APPLICATION OF AHP AND GIS FOR OPTIMAL SOLAR SITE IDENTIFICATION IN MADHESH PROVINCE, NEPAL

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ABSTRACT

Solar-based renewable energy adoption is in its early stage in the power system of Nepal complying with its commitment to carbon neutrality. The government of Nepal has declared a goal of setting up solar power plants of at least 200 MW in Madhesh Province, but the selection of optimal sites will be the decisive factor in achieving this goal.

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Therefore, rigorous investigation is necessary for optimal site selection. A three-step framework combining the Analytic Hierarchy Process (AHP) and the Geographical Information System (GIS) has been adopted to identify the optimal location for solar power plant installation in Madhesh Province. The framework includes the creation of weighted individual raster images for the different criteria, images of restricted areas for solar installation, and a combination of all the rasters into a single raster using GIS-based software. The weights of the criteria and sub-criteria have been evaluated using the AHP model, which is an expert judgments-based model. The criteria considered were solar irradiance, annual mean temperature, distance from the road, distance from the substation, distance from the urban area, elevation, aspect, and land use. The results were graded from the least preferred area to the most highly suitable area. The most highly suitable areas were in the Saptari, Siraha, Dhanusa, and Mahottari districts, while the districts in the western region of the province had less suitable areas. Thus, the province's eastern region is most suitable for installing solar power plants.

Keywords: AHP; GIS; renewable energy; solar power plant

1. Introduction

With increasing concern about the detrimental impacts of fossil fuels on the sustainability of the environment, focus has shifted towards cleaner sources of energy with solar power being the most promising candidate among all the available resources. Countries around the globe have formulated their policies to promote the integration of solar power into their power network (International Energy Agency, 2021). The International Energy Agency (2021) estimates that global solar power generation in 2020 has increased by an astounding value of 23% from the previous year with an annual generation of 820 TWh and is estimated to reach 6970 TWh by 2030.

In the Nepalese context, solar power is making its way into the hydro-dominated power system. Historically, the energy demands of the country have been fulfilled by hydropower and imports from the neighboring country of India. No significant changes in the energy mix have yet been achieved. Most of the hydropower plants in Nepal are Run of River (RoR) types whose capacity reduces by more than 50% during the dry season. The resulting deficit of energy is fulfilled by heavy imports from the Indian power market. Accounting for these factors, the Government has proposed the introduction of alternative sources of energy into the energy mix of the country. The current installed capacity of the grid-connected solar power plant is around 54.6 MW, accounting for less than 2.5% of the total installed capacity, while 1239.69 MW have received a survey license, 137.56 MW have received a construction license, 197.4 MW have applied for a survey license and 15 MW have applied for a generation license, respectively (Department of Electricity Development, 2022; Nepal Electricity Authority, 2022). Most of the solar power plants that have been installed or are in different phases of being established are located in the northern belt of the country. The government of Nepal has formulated a plan to establish a minimum of 200 MW solar power plants in Nepal (Water and Energy Commission Secretariat, 2010). These data indicate the aggressive approach that has been adopted to promote solar power plants in Nepal. With increasing interest and investment in solar photovoltaics, it is necessary to have an overview for developers during the initial stage of planning for suitable sites to establish a solar power plant. There have been limited previous studies for optimal solar site identification in the Nepalese context. This study was conducted to fill in the missing piece of the puzzle. The

AHP and GIS have been used to create a suitability map displaying the best possible sites for solar power installation.

A proper site for plant location must not be decided solely based on the level of solar irradiation available in the area. A single criterion is insufficient to make a decision; multiple criteria must be considered for site selection.

2. Literature review

The AHP can be applied for tasks such as planning of renewable energy, allocation of energy resources, management of building energy, and planning of electricity utilities (Xin, Chen, Yang, Miao & Li, 2019; Ahmad & Tahar, 2014). It has been applied in the determination of installation sites for power plants. Studies have combined AHP, one of the methods within Multicriteria Decision Analysis (MCDA), and Geographical Information System (GIS) to determine the location of solar power plant installation (Choi, Suh, & Kim, 2019). Different methods of MCDA, namely, AHP, ELECTRE, TOPSIS, and VIKOR have been applied to determine the optimal location of solar power plants in Turkey with three different criteria, i.e., solar irradiation, surface slope, and feeder capacity (Akkas, Erten, Cam, & Inanc, 2017). Watson and Hudson (2015) conducted similar work in Southern England using a combination of AHP and geospatial data constrained to solar radiation, distance from residential areas, distance from wildlife, distance from transportation link and distance from network connections. The AHP in combination with GIS has provided the optimal locations for concentrated solar power plants in West Africa and Morocco with solar irradiation, slope, distance from the road, and distance from the urban area as the criteria set forth for AHP (Yushchenko, de Bono, Chatenoux, Patel & Ray, 2018; Tahri, Hakdaoui & Maanan, 2015). Sánchez-Lozano, Teruel-Solano, Soto-Elvira & Socorro García-Cascales (2013) considered two different methods of MCDA combined with GIS to evaluate the location of solar power in South-eastern Spain. A case study was conducted in Mauritius to determine the location of solar power plants using the AHP and GIS with proximity to transmission lines and roads, slope, elevation, aspect, global solar radiation, sunshine duration, air temperature, and relative humidity as the evaluation criteria (Doorga, Rughooputh, & Boojhawon, 2019). A site suitability assessment for West Kalimantan Province, Indonesia merging AHP and GIS constrained to Global Horizontal Irradiation (GHI), temperature, relative humidity, elevation, slope, aspect, proximity to power grid, road infrastructure, and major settlements concluded that only 0.03-0.07% of the total area of the particular province was optimal for solar plant installation (Ruiz, Sunarso, Ibrahim-Bathis, Murti, & Budiarto, 2020). Likewise, Nebey, Taye & Workineh (2020) investigated the site suitability for South Gondar Zone, Ethiopia using a blend of AHP and GIS with similar criteria considered by Ruiz, Sunarso, Ibrahim-Bathis and Budiarto (2020) for Indonesia and concluded that 86% of the total land within the South Gondar Zone was suitable for solar plant installation.

A similar strategy was applied for Mongolia (Munkhbat & Choi, 2021), Saudi Arabia (Al Garni & Awasthi, 2017), Thailand (Ali, Taweekun, Techato, Waewsak, & Gyawali, 2019), and Tanzania (Aly, Jensen, & Pedersen, 2017) using the AHP and GIS with similar criteria considered by the studies mentioned above. Only one study found in the available literature has been conducted in the Nepalese context. The solar sites around Kathmandu Valley, the capital city of Nepal have been identified using AHP and GIS (Paneru, 2016) with slope, aspect, and, proximity to the road as the evaluation criteria.

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Table 1 provides a summary of the literature survey considered for the application of the AHP and GIS for optimal site identification for solar plants.

