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MULTI-CRITERIA GIS-BASED ASSESSMENT OF SOLAR POWER PLANT SITE SUITABILITY IN GÖNEN DISTRICT, ISPARTA, TÜRKİYE

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ABSTRACT

Solar energy has an important place among clean energy sources due to its environmental friendliness, energy supply security and sustainability features. In this research, the most suitable areas for Solar Power Plants (SPPs) in the Gönen district of Isparta were determined by applying a GIS-based Analytic Hierarchy Process (AHP) multi-criteria analysis. In the study, SPP site suitability factors such as elevation, slope, aspect, temperature, Global Horizontal Irradiance (GHI), annual precipitation, wind speed, Land Surface Temperature (LST), distance to roads and energy transmission lines, and land-use suitability were considered as the main criteria in SPP site selection. The top three criteria in SPP site selection were slope (18.8%), aspect (17.5%), and GHI (15.8%). Less influential factors are land use (3.9%), elevation (2.5%), and distance to roads (2.1%) and energy transmission lines (2.0%). According to the resulting SPP suitability map 16.55% of the district is in the "very high" suitability class, 27.55% in the "high" suitability class, and 27.21% in the "moderate" suitability class. Furthermore, more than 80% of the existing solar power plants lie in "high" and "very high" suitability classes. This emphasizes the appropriateness of the criteria used in this study and also the technique applied.

Keywords: Solar Power Plant (SPP), Analytic Hierarchy Process (AHP), Site Suitability, Gönen-Isparta.

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INTRODUCTION

Due to increasing consumption of fossil fuels, environmental issues such as climate change, global warming, and pollution have increased, thus accelerating the need for using sustainable and renewable energy sources. Among these energy alternatives, solar energy is considered a clean source, a reliable source, and an infinite source of energy in the future. To attain this objective, a radical shift towards the use of renewable energy sources such as solar, wind, and hydroelectric power, among others, after decreasing reliance on fossil fuels is mandatory. To facilitate this shift during the course of achieving this objective, a systematic and analytical methodology will be considered in selecting an investment location for clean and renewable energy sources. Furthermore, this is a mandatory requirement given the widespread emergence of SPP projects recently. Selecting a suitable location for a solar power plant not only considers high solar intensity but adopts a simultaneous assessment factor for other major parameters including slope, orientation, height, land use, wind speed, surface temperature, distance to roads, and distance to power lines. Integrating all these parameters will create a complicated situation in Multi-Criteria Decision Analysis (MCDA) / Multi-Criteria Decision Making (MCDM). Assessing inter-relationship among these parameters and their role in location selection is a complicated problem. To address these issues, studies conducted have effectively clarified that methods such as AHP analysis are very efficient in inter-linking these parameters with their relative weights successfully in AHP analysis (Aydin et al., 2013; Al Garni & Awasthi, 2017; Ozcelik & Sarp, 2018; Giamalaki et al., 2019; Gacu et al., 2023; Ahadi et al., 2023; Amiri et al., 2024). Past studies have clarified the significance of selecting a location for a solar power plant in literature (Bazmi & Zahedi, 2011; Mardani et al., 2015; Infield & Freris, 2020). Other studies undertaken clarify an integration strategy using GIS & MCDA/MCDM in order to reach an accuracy level in selecting a suitable location efficiently (Datta et al., 2011; Lund et al., 2024; Ukoba et al., 2024; Amiri et al., 2024). AHP analysis in these studies is used given its methodology, capacity to assess different parameters simultaneously based on priority parameters, and transparent analysis.

The Analytic Hierarchy Process (AHP) proposed by Saaty in 1972 is a technique used in MCDM. It is particularly useful in studies where decision makers must evaluate multi criteria to compare various options (Saaty, 1980). AHP has found many applications in renewable energy projects related to site selection (Al Garni&Awasthi, 2017; Yankiv-Vitkovska et al., 2020; Gacu et al., 2023; Amiri et al., 2024).

Despite the extensive literature on GIS–AHP-based solar site selection, region-specific studies that integrate long-term climatological variables with high-resolution spatial data at the district scale in Türkiye remain limited. Furthermore, the combined evaluation of static, quasi-static, and climatic parameters within a unified decision-support framework has not been sufficiently explored in local renewable energy planning contexts.

