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Suitability analysis of PV solar power plant sites in Gandaki province: Application of GIS and Remote sensing

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Abstract

The escalating global demand for energy has triggered a shift towards cleaner alternatives due to mounting environmental concerns. Emerging as a viable substitute, solar power has gained prominence as fossil fuels' adverse impact becomes evident. Historically reliant on hydropower, Nepal is exploring alternative energy sources to mitigate seasonal output variations. Despite abundant renewable resources like biomass, wind, and solar energy, Nepal's energy sector faces funding and technical expertise challenges. Solar energy presents significant promise as a primary renewable source in Nepal, boasting ample sunlight due to its location. However, the current solar capacity remains limited at around 54.6 MW, comprising less than 2.5% of the total installed capacity. The critical factor is the identification of suitable sites for solar power plants. Geographical Information System (GIS) and Multi-Criteria Decision-Making (MCDM) methods have been employed for suitability analysis. This study employs the Analytic Hierarchy Process (AHP), a robust MCDM technique, to assess site suitability. The research is carried out in the Gandaki province, Nepal, encompassing the Himalayan, Hilly, and Terai regions. Criteria like solar radiation, slope, aspect, land use/land cover, proximity to roads, and substations are considered. These criteria are reclassified into suitability categories based on expert opinions and guidelines. The results indicate areas highly suitable for solar power generation, covering 12.40 km2 (5.64% of the study area), followed by regions least suitable, spanning 7681 km2 (34.93% of the province's area). This research contributes to the effective deployment of solar power by identifying optimal locations for solar power plant construction, thus advancing Nepal's renewable energy goals.

Keywords: GIS; MCDM; Photovoltaic; Remote sensing; Solar Plant; Spatial analysis

1. Introduction

The requirement for energy on a worldwide scale has steadily increased in the contemporary era. In the 20th century, fossil fuels provided around 80% of our energy [1]. Between 2011 and 2035, there will be a 1/3 rise in the world's energy usage. Demand for all energy sources is rising even as the share of fossil fuels in the world's energy mix will decline from 82% to 76% by 2035. Focus has switched to cleaner energy sources as awareness of the harm fossil fuels do to the environment has increased, with solar power emerging as the most practicable substitute [2].

In Nepal, hydropower has historically been a key source of electricity. In Nepal, ROR hydropower plants account for most of the country's hydroelectric facilities. The Runoff River (RoR) hydropower plants' energy output declines to around 40% of what it was during the rainy season due to the river's lower water level during the dry season. The administration has suggested incorporating alternative energy sources into the country's energy portfolio while considering these considerations [3]. Despite abundant biomass, wind, and solar resources, Nepal lacks the financing and sophisticated technological expertise necessary to use these resources efficiently [4].

Solar energy has a lot of promise as one of Nepal's primary renewable energy sources. Nepal has the advantage of a sufficient supply of solar radiation because of its ideal location. There are over 300 days of daylight each year when the sun is out, and daily solar radiation levels normally range from 3.6 to 6.2 kWh/m^2 [3]. With such plentiful solar resources, grid-tied PV solar systems may effectively meet the energy demand during daylight hours, widening the energy mix [3]. Despite being connected to the grid, the solar power plant's capacity is only roughly 54.6 MW, or less than 2.5% of the total installed capacity [5]. Finding suitable locations to construct solar power plants is

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crucial in this case.
In the area of suitability analysis, several research have been done. GIS may greatly assist suitability evaluations as a decision-support tool. Based on established criteria, GIS analysis assists in selecting the best zones for future development. Most of the reviewed literature demonstrates how multicriteria decision-making (MCDM) techniques have been used for GIS tools in various industries, including resource allocation, energy management, and planning for renewable energy sources [6].
A range of diverse methodologies, each with its own characteristics and computational procedures, are used in MCDM. One of the various MCDM methods is the Analytic Hierarchy Process (AHP), which Saaty developed in 1977. It is a methodical decision-making approach based on a hierarchical structure produced by mathematical pairwise comparisons. The ability of the AHP to rationally integrate qualitative values into the analysis is by far its greatest asset [7-9]. When qualitative and quantitative data can be merged into a single scale, it stimulates participation from all parties. It makes it possible to include social variables and public opinion in the research. The option dilemma is presented hierarchically in the decision issue, which is another characteristic [7-9].
As a result, this study aims to use AHP technology to conduct a suitability analysis and identify the best locations for constructing solar power plants.