Table 1
Summary of literature considered for a combination of AHP and GIS for optimal solar site identification

No.	MCDA Technique	Location	Reference
1	AHP	Turkey	(Akkas, Erten, Cam, & Inanc, 2017)
2	AHP	Southern England	(Watson & Hudson, 2015)
3	AHP	West Africa	(Yushchenko, de Bono, Chatenoux, Patel, & Ray, 2018)
4	AHP	Morocco	(Tahri, Hakdaoui, & Maanan, 2015)
5	AHP	South Eastern Europe	(Sánchez-Lozano, Teruel-Solano, Soto-Elvira, & Socorro García-Cascales, 2013)
6	AHP	Mauritius	(Doorga, Rughooputh, & Boojhawon, 2019)
7	AHP	Indonesia	(Ruiz, Sunarso, Ibrahim-Bathis, Murti, & Budiarto, 2020)
8	AHP	Ethiopia	(Nebey, Taye, & Workineh, 2020)
9	AHP	Mongolia	(Munkhbat & Choi, 2021)
10	AHP	Saudi Arabia	(Al Garni & Awasthi, 2017)
11	AHP	Thailand	(Ali, Taweekun, Techato, Waewsak, & Gyawali, 2019)
12	AHP	Nepal	(Paneru, 2016)
13	AHP	Tanzania	(Aly, Jensen, & Pedersen, 2017)

3. Material and methods

3.1 Study area

Nepal is a landlocked country that lies between 26° and 31°N latitude, and 80° and 89°E longitude. Nepal stretches to a length of about eight hundred kilometers and a breadth of two hundred kilometers with an area of 147,516 km2. Terai is the southern belt of Nepal distributed over the entire length of the country and occupies 56% of the total area (Timilsina & Tiwari, 2019). Nepal has an estimated potential of 2100 MW of solar power generation as it has an average solar radiation varying from 3.6-6.2kWh/m2day with 300 days of sunshine within a year (Water and Energy Commission Secretariat, 2010). Figure 1 shows the solar power potential of Nepal (The World Bank, 2017).

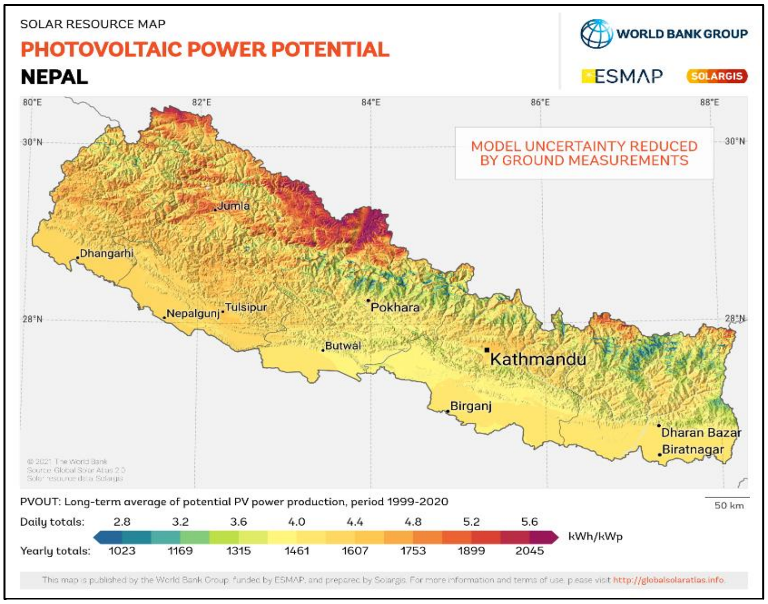

Figure 1 Solar photovoltaic potential of Nepal

Energy consumption in Nepal grew at an average annual growth rate of 10% during the last decade with an annual consumption of 8851GWh in the fiscal year 2020/2021 (Nepal Electricity Authority, 2022). The total installed capacity of the integrated Nepal power system is 2189.918 MW, out of which 2081.788 MW is from hydropower plants, 53.41 MW from thermal (diesel and multi-fuel), and 54.6 MW from solar. Hydropower accounts for about 95% of the generation capacity in Nepal, while the remaining 5% of the installed capacity is thermal and solar (Nepal Electricity Authority, 2022).

Among the seven provinces, Madhesh Province (previously called Province 2) was considered for this study. Only the Terai belt is within this province. The study areas lie in the southern part of the country, which receives ample solar radiation for the location of a solar power plant. Madhesh Province has eight districts, namely, Saptari, Siraha, Dhanusa, Mahottari, Sarlahi, Rautahat, Bara, and Parsa as depicted in Figure 2. It has an area of 9,661 sq. km and occupies 6.56% of the total area of the country. Madhesh Province has sunny days with temperatures up to 40 degrees Celsius, and in winter temperatures drop below 5 degrees Celsius. Madhesh has an average rainfall between 1100-2100 mm (Nepal Outlook, 2020).

In the fiscal year 2020/21, the total energy consumed within Madhesh Province was 1253 GWh which was 0.9 % less than the previous fiscal year. The industries occupied the major source of consumption with 54.6 %, followed by domestic and commercial sectors with 34.45% and 3.17%, respectively. The province has no hydropower in operation, but has one 10 MW solar plant in operation (Development, 2021). As per license status for Madhesh Province, a total of eight solar projects with a cumulative capacity of 60.7 MW have received survey licenses, four projects with a cumulative capacity of 18 MW have received a construction license, nine projects with a cumulative capacity of 109 MW have applied for a survey license and two projects with a cumulative capacity of 5 MW have applied for a generation license (Department of Electricity Development, 2022). Among the survey license applications, Mahottari district has the highest number of applications with six projects of a cumulative capacity of 90 MW.

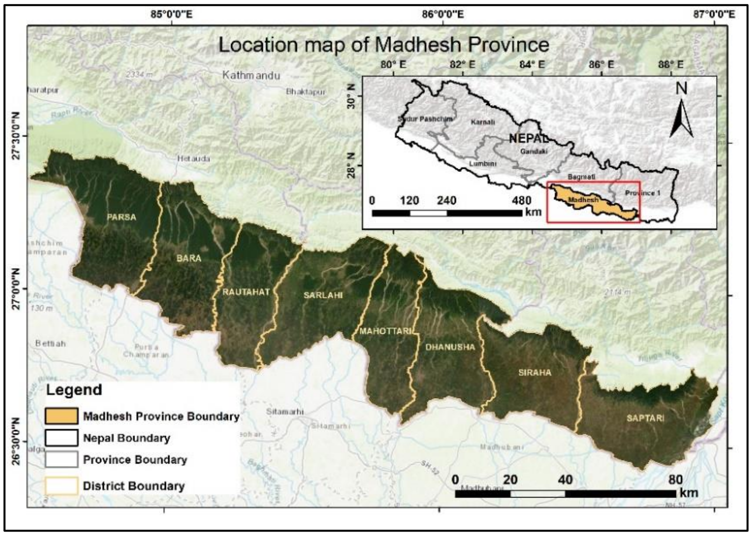

Figure 2 Location map of Madhesh Province in Nepal

3.2 Geographical Information System

A geographic information system (GIS) creates, manages, analyzes, and maps all types of data (ESRI, 2021). It is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (Kanichakra, 2018). There are several applications of GIS in environment and natural resource management, street networks, land information systems, planning, and engineering. There are several studies that combine GIS with multicriteria decision analysis techniques to determine the optimal location for solar plant installation (Choi, Suh, & Kim, 2019).