The present study proposes a GIS–AHP-based multi-criteria site suitability model to identify optimal solar power plant locations in the Gönen District (Isparta, Türkiye). The novelty of this study lies in the integration of a comprehensive set of carefully selected parameters representing topographic, climatic, environmental, and infrastructural conditions, the combined use of long-term climatological averages and high-resolution spatial datasets, and the production of a locally applicable suitability map to support regional renewable energy planning and decision-making. The selected parameters, such as elevation, slope, aspect, temperature, Global Horizontal Irradiance (GHI), annual precipitation, wind speed, Land Surface Temperature (LST), distance to roads, distance to energy transmission lines, and land-use suitability, which were selected based on their demonstrated relevance in previous GIS–MCDA/AHP studies and their direct influence on the technical feasibility, environmental compatibility, and economic viability of solar power plant installations.

Subsequently, the AHP method was performed in order to handle the complex decision-making processes among these parameters and to compute the importance, which continuously weighed the factors. Importance levels (weights) obtained from AHP were used to analyze and integrate the spatial data obtained through GIS, and the spatial distribution of suitable sites was determined. This integrated analysis is of immense value for identifying potential sites with high accuracy for the construction of a clean and sustainable solar power plant at Gönen.

1. STUDY AREA

The study area is the Gönen district of Isparta located in the Lakes Region of southwestern Türkiye (Fig.1a, b). The district has a high potential for solar power plant investments due to its location, and the widespread use of solar power plants in the district indicates this (Fig. 1c, d). According to Solar Energy Potential Atlas (GEPA) of Türkiye, the lowest radiation level observed in the district was 1.80 kWh/m²-day (December), and the highest radiation level was 6.73 kWh/m²-day (June). In May and August, radiation levels exceed 6 kWh/m²-day. On the other hand, while the sunshine duration in the district is around 3.85 hours in December and 4.33 hours in January during the winter months, these durations are around 11.06 hours and 11.64 hours in June and July during the summer months. This indicates a strong potential for SPP installation in the district (https://gepa.enerji.gov.tr/pages/32.aspx). These high radiation values support the economic viability of the project in the district. Therefore, Gönen is considered a suitable region for determining SPPs site suitability.

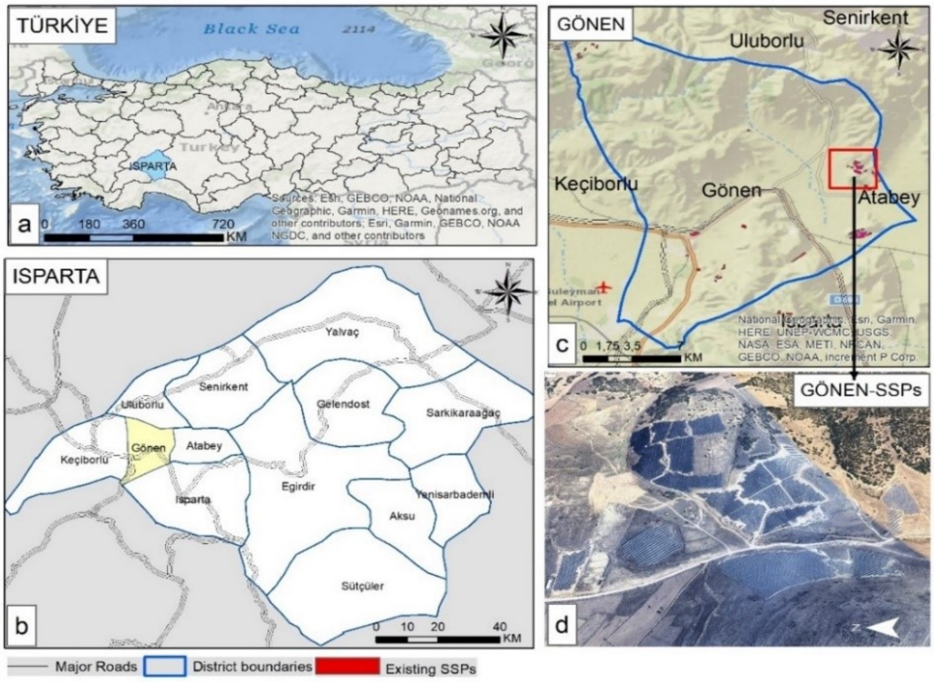

Figure 1. Study area maps: (a) Location of Isparta within Türkiye; (b) Location of Gönen within Isparta Province; (c) Detailed map of the Gönen district; (d) Example Google Earth imagery showing existing Solar Power Plants (SPPs) in Gönen.