2. Materials and Method

2.1 Study Area

The Gandaki province is in the country's central-western region with an area of 21,733 km2, or around 14.66% of Nepal's total land area. The province is divided among the Himalayan, Hilly, and Terai regions, with 5,919 km^2 (26.8%) falling under the Himalayan region, 14,604 km^2 (67.2%) under the Hilly region, and 1,310 km^2 (6%), under the Terai region [12]. With a range of 2.21 KWh/m^2 to 6.348 KWh/m^2 and a mean value of 4.47 KWh/m^2 [13], the Gandaki province in Nepal has the widest range of GHI among its seven provinces. Given this information, the subject region for this research is the Gandaki Province.
To achieve the pre-defined goal of the research, the fundamental process was divided into five steps, which are explained below.

2.2 Criteria Setting

Solar radiation, slope, aspect, land use, land cover, and proximity to the road access are the criteria employed by most of the study while considering the characteristics indicated by AEPC [10], the literature review, and the accessible data source. However, a study within Kathmandu Valley has indicated the limitation of not using the national power grid position as a restriction [11]. Therefore, this study considered factors such as global horizontal irradiation (solar radiation) as a climatic component, slope and aspect as a topographical feature, land use and land cover, and economic considerations such as accessibility to roads together with the substation site.

2.3 Data Collection

According to the assessment criteria, the raw data for this study was gathered from several sources. First, a 30-meter resolution Aster GDEM that was freely accessible was downloaded from the NASA webpage. It was used to determine the sun irradiation, a crucial element in appraising solar energy project sites. ArcGIS software was also used to calculate slope and aspect data. The data for the highway networks was provided by Nepal's Survey Department's Geoportal National Spatial Data Center. The ICIMOD land use/land cover map of 2019 was used to collect the land use data at a 30-meter resolution.

The location information for the substation was given by the Nepal Electricity Authority, Gandaki Province. Several rules or restrictions must be implemented in addition to the requirements to exclude areas inappropriate for building solar power plants. The limits indicated were looked into, and which criteria to exclude from the appropriateness study were determined. Protected places, aquatic bodies, developed areas, and active airports are limited regions.

Table 1. Data and their sources used in the study

S.N.	Data	Nature	Source
1	DEM	Raster	ASTER GDEM
2	LULC	Raster	ICIMOD
3	Highway	Vector	Dos, Nepal
4	Slope	Raster	ASTER GDEM
5	Aspect	Raster	ASTER GDEM
6	Solar Radiation	Raster	ASTER GDEM
7	Location of Substation	Vector	NEA, Gandaki Province

2.4 Reclassification

Following the collection of the data, all of the information was divided into four appropriateness categories: Highly Suitable, Moderately Suitable, Least Suitable, and Not Suitable based on AEPC guidelines, interviews with a number of solar professionals from various projects, and literature.

2.4.1 Solar Radiation

The amount of solar radiation that enters the system determines the potential power output of a particular PV module. Even though there is plenty of sunlight everywhere, solar insolation varies according to light quality and daily sunshine hours; sites that receive more solar radiation are desirable since they provide more energy. The Global Horizontal Irradiance (GHI) should be deemed to have a greater energy yield if it exceeds 4 kWh/m^2/day (1.4 e+006 Wh/m^2/year), according to the AEPC guidelines. The worldwide solar radiation layer was divided into four groups, as indicated in the table below, using the AEPC guidelines and experts' opinions.

Table 2. Reclassification of Solar Radiation

S.N	Solar Radiation	Suitability Index
1	Greater than 5	High Suitable
2	4.5 – 5	Moderate Suitable
3	4 – 4.5	Least Suitable
4	Less than 4	Not Suitable

2.4.2 Aspect

For sites in the northern hemisphere, it is best to have flat or sloping terrain facing south for maximum effectiveness. Nine separate categories were used to group the elements. The direction with the greatest sun exposure is given more weight than the other nine directions (N, NE, NW, E, SE, S, SW, W, and Flat Areas). The range of aspect values is -1 to 360, with a value of -1 denoting a flat surface and a greater positive number denoting variations in accordance with the cardinal directions.