3.3 Analytical Hierarchical Process

The Analytical Hierarchical Process (AHP) was developed by Saaty in 1980 (Saaty, 1980), and is one of the most popular tools for Multi-Criteria Decision Analysis. The AHP helps determine the importance of different tangible and intangible factors in a multicriteria decision problem by providing a relative scale of importance in numerical value as shown in Table 2.

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Table 2
Pairwise Comparison scale (Gašparović, I., & Gašparović, 2019; Saaty, 1980)

Importance Degree	**Definition**	**Description**
1	Equally preferred	Both the activities have equal contributions towards achieving the objective
3	Moderately preferred	One of the activities is slightly favored over the other.
5	Strongly preferred	One of the activities is strongly favored over the other.
7	Very strongly preferred	One of the activities is very strongly favored over the other.
9	Extremely preferred	One of the activities is favored over the other of the highest possible degree.
2,4,6,8	Intermediate values	Between the degrees of importance

The weight or the importance of the factor is then calculated through a pairwise decision matrix based on the relative priority between different criteria and sub-criteria. The formation of the pairwise matrix includes the following steps (Munkhbat & Choi, 2021; Al Garni & Awasthi, 2017):

a) For an “N” number of criteria with their preference score as per Saaty (1980), a pairwise matrix “M” of size N*N is created such that if M_{ij} is the entry in the i^{th} row and j^{th} column, the product of M_{ij} and M_{ji} must be unity.
b) Then, a normalized pairwise matrix is prepared by dividing each entry of the column by the total sum of the elements of the same column.
c) The average of each entry of the row provides the relative weight of the criteria.

After the computation of the weights, a factor called the consistency ratio (CR) is employed to check the consistency of the AHP and the weights. It is the ratio of the Consistency Index and the Random Index. The Consistency Index is calculated using Equation 1 as follows:

$$CR=\frac{\alpha_{max}-N}{N-1} \tag{1}$$

where, α_{max} is the maximum eigenvalue of the pairwise comparison matrix. The random index as defined by Saaty (1980) and depends on the number of criteria being considered as shown in Table 3.

Table 3
Random Index for different number of criteria

N	2	3	4	5	6	7	8	9	10	11	12
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

If the Consistency Index is less than 0.10, the results obtained are considered to be satisfactory; otherwise, recalculation must be performed due to inconsistencies in the pairwise comparison (Al Garni & Awasthi, 2017).

Weights of each criterion and sub-criterion are calculated based on the decision matrix as described above. The global weight of an attribute is then determined by the product of weights of criteria and sub-sub-criteria; the total score of the weightage is determined by the summation of the global weight of each sub-criterion.

3.4 Criteria selection

The criteria for the selection of an optimal site for solar PV power plants must include all the factors. Several studies have considered criteria for evaluation (Uyan, 2013; Prieto-Amparán, et al., 2021; Albraheem & Alabdulkarim, 2021; Gašparović & Gašparović, 2019; Arán Carrión, et al., 2008). They all had common criteria of slope, irradiation, land use, distance from the road, distance from an urban area, and distance from power lines.
The criteria can be broadly divided into two categories, technical and socio-economic. Technical criteria include solar irradiation and annual mean temperature while the socioeconomic criteria include land use/land cover, distance from main roads, distance from an urban area, distance from substations, elevation, slope, and aspects. For this study, the technical and socio-economic criteria stated above have been considered including sub-criteria. Table 4 lists the criteria considered for the study along with a description. Table 5 lists the personnel involved in determining the importance of each criterion for this particular study.

Table 4
Description of criteria

Criteria	Description
Solar radiation	Sites with higher solar irradiation are preferred as they yield more energy.
Annual mean temperature	Energy production decreases as temperature increases. Areas with lower temperatures are preferred.
Distance from roads	Increased distance from roads increases transportation costs. Sites closer to roads are preferred.
Distance from substation	Sites near substations reduce the cost of transmission infrastructures and thus are preferred.
Distance from urban areas	Solar sites farther from an urban area are preferred as their adverse effect on urban growth is limited.
Elevation	Sites with higher elevation are preferred as they receive more solar irradiation.
Slope	Sites with smaller slopes are preferred as such sites get more solar irradiation.
Aspect (orientation)	South-facing sites are preferred as they receive more solar irradiation.
Land Use	Sites on barren land are preferred.

Table 5
Information on personnel involved

Designation	Affiliation
Senior Manager	NEA Engineering Company
Senior Manager	Nepal Electricity Authority
Stakeholder	Independent Power Producer
Stakeholder	Independent Power Producer
Research Student	Hokkaido University
Research Student	Texas A&M University
Engineer	NEA Engineering Company
Engineer	Nepal Electricity Authority

Along with the criteria, some constraints or restrictions must be applied to eliminate the unsuitable areas for installation of solar power plants. The constraints as considered by Albraheem and Alabdulkarim (2021) were studied while those shown in Table 6 have been adopted for the study.

Table 6
Constraints for solar site selection

1	Forest Areas
2	Bodies of water
3	Flooded Vegetation

3.5 Data collection

The raw data for this study were gathered from several sources. Data for solar irradiation was derived from a repository of the Global Solar Atlas while the temperature was purchased from the Department of Hydrology and Meteorology, Nepal. The data for the road networks were obtained from the road network of the Hindu Kush Himalayan Region created by the International Centre for Integrated Mountain Development (ICIMOD) while Mapruzin was used to obtain information regarding the buildings. Land usage has been retrieved from the land use/land cover map created by ESRI. For slopes, distance from an urban area, elevation, slope, and land aspects, the data were derived from ASTER DEM. The location of the substation was obtained from the Nepal Electricity Authority. The sources of data are shown in Table 7.

Table 7
Source of dataset

Dataset	Source
Solar radiation	Global Solar Atlas (https://globalsolaratlas.info/download/nepal)
Annual mean temperature	Department of Hydrology and Meteorology, Nepal (http://www.dhm.gov.np/)
Distance from roads	Road Network of Hindu Kush Himalayan (HKH) Region (https://rds.icimod.org/home/datadetail?metadataid=398)
Distance from substation	Nepal Electricity Authority (www.nea.org.np)
Distance from urban areas	ASTER GDEM V2 (https://earthexplorer.usgs.gov)
Elevation	ASTER GDEM V2 (https://earthexplorer.usgs.gov)
Slope	ASTER GDEM V2 (https://earthexplorer.usgs.gov)
Aspect (orientation)	ASTER GDEM V2 (https://earthexplorer.usgs.gov)
Land use	Esri Land Use (https://www.arcgis.com/home/item.html?id=d6642f8a4f6d4685a24ae2dc0c73d4ac)

3.6 Methodology to create land suitability map

The methodology adopted for the study is shown in Figure 2. All the datasets were rasterized and reprojected into UTM 45 and resampled into 10m and then applied for further processing in the MCDA-AHP model the in GIS environment to layer for each criteria map. Each thematic layer or the criteria has then been reclassified to create sub-criteria.