2. MATERIALS AND METHODS

2.1 Data Sources and Preprocessing

Multiple datasets were used in this study to evaluate site suitability for SPPs. Topographic and morphometric parameters, including slope, aspect, and elevation, were derived from the SRTM 1 arc-second Digital Elevation Model (DEM) provided by NASA/USGS, which has a spatial resolution of 30 meters (https://www.earthdata.nasa.gov). Global Horizontal Irradiance (GHI) data were obtained from the Global Solar Atlas (World Bank Group), providing annual average values of GHI (https://globalsolaratlas.info/download/turkey), and wind speed data were retrieved from the Global Wind Atlas (https://globalwindatlas.info/en/). LST was calculated using Band 10 of the Thermal Infrared Sensor (TIRS) onboard Landsat 9 imagery acquired on 23 June 2025 from the USGS EarthExplorer (https://earthexplorer.usgs.gov/), with a spatial resolution of 100 meters. Precipitation and mean temperature data were obtained from the WorldClim v2.1 database at a spatial resolution of 30 arc-seconds (~1 km²), representing long-term climatic averages for the period 1970–2000 (Fick and Hijmans, 2017). Land cover and land use information were obtained from the CORINE Land Cover 2018 dataset (EEA) at 100-meter resolution, facilitating the identification of suitable and unsuitable terrain types (https://land.copernicus.eu/en/products/corine-land-cover). Road and power transmission line data were obtained from OpenStreetMap (OSM) using the Overpass Turbo query tool (https://overpass-turbo.eu/). Although the datasets originate from different temporal periods, long-term climatological averages were used to represent stable background conditions, while the most recent Landsat 9 imagery was selected to reflect the most recent surface thermal conditions important for evaluating solar power potential. This combination of multi-temporal datasets is commonly adopted in GIS-based spatial suitability analyses.

Preprocessing in a GIS environment was carried out before the analysis of all datasets. Preprocessing steps included geometric correction, coordinate transformation, and resampling to ensure consistency in spatial resolution across datasets. All layers were projected to a common coordinate system (UTM Zone 36N, WGS 84) and clipped to the district boundaries. To enable comparison across all datasets with the different units and scales, normalization to 0–1 range was performed.

2.2 Site Selection Criteria for Solar Power Plants

The performance and applicability of green energy systems depend on many factors, including the characteristics of energy sources, efficiency, physical and environmental characteristics of the technologies used, and potential installation sites. High-quality data is needed for economically viable and efficient location of solar power plants. The selection of criteria used in this study, including elevation, slope, aspect, temperature, GHI, annual precipitation, wind speed, LST, Euclidean distance to roads, Euclidean distance to power lines, and land use suitability (Fig.2), was based on an extensive literature review.