Table 3. Reclassification of Aspect

S.N	Aspect	Suitability Index
1	Flat and South	High Suitable
2	South East South West	Moderate Suitable
3	East/ South-East West/ South-West	Least Suitable
4	Remaining	Not Suitable

2.4.3 Slope

The intensity of solar radiation that strikes the solar panel is largely influenced by slope. Installing solar energy collecting systems on steep terrain has a number of disadvantages, including the possibility of soil-related issues and the high expense of creating access roads. Due to the lack of a clearly defined permissible slope percentage, the experts claimed that a slope of 30 degrees is realistic and that, at most, a slope of 45 degrees can be acceptable since it can function as a natural tilt.

Table 4. Reclassification of Slope

S.N	Slope (Degree)	Suitability Index
1	0 – 15	High Suitable
2	15 – 30	Moderate Suitable
3	30 – 45	Least Suitable
4	Greater than 45	Not Suitable

2.4.4 Proximity to Substation

The efficiency and dependability of the power system can also be increased by placing power-producing facilities close to existing substations. Power generated at the plant is more conveniently transferred to Substations and may reach end customers with a lower chance of transmission losses or interruptions. In light of the study conducted in Madhesh province and taking into account expert opinion, categorization was done in the range given below.

Table 5. Reclassification of Proximity to Substation

S.N	Distance (in Km)	Suitability Index
1	Up to 5	High Suitable
2	5 – 10	Moderate Suitable
3	10 – 20	Least Suitable
4	Greater than 20	Not Suitable

2.4.5 Land Use Land Cover

In the context of our investigation, the LULC raster we employed included a total of 11 classes. As a result of an expert's opinion and research in the countryside, they were further divided into the four groups in the table below.

Table 6. Reclassification of Land Use Land Cover

S.N	LULC	Suitability Index
1	Bare soil Bare rock Grassland	High Suitable
2	Cropland Woodland	Moderate Suitable
3	Forest, Snow	Least Suitable
4	Waterbody Built up Glacier Riverbed	Not Suitable

2.4.6 Proximity to Highway

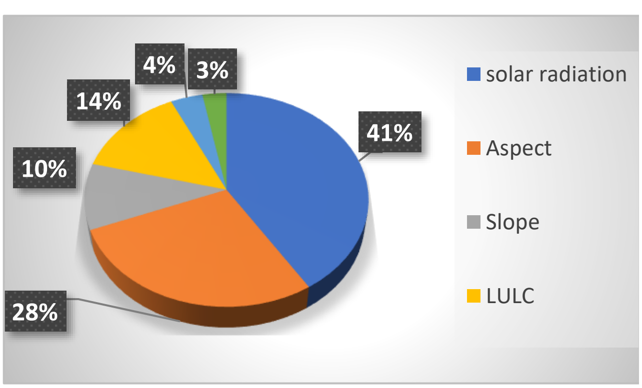
Given the significance of roads and plant accessibility, this criterion had been utilized for base selection on the distance from the roads. Roads are a crucial connectivity method for transporting and installing the numerous equipment required to create solar energy. A site is more suited for installing a solar plant closer to the road system. In this study, a distance of 5 km from the main road network was deemed a highly suitable region.

Table 7. Reclassification of Land Use Land Cover

S.N	Distance (in Km)	Suitability Index
1	Up to 5	High Suitable
2	5 – 10	Moderate Suitable
3	10 – 15	Least Suitable
4	Greater than 15	Not Suitable

2.4 AHP and Weight Calculation

After reclassifying each criterion, a pairwise comparison matrix was created based on the consensus opinion of the experts. AHP Priority calculator and AHP calculation software from CGI constructed the matrix. It is common knowledge that the consistency ratio for the pairwise comparison should be smaller than 0.1. In our instance, the consistency ratio was 0.094, regarded as acceptable for additional processing. The relative weights obtained in this instance are high (41% for solar radiation), 28%, 10%, 14%, 4%, and 3%, respectively, for aspect, slope, LULC, proximity to substation, and proximity to highway. The relative weights for each criterion were determined and are shown below.