After the calculation of the weights of criteria and sub-criteria, the weighted sum overlay tool in GIS was applied to determine the potential sites for solar plant installation. The following procedure was followed to obtain the desired map (Al Garni & Awasthi, 2017):

1. Nine layers, one for each criterion with their corresponding weights and the weight of the sub-criteria were created. Each criterion was brought to a common scale as it contained different values and ranges. Values of input maps were then reclassified into a common preference scale of suitability range.
2. Each criteria layer along with its sub-criteria was multiplied by its respective weight and the resulting cell values were added together to generate the ultimate combined layer in Arc GIS.
3. A restriction layer consisting of the factors was created to isolate unsuitable areas for solar installation.

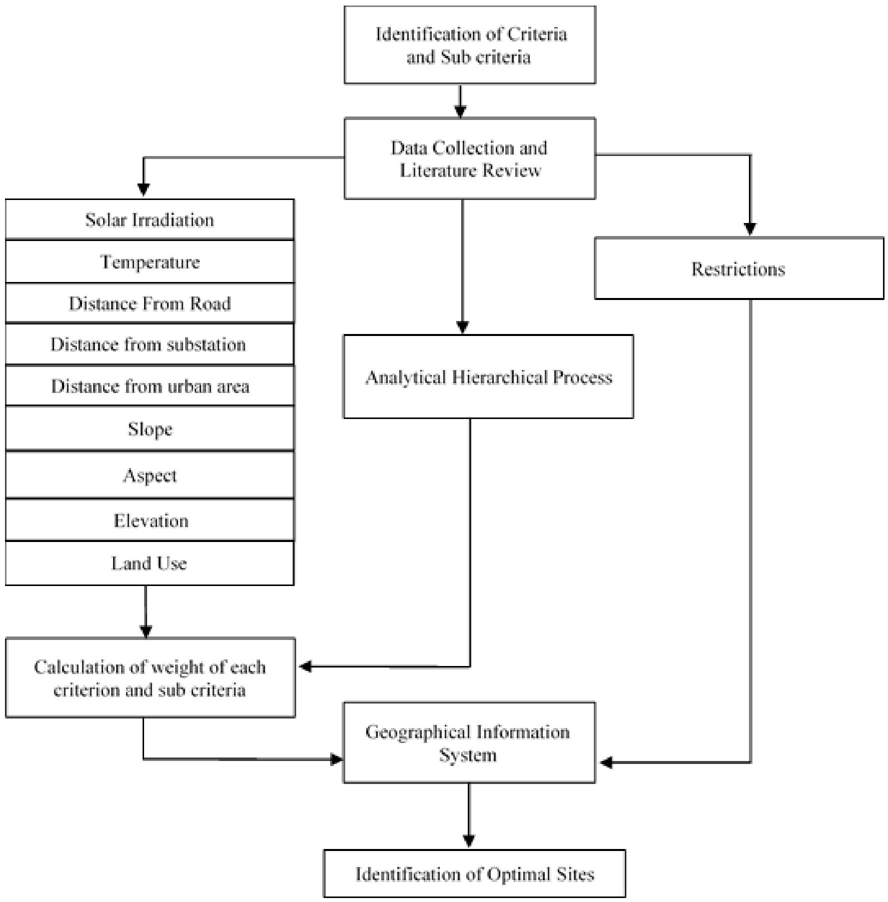

Figure 3 Methodology

4. Results and discussion

Nine criteria were considered to identify the optimal site for solar plant installation using a combination of the AHP and GIS. Table 8 shows the pairwise comparison matrix for the criteria considered for the present study while Table 9 depicts the weight of each criterion. The procedure for computation of the pairwise matrix has been described in Section 3.3

The calculated consistency ratio is well below 0.1 which indicates that the pairwise comparison is consistent. Solar irradiation was assigned with the highest weight followed by annual mean temperature, while land use was assigned the minimum weightage. Figure 4 shows the map of each criterion that was considered for the study (a-i), a map for restricted area (j), and a land suitability map (k).

Table 8
Pairwise Comparison matrix using AHP for optimal solar sites identification

	SI	AMT	DFR	DFS	DFU	EL	SL	AS	LU
SI	1.000	3.000	5.00	5.00	5.00	5.00	5.00	7.00	7.0
AMT	0.333	1.000	5.00	5.00	5.00	5.00	5.00	5.00	5.0
DFR	0.200	0.200	1.00	3.00	3.00	3.00	3.00	3.00	3.0
DFS	0.200	0.200	0.33	1.00	3.00	3.00	3.00	3.00	3.0
DFU	0.200	0.200	0.33	0.33	1.00	3.00	3.00	3.00	3.0
EL	0.200	0.200	0.33	0.33	0.33	1.00	2.00	3.00	3.0
SL	0.200	0.200	0.33	0.33	0.33	0.50	1.00	3.00	3.0
AS	0.143	0.200	0.33	0.33	0.33	0.33	0.33	1.00	3.0
LU	0.143	0.200	0.33	0.33	0.33	0.33	0.33	0.33	1.0

SI: Solar irradiance, MT: Annual Mean Temperature, DFR: Distance from the road, DFS: Distance from Substation, DFU: Distance from an urban area, EL: Elevation, AS: Aspect, LU: Land Use

Table 9
Weight of each criterion

Criteria	Weight
SI	0.33
AMT	0.24
DFR	0.11
DFS	0.09
DFU	0.07
EL	0.05
SL	0.04
AS	0.03
LU	0.03
Inconsistency Check	
α_{max}	10.141
Consistency Index, CI	0.143
Random Index, RI	1.450
Consistency Ratio, CR	0.098

Each of the criteria has its own sub-criteria. The weights of the sub-criteria were calculated using the AHP and the consistency ratio was kept below 0.1. The combined weights of criteria and sub-criteria are shown in Table 10.
.