In the context of Gönen District, all these criteria have different spatial patterns that affect SPP suitability. According to the elevation data, the general altitude increases toward the northern and northwestern parts of the district, potentially limiting SPP installation in those areas due to cooler temperatures and stronger wind effects (Fig. 2a). Slope, on the other hand, was expressed as the steepness of the terrain. Steeper slope values were evident in northern and northwestern mountainous regions, which are considered as a limiting condition for SPP installation, while its gentler slopes in the southern and southeastern of the area seemed more favorable (Fig. 2b). Aspect maps showed slope orientation, which had an influence on the amount of exposure to solar radiation. South orientation offered favorable conditions (Fig. 2c). Temperature data were analyzed with respect to thermal conditions. Higher temperature values were evident in the centre and southeast part of the area, which would be favorable for energy generation (Fig. 2d). GHI was higher in the east and southeast, indicating greater solar potential in those areas (Fig. 2e). In some parts towards the north of the district, the annual precipitation is relatively higher than in other areas, which will affect the maintenance process of solar panels to be built in these parts (Fig. 2f). Wind speed shows higher values in the northern and northwestern parts of the district, where topographic exposure contributes to stronger air flow, potentially limiting the feasibility of SPP installations (Fig. 2g). LST results reveal lower temperatures in the northern and northwestern areas with higher elevation, while temperatures increase towards the central and interior parts. Elevated temperatures in these central regions may enhance the performance and energy yield of solar power plants, making them more suitable for SPPs installation (Fig. 2h). Euclidean distances to roads and energy transmission lines were calculated to evaluate accessibility and connection efficiency. Proximity to a road offers convenience for construction and maintenance, while closeness to existing energy lines reduces connection costs. Accordingly, areas far from roads or transmission lines are considered less suitable (Fig. 2i–2j). Land use information from the CORINE Land Cover dataset has been reclassified into four suitability categories for SPPs installation: Highly Suitable (meadows, pastures, sparse vegetation, rocky areas, non-irrigated agricultural lands), Moderately Suitable (shrubland, mixed vegetation, orchards), Low Suitable (dense forests, built-up areas), and Not Suitable (wetlands, irrigated agricultural lands, water bodies), based on land-use compatibility, environmental protection constraints, and criteria widely adopted in GIS-based solar power plant site suitability studies (Carrión et al., 2008; Uyan, 2017; Khan et al., 2023). The spatial distribution of these land-use suitability classes is illustrated in Fig. 2k.