2.5 Weighted Overlay

A weighted overlay method was employed to finish the suitability modeling. According to AHP findings, the factors were weighted based on significance. The input requirements were categorized into a common preference scale of 0 to 4. Higher values correspond to more favorable conditions.

3. Results and Discussion

3.1 Reclassification

After identifying the classification range for each criterion, the following results were obtained for each class of every used criterion variable.

Table 8. Percentage coverage of area for each criterion

Criteria	High Suitable	Moderate Suitable	Least Suitable	Not Suitable
C1	35.29	16.55	24.25	23.90
C2	14.68	27.11	11.83	46.38
C3	19.30	38.37	32.38	9.95
C4	29.42	17.74	43.85	8.99
C5	6.18	14.08	28.30	51.43
C6	79.56	15.82	4.35	0.26

Here, the variables denote the following:
C1 = Solar Radiation
C2 = Aspect
C3 = Slope
C4 = Land Use Land Cover
C5 = Proximity to Substation
C6 = Proximity to Highway

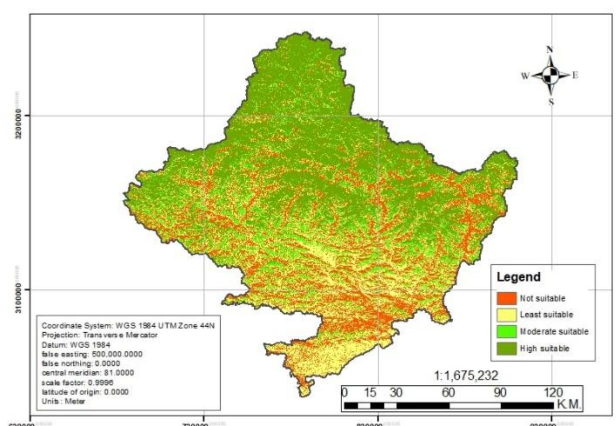


Figure 1. Solar Radiation Suitability Map

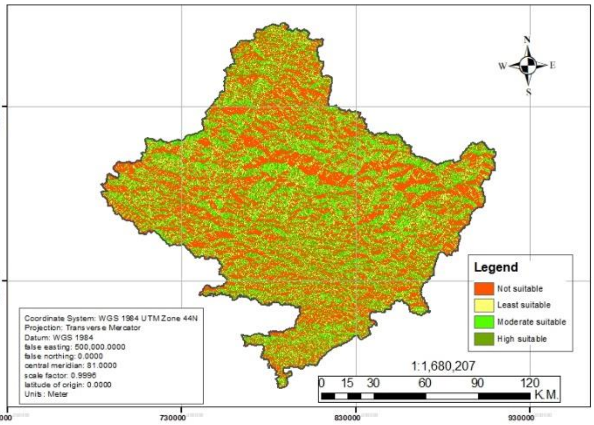


Figure 2. Aspect Suitability Map

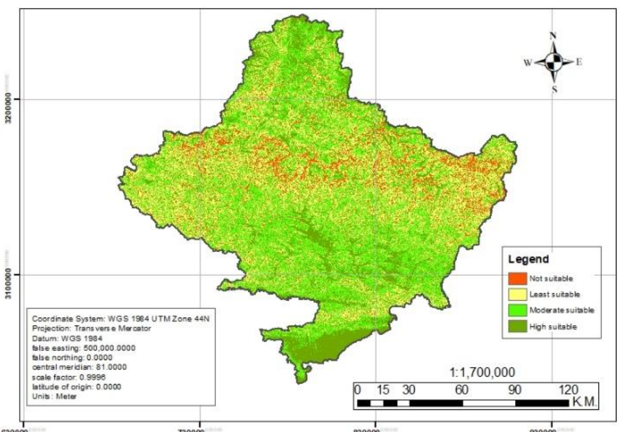


Figure 3. Slope Suitability Map

3.2 Weighted Overlay

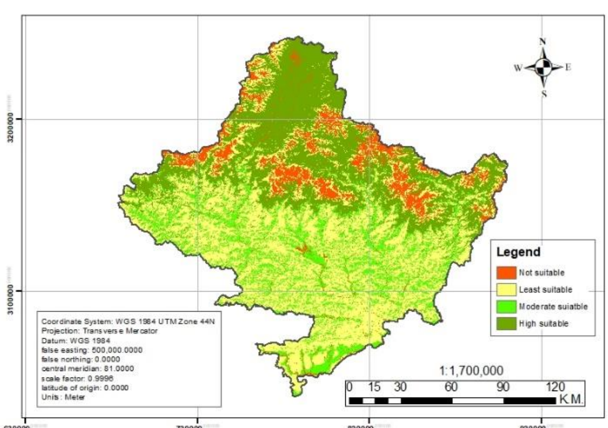


Figure 4. Land Use Land Cover Suitability Map

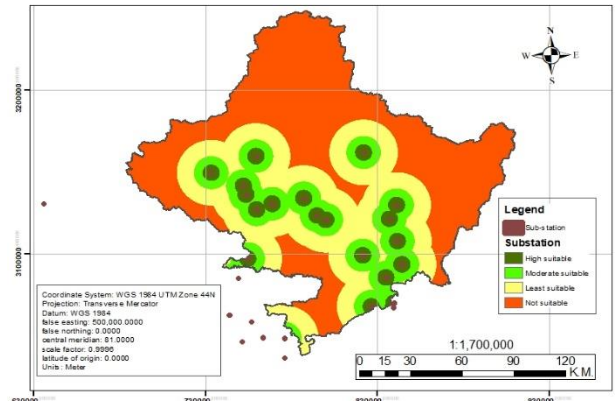