Table 10
Summary of weights of criteria and sub-criteria using AHP for optimal solar sites identification

Criteria	Weight	Sub criteria	Weight	Final Weight
SI (kWh/m^2)	0.332	4.785-4.860	0.677	0.225
		4.731-4.785	0.172	0.057
		4.669-4.731	0.097	0.032
		4.308-4.669	0.054	0.018
AMT(^{0}C)	0.241	28.3-28.7	0.731	0.176
		28.7-29.2	0.188	0.045
		29.2-29.6	0.081	0.020
DFR (meter)	0.113	<5	0.638	0.072
		5-10	0.212	0.024
		10-15	0.099	0.011
		15-20	0.050	0.006
DFS (meter)	0.089	<4	0.638	0.057
		4-8	0.212	0.019
		8-12	0.099	0.009
		>12	0.050	0.004
DFU (meter)	0.070	<4	0.638	0.044
		4-8	0.212	0.015
		8-12	0.099	0.007
		>12	0.050	0.004
EL (m.a.s.l)	0.052	<100	0.638	0.033
		100-150	0.212	0.011
		150-200	0.099	0.005
		>200	0.050	0.003

Criteria	**Weight**	**Sub criteria**	**Weight**	**Final Weight**
SL (degree)	0.045	<1	0.638	0.029
		1-5	0.212	0.009
		5-10	0.099	0.004
		>10	0.050	0.002
AS	0.032	Flat/South	0.638	0.021
		South East	0.212	0.007
		East or West	0.099	0.003
		Other	0.050	0.002
LU	0.025	Bare ground	0.743	0.019
		Grass/Shrub	0.194	0.005
		Agricultural Land	0.063	0.002

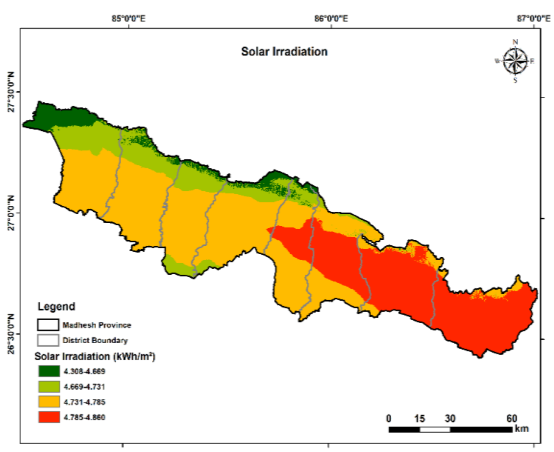

Figure 4a Maps of solar irradiation

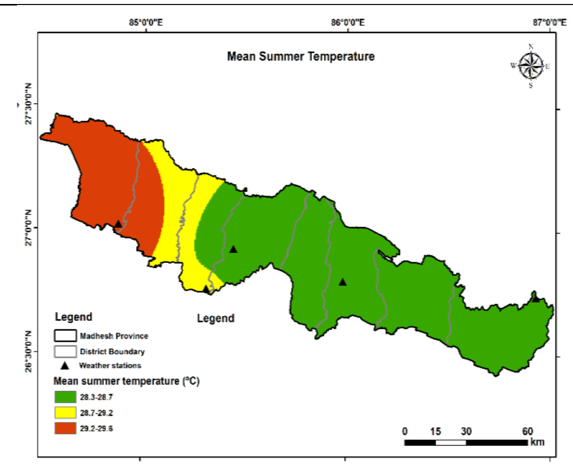

Figure 4b Map of mean summer temperature

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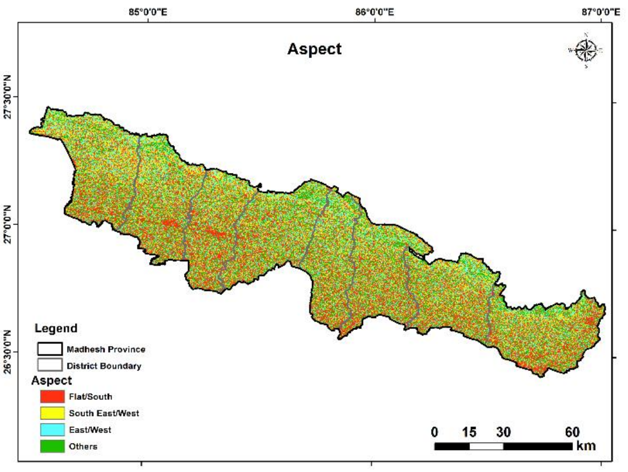