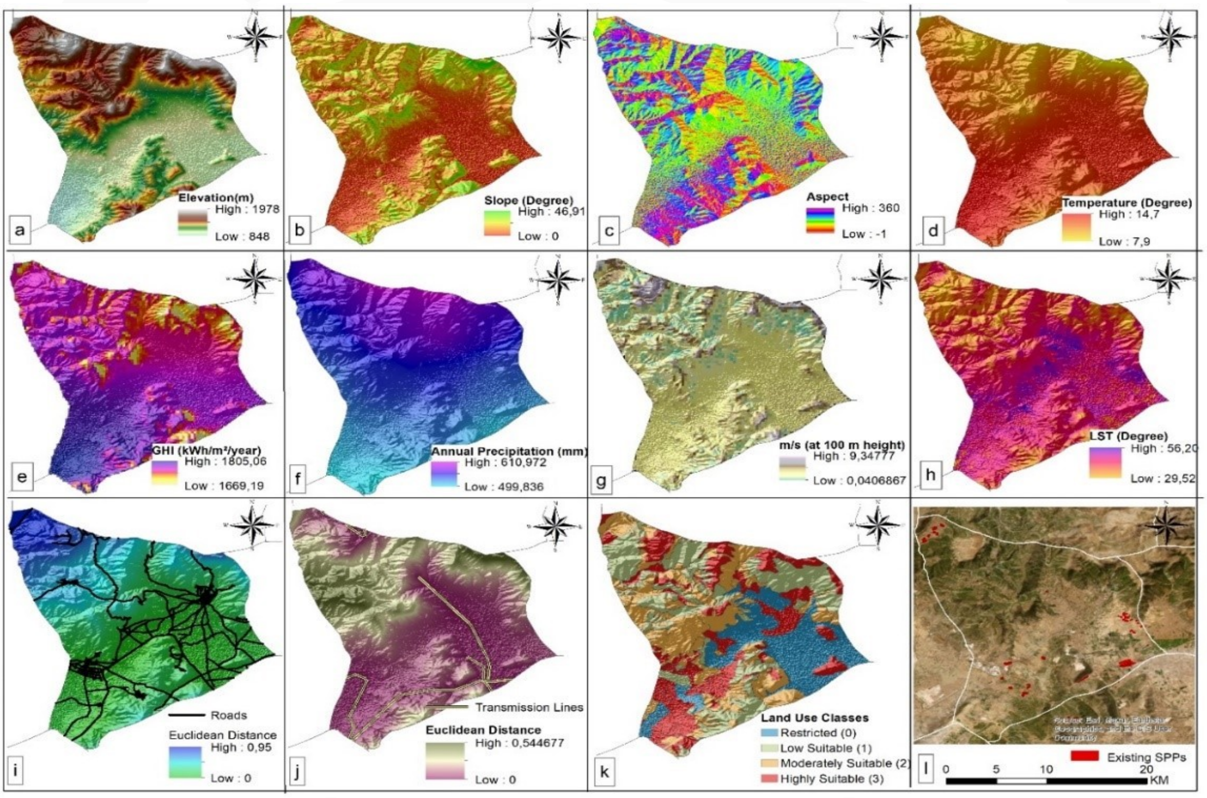

Figure 2. Thematic maps of the Gönen district illustrating topographic, climatic, and infrastructural factors influencing solar power plant (SPP) site suitability: (a) Elevation, (b) Slope, (c) Aspect, (d) Temperature, (e) Global Horizontal Irradiance (GHI), (f) Annual precipitation, (g) Wind speed, (h) Land Surface Temperature (LST), (i) Euclidean distance to roads, (j) Euclidean distance to energy transmission lines, (k) Land-Use suitability, and (l) Existing SPPs displayed over an ESRI basemap.

2.3 Criteria Normalization for Suitability Analysis

Datasets used in MCDA studies often have different units, scales, and value ranges. For this reason, data normalization is required to bring all criteria onto a comparable scale before applying weighting and overlay procedures. This step ensures that no single variable dominates the evaluation due to its numerical magnitude. In this study, all the continuous criteria were standardized to a 0–1 interval before the weighting and overlay stages. Slope, elevation, LST, wind speed, annual precipitation, and distances to roads and energy transmission lines were treated as cost criteria because they negatively affect site suitability with increasing values. These datasets were normalized using an inverse min–max transformation, based on the Linear Scale Transformation (Max–Min) technique given in Eq.1 (Çelen, 2014). This technique ensures that each attribute is rescaled within a strict interval of 0–1, within which its range is clear and comparable (Chakraborty & Yeh, 2007, 2009). GHI was considered a benefit criteria, since higher irradiation values indicate greater suitability for solar energy production. For this variable, standard min-max normalization was used (Eq.2):

$$Normalized\ Value = \frac{X_{max} - X}{X_{max} - X_{min}} \tag{1}$$

where X is the raw value, and Xmin and Xmax are the minimum and maximum values of the dataset. This inversion ensures that larger values correspond to lower suitability.

$$Normalized\ Value = \frac{X - X_{min}}{X_{max} - X_{min}} \tag{2}$$

where X is the value in the original cell, and Xmin and Xmax are the minimum and maximum values of the dataset. The result of this transformation rescales all values to a range between 0 and 1, which means higher normalized scores will result in a higher degree of suitability depending on the nature of the criterion.

The criteria pertaining to categories were considered individually. The aspect values were initially recoded into directional aspects, with all southern directions assigned a score of the highest suitability. Suitability scores were assigned to land cover classes based on their association with conducting a solar power plant setup. The categories were already in a standard scale and thus did not need any normalization.

By using this method, it can be ensured that both continuous and nominal variables possess a common scale of measurement so that they can be unified in AHP analysis.

2.4 Integration of Thematic Layers to Define Suitable Zones for SPPs

Suitable zones for SPPs in Isparta-Gönen were identified using the AHP, which was introduced by Saaty (1972). AHP is one of the MCDA techniques that allows both objective and subjective factors to be taken into consideration during decisions. As with other MCDA methods, it provides a structured approach for dealing with complex, unstructured decision-making problems. The process involves establishing a hierarchy of decision criteria and allowing pairwise comparisons to be made between them in matrix form, assigning relative weights, and calculating a Consistency Ratio (CR). Comparisons are based on a numerical scale ranging from 1 to 9, indicating the relative importance of one criterion compared to another. All these values have to be determined with great care instead of arbitrary setting. The CR, proposed by Saaty (1977), should be checked for the consistency of the comparison matrix, and according to Saaty and Vargas (1991), the matrices having a CR value above 0.1 must be revised. CR is calculated as given in (Eq. 3):

$$CR = \frac{CI}{RI} \tag{3}$$

where CI is the consistency index and RI is the average consistency index for a randomly generated matrix. In this study, the CR was calculated based on the RI value that matched the size of the matrix in the AHP model. Given that there were 11 criteria involved in the pairwise comparison, the RI value was considered to be 1.51, according to Saaty and Vargas (1991). The CI is calculated from the pairwise comparison matrix through (Eq. 4):

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{4}$$

where $\lambda_{\max}$ is the largest eigenvalue of the comparison matrix, and n is the matrix order.