Figure 5. Proximity to Substation

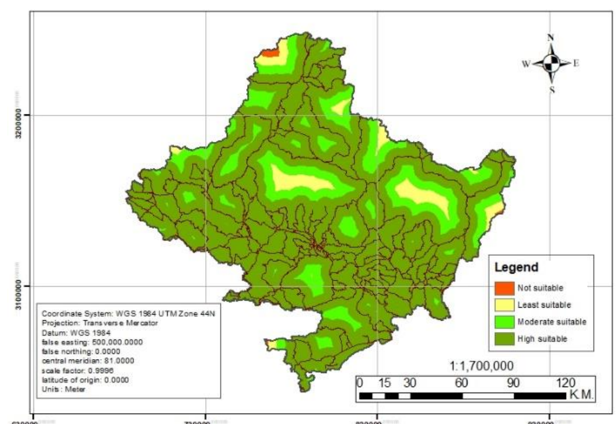


Figure 6. Proximity to Highway

The graphic below displays the results of the weighted overlay operation. The locations where a solar energy collecting facility would produce the most solar energy are considered very appropriate.

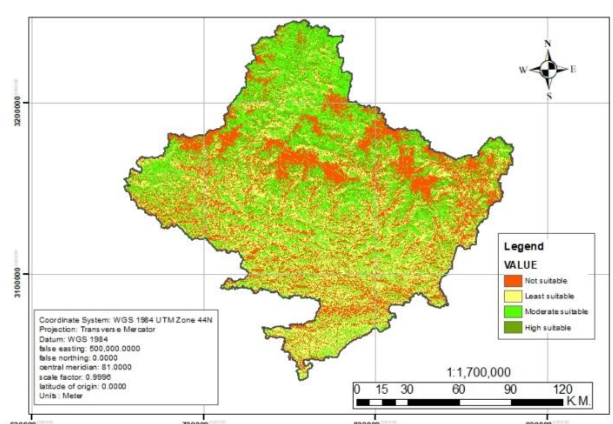


Figure 7. Final Suitability Map

According to the map, 12.40 km^2 (5.64% of the total area) is covered by highly suitable regions, followed by 7681 km^2 (34.93% of the total area of Gandaki province) and 6320 km^2 (28.74% of the total area of Gandaki province) by regions that are least suitable for solar power generation sites.

4. Conclusions

It has been determined from the study that just a small area of the Gandaki province has the optimum potential for the building of solar PV plants. Due to greater sloping areas and undulating terrain, the suitability inside the Gandaki Province is constrained, which is the cause of this significantly lower suitability. Furthermore, many locations, such as conservation zones, forbid the construction of solar power facilities. As a result, as a final observation, this study can offer the first insight into policy-making for identifying a good site for the construction of solar power plants.

Acknowledgment

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