Figure 4c Map of aspect

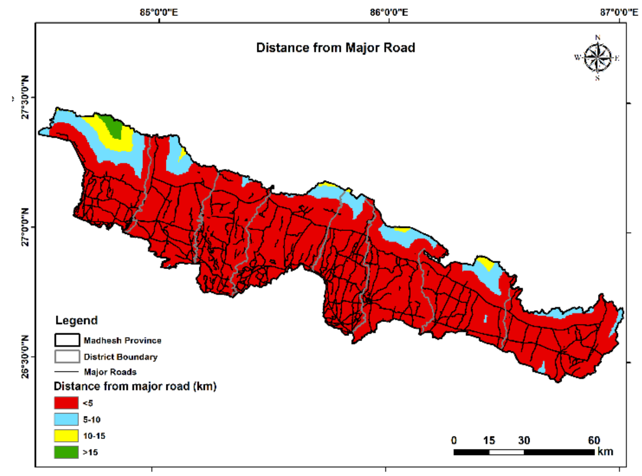


Figure 4d Map of distance from major road

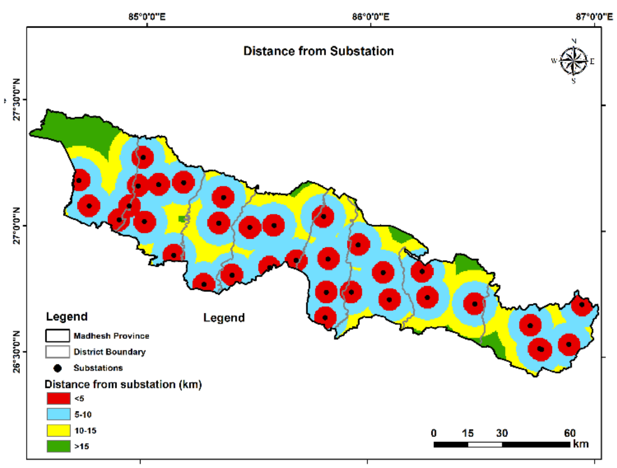


Figure 4e Map of distance from substation

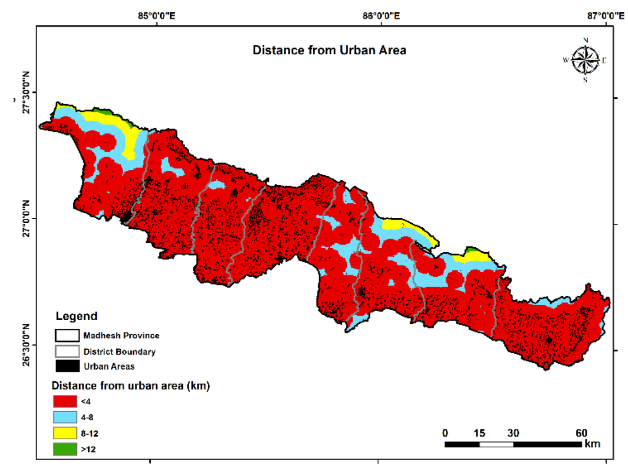


Figure 4f Map of distance from urban area

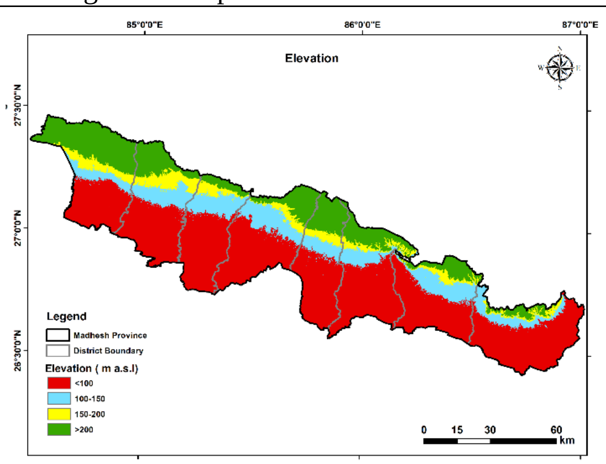


Figure 4g Map of elevation

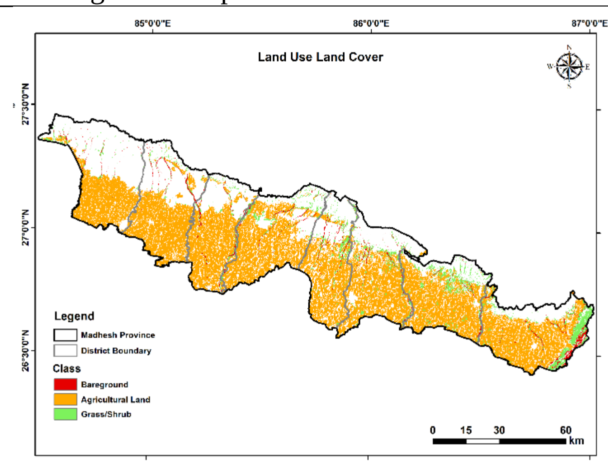


Figure 4h Map of land use land cover

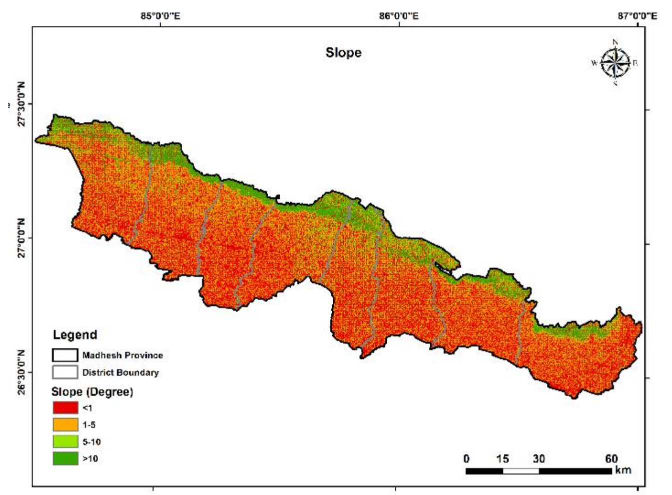


Figure 4i Map of slopes

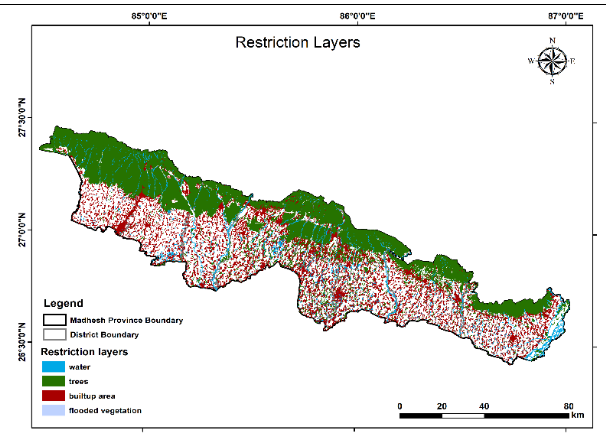


Figure 4j Map of restriction layers

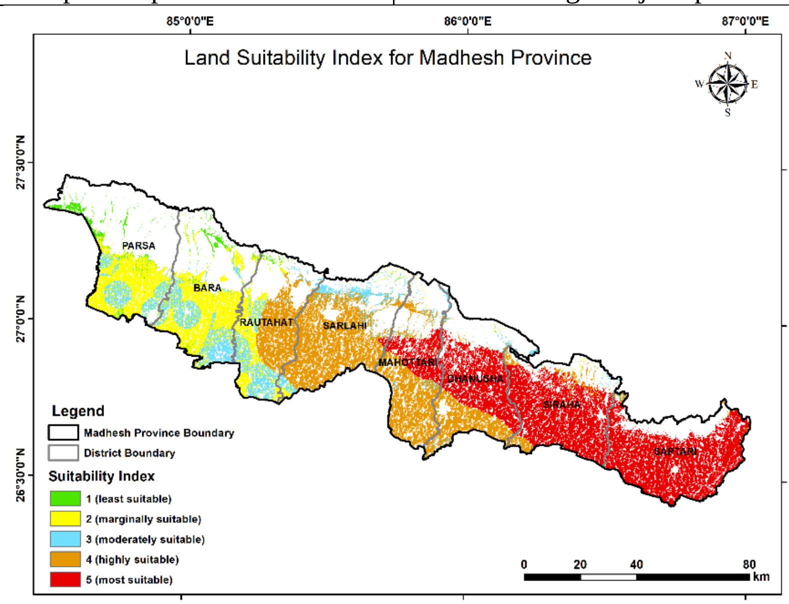


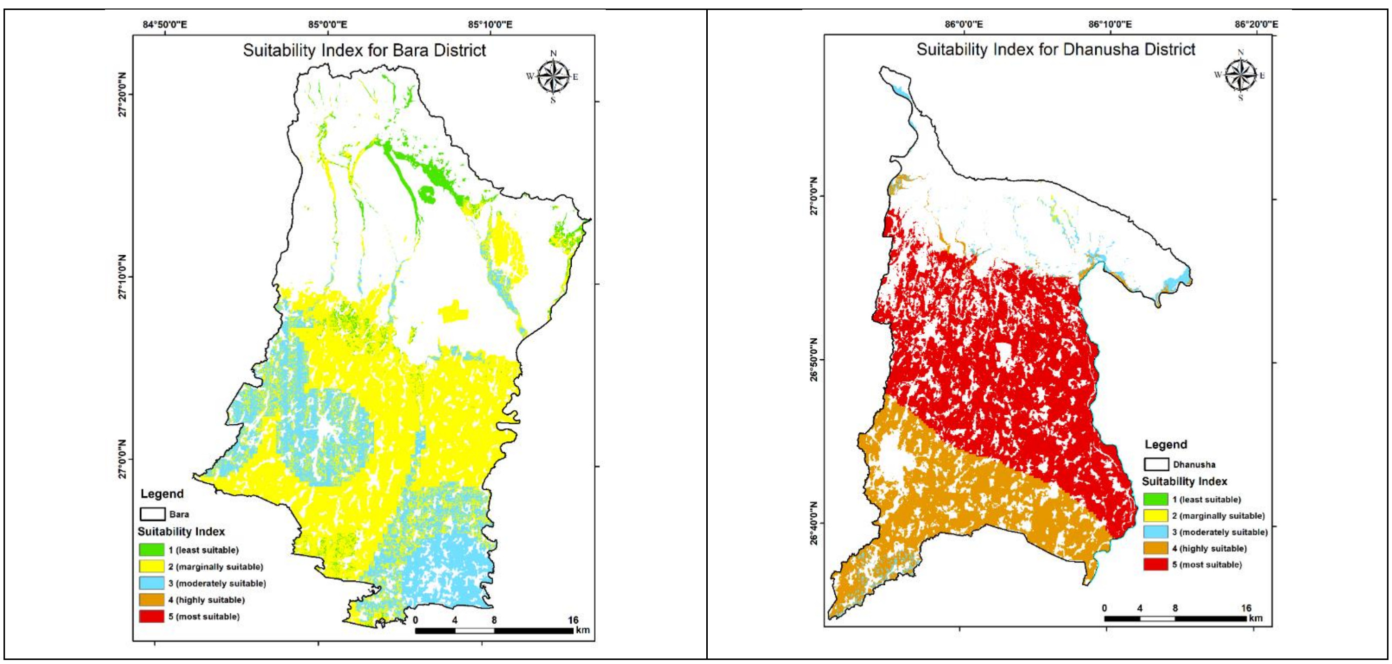
Figure 4k Map of land suitability index for Madhesh Province

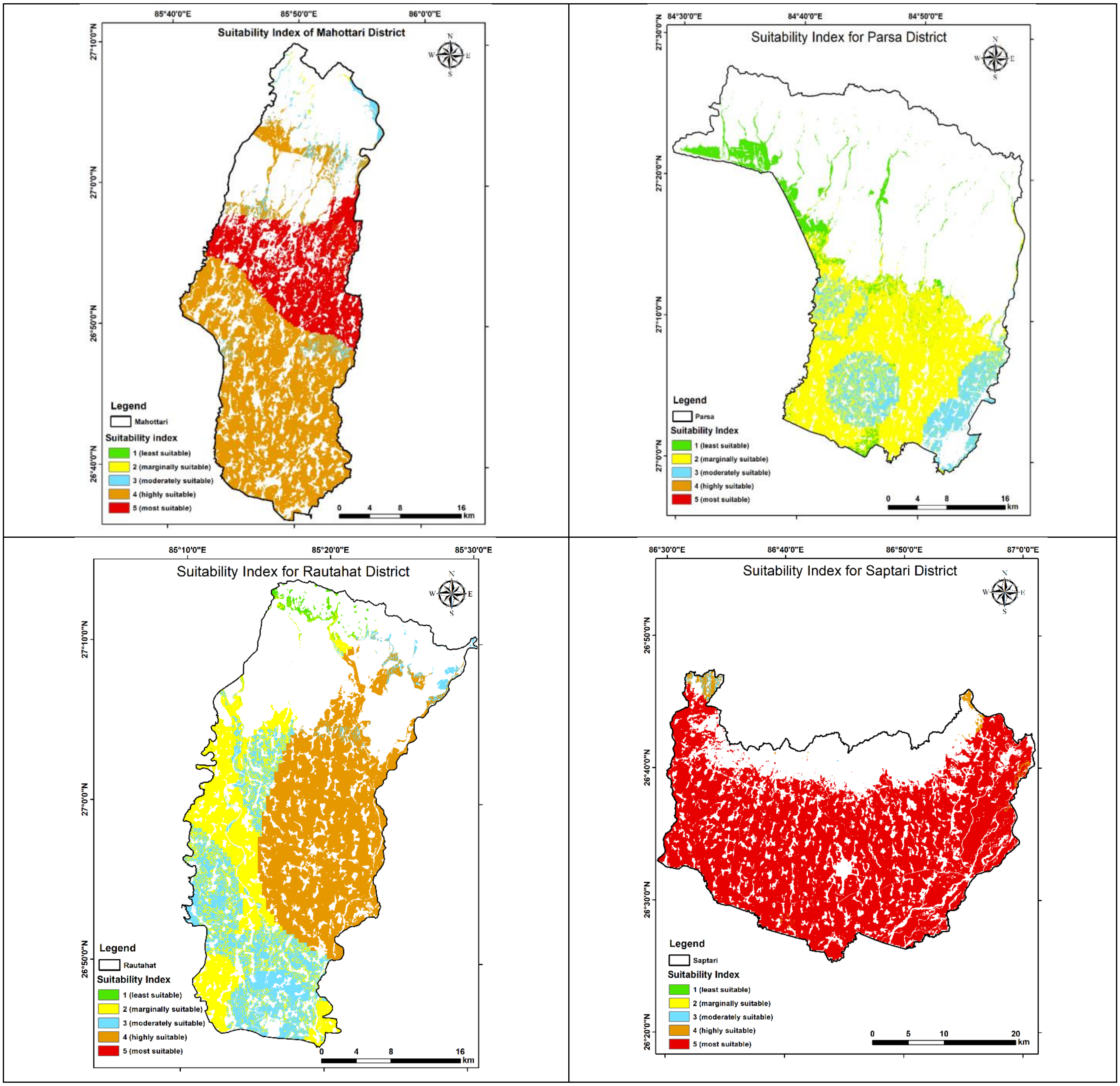
A land suitability index (LSI) defined as the degree to which each site is suitable for the placement of PV plants according to the associated criteria and excluding all restrictions (Al Garni & Awasthi, 2017) was employed to differentiate the land suitable for solar power plant installation with less suitable land. Index One (1) represents the least preferred area while five (5) represents the most suitable area. The highly suitable sites were found in the Saptari, Siraha, Dhanusa, and Mahottari districts while the district in the western region of the province had less suitable areas. Although the entire region from Saptari to Mahottari has high solar irradiation, these districts are also densely populated urban areas thereby reducing the amount of land suitable to set up the solar power plant. Solar irradiation had a major impact on the suitability of the land for solar power plant placement. Table 11 shows the land suitability index of each of the districts of Madhesh Province in terms of the total area of that district. Saptari district has 61.5% of the land with an index of five, followed by Siraha with 56.7% and Dhanusa with

35.4%. Bara, Parsa, and Rautahat districts lacked a suitability index of five but had an index ranging from 2 to 4. Districts on the western side of the province have national parks and reserves that have reduced the area suitable for the installation of solar power plants. Figure 5 depicts the suitability index of each district of Madhesh Province.