In the next step, the relative importance of the eleven thematic layers was assessed by a pairwise comparison method. In this respect, each pair of criteria was assigned a numerical value ranging between 1 and 9 to indicate the strength of preference among the concerned pairs. These values were determined by making comprehensive judgments with the aid of expertise in geoscience and remote sensing. The obtained pairwise comparison matrix is shown in Table 1.

Table 1. Pairwise comparison matrix of the eleven criteria.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11
C1	1	2	3	2	3	2	2	4	4	6	6
C2		1	3	4	3	1	1	6	6	7	7
C3			1	3	3	1	2	5	6	5	5
C4				1	2	1	1	3	8	6	4
C5					1	1	1	2	2	2	2
C6						1	7	5	6	6	6
C7							1	5	5	4	4
C8								1	4	3	3
C9									1	2	2
C10										1	1
C11											1

Criteria Exp: C1 – Slope; C2 – Aspect; C3 – Precipitation; C4 – Temperature; C5 – Wind speed; C6 – Solar radiation (GHI); C7 –Land surface temperature (LST); C8 – Land use; C9 – Elevation; C10 – Distance to roads; C11 – Distance to energy transmission lines.
Principal eigen value = 12.169
Eigen vector solutions: six iterations delta = 7.6E–8

Applying the principal eigenvector method, the final weights of the criteria were derived after pairwise comparison (Table 2). Among the thematic layers, slope received the highest weight (18.8%), followed by aspect (17.5%) and GHI (15.8%). Other important criteria included precipitation (13.1%), temperature (9.5%), LST (8.9%), and wind speed (6.0%). The criteria with the lowest influence were distance to energy transmission lines (2.0%) followed by distance to roads (2.1%), elevation (2.5%), and land use (3.9%), clearly reflecting the minor role of accessibility and land-use considerations in determining suitable sites for solar power plants. The CR of the pairwise comparison matrix was calculated as 0.077, which is below the threshold of 0.1 and indicates that the judgments are consistent enough for further analysis.

Table 2. Priority weights and rankings of criteria derived from AHP.

Criteria	Priority (%)	Rank	(+ %)	(- %)
Slope	18.8	1	9.0	9.0
Aspect	17.5	2	9.3	9.3
Precipitation	13.1	4	5.9	5.9
Temperature	9.5	5	4.1	4.1
Wind speed	6.0	7	3.1	3.1
Solar radiation (GHI)	15.8	3	13.8	13.8
Land surface temperature (LST)	8.9	6	4.5	4.5
Land use	3.9	8	2.1	2.1
Elevation	2.5	9	1.1	1.1
Euclidean distance to energy transmission lines	2.0	11	0.6	0.6
Euclidean distance to roads	2.1	10	0.6	0.6

2.5 GIS Integration and Weighted Overlay

The spatial suitability of potential solar power plant installation sites was assessed by integrating the AHP-derived weights of raster parameters used in the study within a GIS environment. The resulting weighting coefficients (Wi) were then applied to the raster layers using the Weighted Overlay approach, one of the most common methods for MCDA, to obtain a suitability map of solar power plants in the study area. This process can be mathematically expressed as the Suitability Score (Eq.5):

$$Suitability\ Score = \sum_{i=1}^{n} w_i Xc_i \quad (5)$$

where wi is the AHP-derived weight of criterion i, n is the total number of criteria used in analysis and Xci is the normalized or classified raster value of criterion i.

