor in finding suitable locations for solar power plant. The earth gradient affects the receiving radiation from the sun. Thus, flat areas receive the most radiation and produce more energy from solar PV[5, 6, 24].

Areas less than 3% gradient were reclassified as highly suitable and greater than 10% gradient was unsuitable (Fig. 4). The slope reclassification data sets were shown that the Western part of the zone was more flat (Table 7). On the other hand eastern part was higher slope areas.

Table 7
Slope reclassification

Old values (%)	New values
< 3%	1
3–7%	2
7–10%	3
> 10%	4

2.3.4 Land use, land cover

Land use, land cover was a key factor in finding optimal location solar PV power plant.

Cultivate/agricultural areas, forest areas, urban areas area were excluded in this study[5, 14]. The open areas were considered as highly suitable areas for solar power plant installations (Fig. 5).

2.3.5 Distance from town

Distance from towns was another important factor in finding suitable sites for solar PV power plant[5, 25]. The farthest distance from town was considered as highly suitable and the shortest was considered as unsuitable for solar PV in this study (Table 8).

Table 8
Town reclassification

Old values (Km)	New values
< 2 Km	1
2-4Km	2
4-6Km	3
> 6 Km	4

The town dataset was reclassified to highly suitable (> 6 km), suitable (4-6Km), moderately suitable (2-4Km), and unsuitable (< 2 Km)(Fig. 6).

2.3.6 Distance from schools

Historical paces, recreation areas and Schools were excluded in indicating optimal locations for solar PV power plant [2, 17, 26]. Based on the nature of the study area, the distances from school were reclassified into four categories, i.e less than 300 m, 300-400m, 400–1000 and greater than 1000 m (Table 9). The farthest distance from schools were considered as highly suitable areas and the shortest distances were considered as the unsuitable sites for solar PV power plant (Fig. 7).

Table 9
School reclassification

Old values (meters)	New values
< 300 m	4
300-400m	3
400-1000m	2
> 1000 m	1

2.3.7 Distance from stream

The solar power plant locations were affected by the streams and water bodies. The most far locations were the most suitable locations [11, 27, 28]. The streams were reclassified into four main categories depending on the distance from the sites. The more far locations were taken as more suitable and the nearest locations were taken as unsuitable (Fig. 8). The distance greater than (2000 m) highly suitable, (1000-2000m) Suitable, (500–1000) moderately suitable, and less than 500 m was unsuitable respectively (Table 10).

Table 10
Stream reclassification

Old values (meters)	New values
< 500 m	4
500-1000m	3
1000-2000m	2
> 2000 m	1

2.3.8 Distance from forest

Distance from the forest was the dominant factor for solar PV power plant site selection. The solar radiation is highly affected by forest shadow [1, 19, 29]. Thus farther the distance from the forest was considered as the most suitable and the nearest distance was considered as unsuitable locations (Table 11).

Table 11
Forest reclassification

Old values (meters)	New values
< 30 m	4
30-60m	3
60-80m	2
> 120 m	1

Forest dataset was reclassified into four classes in this paper, greater than (120 m) highly suitable, (80–100) suitable, (30-60m) moderately suitable, and less than (30 m) unsuitable (Fig. 9).

2.3.9 Soil reclassifications

Soil was also an important factor in finding optimal location solar PV power plant. The support erection of the solar PV is influenced by the type's soil. Thus luvisol was considered as the most suitable for support erection of solar PV and laptosol was considered as unsuitable for support erections[5, 30].

The based on the nature of study area soil type was reclassified into four main categories, these were (luvisol) highly suitable,(fluvisol)suitable,(vertisol)moderately suitable, and (laptosol) unsuitable(Fig. 10).

2.4 Weighted overlays of Solar Photovoltaic suitability analysis

All weights of the criteria were combined by using the ArcGIS10.4.1 weight overlay tool. The reclassified data set of the criteria which includes solar irradiance, distance from roads, distance from schools, and distance from town, slope, and distance from forest, soil type, and land use land cover were overlaid to the aggregate base on its weight[9, 18, 21, 31].

The final map of suitability was obtained by multiplying each reclassified value with each weight value and summing up all layer products. The range of solar PV suitability was from one to four. Thus study area was separated into four main categories and highly suitable areas for placing solar PV Value was one (Table 12).

Table 12
Study area solar suitability in percent

No.	Area	Percent	Suitability
1	32925525.8544	13.5	Unsuitable
2	61558441.5047	25.3	Moderately Suitable
3	86790957.7469	35.7	Suitable
4	62078674.8941	25.5	Highly Suitable

3. Result And Discussion

The Western and South-West part of South Gonder were suitable for solar PV from the candidate locations. This, mainly, due to high solar irradiance, low slope, short distance from roads, far from town, and far from forest, and far from stream. The North-Western areas were also suitable in addition to Western and South-Western parts of South Gonder and there were some solar potential areas in the South-East of the Zone. The most unsuitable areas were found in North-East parts of Zone due to near to the forest and Gumara stream (Fig. 11).

From total of 243353600 Km² candidate areas, taken in this study 62078674.8941 Km² were highly suitable which were represented by 25.5% of the study area. 86790957.7469 Km² areas (35.7%) were suitable, and 25.3% of the areas were moderately suitable. Around 13.5% of the study area was unsuitable for solar power plant placement (Table 12).

4. Conclusion

There were higher potentials of solar power generation in the Western and South-West part of the South Gonder Zone. This potential contributes to fill the energy gap between the demand and supply of the country. It also used to Bridge the energy gap between rural and urban communities, if the country start to use this high green solar potential to generate power needs.

The Majority of areas fulfilled the suitability analysis criteria. Solar irradiance, slope, soil type, land use, land cover, distance from roads, forest, town, stream, and schools were the determinant factors for solar PV power site suitability analysis. Recommendations to increase rural electrification by finding the optimal locations for solar PV were: Ethiopian electric power workers who are working, participating and educating the community and stakeholders to bring a good perception, on renewable energy and related traditional practices like decorating and harmful of fossil fuel on the environment.

Limitations

This suitability study had limitations. The major limitation of this work was the area coverage. This study considered only South Gondar. Therefore, further studies which covers large area is recommended.

Abbreviations

PV
Photovoltaic
GIS
Geographic information system
Kwh
Kilo wat hour
Km
kilo meter

Declarations

Author's contributions

Authors' contributions Abraham, Biniyam, and Tewodro , contributed to the design of this study. Authors conceived and designed study, collected, analyzed and interpreted data. Abraham drafted the manuscript for important intellectual content. All authors read and approved the final manuscript.

Availability of data and materials

The date of this study will not be shared publically.

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Competing interest

The authors declare that there no competing interest in regarding the publication of this paper.

Consent to publish

Not applicable

Ethics approval and consent to participate

Ethical approval of the study was obtained from Bahir Dar University, institute of technology and school of electrical engineering ethical review committee. The ethical letter was submitted to Bahir Dar Ethiopian electric power and permission was obtained to conduct the study.

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Figures

Figure 1

The Map of Amhara Region and the study area

Figure 2

Solar PV irradiance suitability map

Figure 3

Suitable distance of roads

Figure 4

Suitable slopes for solar Photovoltaic

Figure 5

Suitable land use land cove for solar Photovoltaic

Figure 6

Suitable town distance for solar Photovoltaic

Figure 7

Suitable school distance for solar Photovoltaic

Figure 8

Suitable stream distance for solar Photovoltaic

Figure 9

Suitable forest distance for solar Photovoltaic

Figure 10

Suitable soils for solar Photovoltaic

Figure 11

Suitability map of solar Photovoltaic