Table 11
Summary of suitability index for districts of Madhesh Province

District	**% Of land with LSI**				
	1	**2**	**3**	**4**	**5**
Saptari	0.0%	0.0%	0.2%	0.8%	61.5%
Siraha	0.0%	0.3%	0.5%	5.6%	56.7%
Dhanusa	0.0%	0.1%	1.8%	19.6%	35.4%
Mahottari	0.0%	0.1%	2.2%	36.7%	16.9%
Sarlahi	0.0%	1.5%	7.6%	49.6%	0.5%
Rautahat	0.6%	16.2%	12.8%	25.3%	0.0%
Bara	2.8%	35.8%	15.9%	0.0%	0.0%
Parsa	4.7%	25.6%	8.1%	0.0%	0.0%




Suitability Index of Mahottari District
85°40'0"E
85°50'0"E
86°0'0"E
27°10'0"N
27°0'0"N
26°50'0"N
26°40'0"N
Legend
Mahottari
Suitability index
1 (least suitable)
2 (marginally suitable)
3 (moderately suitable)
4 (highly suitable)
5 (most suitable)
0 4 8 16 km
Suitability Index for Parsa District
84°30'0"E
84°40'0"E
84°50'0"E
27°30'0"N
27°20'0"N
27°10'0"N
27°0'0"N
Legend
Parsa
Suitability Index
1 (least suitable)
2 (marginally suitable)
3 (moderately suitable)
4 (highly suitable)
5 (most suitable)
0 4 8 16 km
Suitability Index for Rautahat District
85°10'0"E
85°20'0"E
85°30'0"E
27°10'0"N
27°0'0"N
26°50'0"N
Legend
Rautahat
Suitability Index
1 (least suitable)
2 (marginally suitable)
3 (moderately suitable)
4 (highly suitable)
5 (most suitable)
0 4 8 16 km
Suitability Index for Saptari District
86°30'0"E
86°40'0"E
86°50'0"E
87°0'0"E
26°50'0"N
26°40'0"N
26°30'0"N
26°20'0"N
Legend
Saptari
Suitability Index
1 (least suitable)
2 (marginally suitable)
3 (moderately suitable)
4 (highly suitable)
5 (most suitable)
0 5 10 20 km

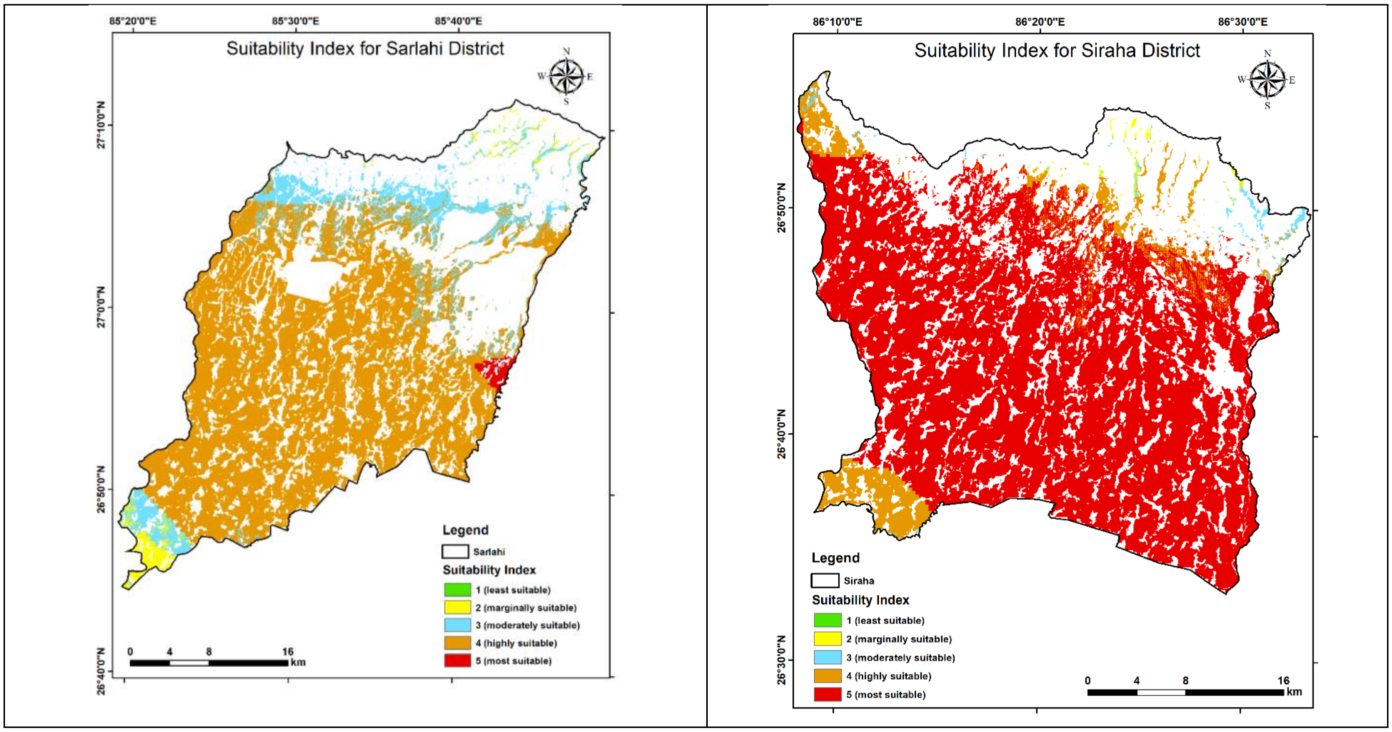


Figure 3 Land suitability index of different districts of Madhesh Province

5. Conclusion

Nepal has adopted the strategy of integrating renewable sources of energy like solar power plants to achieve the goal of carbon neutrality. The Nepal Electricity Authority, the sole buyer of the energy, provides an attractive Feed-In Tariff (FIT) for the solar power plants, which attracts investors. Despite many of the benefits of solar power plants, a research gap during the initial planning phase to determine the optimal areas for setting up the power plants still exists. Identification of the optimal location is by far the most crucial factor in setting up a power plant. This study can be a guide for the planners, developers, and the government regarding the optimal sites for utility-scale solar power plants.

A more realistic and practical approach has been adopted in this study by considering the criteria and sub-criteria that covered the technical, environmental, geographical, and economic aspects of setting up a solar power plant. The application of the AHP combined with GIS has given a better overview of land that is suitable for the installation of solar power plants. The method indicated that the areas on the eastern side of the province are more highly suitable to establish solar power plants while the western side has the least suitable areas to establish solar power plants. Saptari district has the highest percentage of land that is suitable for solar power plants while the Parsa district has the lowest.

The major limitation of this study was the use of secondary data on solar irradiation rather than data available from weather stations. More reliable data from weather stations can provide more accurate results for site suitability. It is recommended for future studies to include spatial data with higher accuracy and integrate data available from weather stations in various locations throughout the country.

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