3. RESULTS AND DISCUSSION

3.1 Effect of Criteria Weights and Spatial Distribution

The integration of the SPPs site selection parameters with the AHP methods reveals that slope was the most influential parameter, with a weight of 18.8%. On the other hand, the Euclidean distance to roads (2.1%) and energy transmission lines (2.0%), along with elevation (2.5%), were found to be less important criteria (Table 2). The prominence of slope factor in this analysis is in accordance with existing research work undertaken using GIS-MCDA for analysis of solar suitability, wherein slope factor has been proved to be a major factor in construction and installation cost favorability (Yankiv-Vitkovska et al., 2020). The lower priority weights given to accessibility factors such as Euclidean distance to roads and transmission lines have also been observed in existing research work based on GIS-AHP in solar site selection analysis (Al Garni & Awasthi, 2017).

Overall, the weighting results indicate a clear dominance of topographic and climatic factors over accessibility-related parameters, ensuring a consistent AHP-based foundation for the subsequent GIS weighted overlay analysis.

The AHP weighted overlay methodology has some intrinsic limitations. Some degree of “very high” suitability in moderately elevated or vegetated regions may reflect favorable solar radiation levels or localized topographic effects rather than actual site feasibility. Despite these limitations, the spatial distribution of suitability classes provides valuable insights into potential SPP locations.

The spatial distribution of suitability classes is illustrated in Fig. 3. “High” and “very high” suitability zones are mainly located in low slope areas and southern parts of this district, and regions of low suitability mainly exist in the northern and northeastern parts with high slopes.

The above results can be used for basic planning of SPP implementation, but verification and technical evaluation are very important in this case. Further research can improve model assessment using other validation methods, for instance, sensitivity analysis of AHP-weighting vector accuracy or comparisons based on other MCDA approaches.

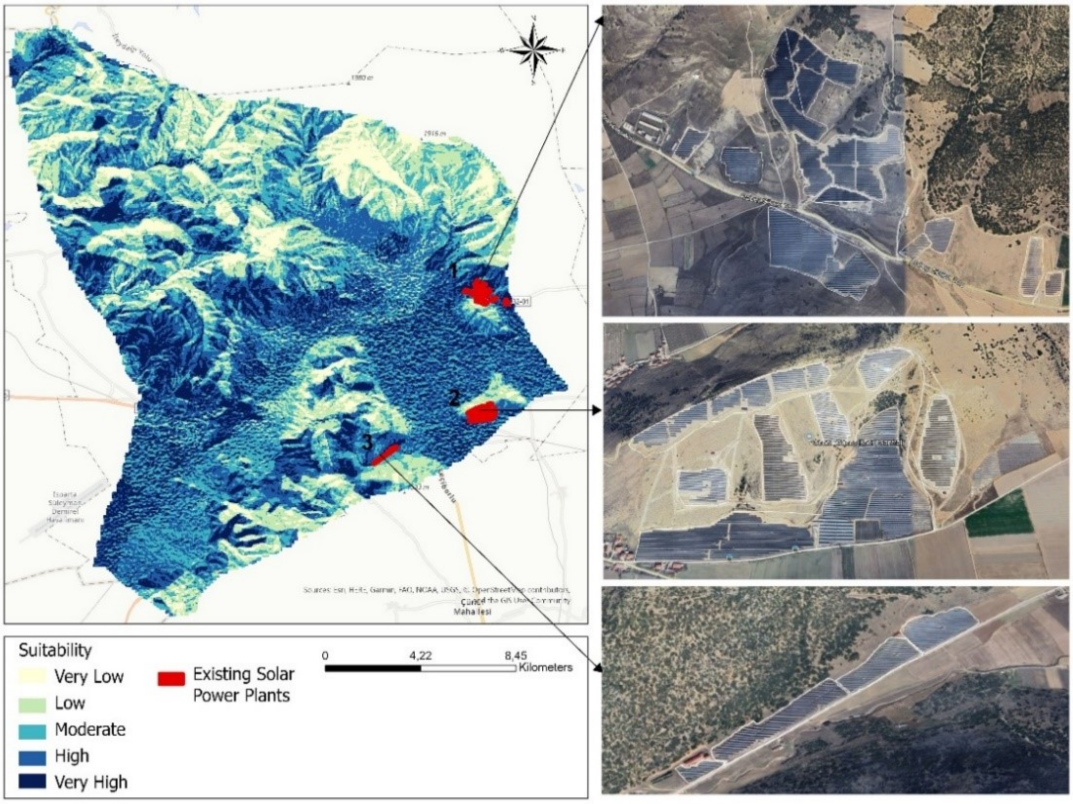

Figure 3. Final SPPs suitability map for Gönen District and detailed close-up Google Earth images of the three existing SPPs areas (on the right).

The numerical distribution of the suitability map is summarized in Table 3. The study region has been classified into five suitability classes. The results indicate that the "moderate suitability" and "high suitability" classes in Gönen occupy 27.21% and 27.55%, respectively, and "very high suitability" class occupies 16.55%. On the other hand, "very low" and "low" suitable regions occupy 9.32% and 19.36%, respectively, corresponding to a combined share of 28.68%, mainly covering the northern and northeastern part of this region with topography being less suitable in nature. Some apparent “very high” suitability in certain mountainous or vegetated areas may result from higher solar radiation values or local topographic variations, rather than reflecting true feasibility. These observations highlight the need for careful interpretation and on-site verification. The AHP-based weighted overlay results provide a relative suitability assessment rather than absolute feasibility; future studies may enhance realism by incorporating exclusionary constraint layers such as slope thresholds, forest masks, protected areas, or post-classification filtering procedures.

Table 3. Comparison of overall suitability classes with the spatial distribution of existing solar power plants (SPPs).

Suitability Class	Area Pixel Count	Total Area (%)	SPPs Pixel Count	SPPs(%)
Very Low	25306	9.32	0	0.00
Low	52532	19.36	59	5.67
Moderate	73818	27.21	119	11.44
High	74774	27.55	442	42.60
Very High	44925	16.55	419	40.29

3.2 Spatial Validation and Reliability Assessment of the Suitability Model

To determine the reliability of the proposed AHP-GIS based suitability model, the existing SPP sites have been traced using Google Earth images. The validation shows that 94.33% of the existing SPPs lie in moderate, high, and very high suitability classes, whereas only 5.67% lie in low and very low classes. Particularly, 82.89% of the existing SPPs lie in high and very high classes as shown in the proposed suitability model (Table 3). The presence of a high degree of similarity between the model output and existing SPPs indicates the reliability of the model output. Though discrepancies always exist in current studies due to certain economical, political, or infrastructural reasons, the present study indicates a preponderant influence of geographical factors for the selection of SPPs in the Gönen district.

Although the result of the accuracy assessment of this study relies exclusively on the comparison of the existing solar energy plants and the created suitability classes through spatial analysis, the fact that the concentration of existing solar energy plants lies in areas of moderate to high suitability suggests that there is a certain level of agreement between the two sets of model outputs and that of reality. Future studies should consider improving this aspect by using ROC/AUC analysis and presence/absence modeling among others.

CONCLUSIONS

This study demonstrates how the combined use of GIS and AHP methods can effectively select suitable sites for SPPs. Evaluation of the parameters used in site selection using the AHP method revealed that the top three factors in SPP site selection are slope (18.8%), aspect (17.5%), and solar radiation (15.8%), followed by precipitation (13.1%), temperature (9.5%), LST (8.9%) and wind speed (6.0%). Less influential factors in SPPs site selection are land use, elevation, and distance to power lines and roads.

According to the resulting map obtained from the analyses and weightings, 16.55% of the district is in the "very high" suitability class, 27.55% in the "high" suitability class, and 27.21% in the "moderate" suitability class. The concentration of more than 80% of existing solar power plants within the "high" and "very high" suitability classes highlights the relevance of the applied criteria and confirms the effectiveness of the proposed suitability assessment approach.

Beyond the identification of suitable sites, this study provides a district-scale GIS-AHP framework that combines long-term climatic variables with high-resolution spatial data and can be a useful decision-support tool for the preliminary solar power plant planning process. The results here express relative suitability, not absolute feasibility, and further studies can enhance the model by the inclusion of more constraint layers or by considering alternative MCDA methods.

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