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Suitability Analysis Using GIS-Based AHP-MCDM for Solar Farm Site Selection in Tanjero Subdistrict: A Study in the Geography of Energy

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ABSTRACT

Nowadays, electricity is one of the most essential and basic daily necessities for human beings everywhere. Hence, ensuring its supply is the primary responsibility of governments. Throughout the Kurdistan Region, and especially in the study area, the government mainly relies on dams and fossil fuels to generate electricity, but still can't meet the all the electricity demands of citizens. However, there is a lack of systematic studies identifying optimal locations for solar power plants in the study area to reduce reliance on polluting generators. Therefore, to cover the electricity shortfall, the government depends on another source - generators that they run on fossil fuels, which are major environmental polluter. Whereas, to address this energy shortage, it can get benefits from eco-friendly green energy. Because if we consider the abundance of sunny days in the study area, solar power is an effective alternative for generators. Accordingly, in this study the most suitable site analysis for establishing solar power plants has been carried out. As well, to obtain the scientifically and more accurate result, Analytical Hierarchy Process (AHP), which it belongs to multi criteria decision making (MCDM) methods, was used. As a result, the study area is highly suitable for generating electricity from solar energy, with approximately 30 percent of the area identified as appropriate for installing photovoltaic panels.

KEYWORDS**:** Tanjero subdistrict, Solar energy, Electricity shortfall, Solar power plants, AHP-MCDM.

1. INTRODUCTION [1]

In the contemporary era, as a result of industrialization and urbanization, Demand for electricity is steadily increasing worldwide. In the 20th century, humans relied on fossil fuels as a primary source to generate electrical energy. However, growing concerns about environmental degradation in the 21st century have led scientists to think about using eco-friendly renewable energy sources as an alternative to conventional energy sources for generating electric power. International Energy Agency Photovoltaic Power System Programme (IEA-PVPS)) reports that solar panels currently generate 5.4% of the world's electricity, a share that continues to grow, making solar energy the third-largest renewable source after hydropower and wind (IEA-PVPS, 2024: 91). The same source figure that solar energy is the third-largest renewable electricity source after hydropower and wind. In consequence, today in global electricity production, renewable energy sources play a significant role. In this direction, solar energy stands out as one of the most important sources of renewable energy. Because of it offers clean, pollution-free power that does not produce carbon monoxide, sulfur compounds, toxic gases or noise. Therefore, it is called an eco-friendly energy source. In the study area, electricity generation still primarily depends on fossil fuels, and the government currently has no plans to utilize renewable energy to meet residents' electricity needs. While several studies highlight the potential of solar energy in Iraq and the Kurdistan Region. For example, Dawod Keya et al.

(2023) found that Sulaymaniyah possesses a high potential for electricity generation from solar radiation. Their study reported an average daily solar radiation of approximately 4.7 kWh/m²/day. Given that the study area in the present study is also located within Sulaymaniyah Province, it shares similar potential for solar power plant installation due to the abundance of

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sunny days throughout the year. This area receives about 2,887 hours of direct solar radiation annually, with annual solar radiation values ranging between 393 and 1,733 kWh/m²/year. It is important to note that in site selection studies for solar cell installation, the areas determined as appropriate typically have maximum exposure to solar radiation, as the amount of electricity generated by photovoltaic panels is directly influenced by the intensity of solar radiation incident on their surface (Ibrahim & Ibrahim, 2021: 1). For this reason, in this study, the amount of solar radiation was considered as a key factor, as it directly influences electricity output from photovoltaic panel.

The main aim of this study is to identify the most suitable area for installing solar power plants with the minimum cost, in order to help address the electricity shortfall, which is estimated at roughly (14.37GWh/day) according to the Tanjero Power Distribution Unit. To achieve this objective, several criteria were considered, including (Solar radiation, proximity to power transmission lines, distance from substations, slope, aspect, landuse/landcover, distance from major roads, distance from rivers). These criteria were integrated and pairwise compared using Saaty's Analytical Hierarchy Process (AHP) matrix, a widely used Multi Criteria Decision Making (MCDM) method, and implemented within ArcGIS software. In the final stage, all criteria were combined using the GIS-based techniques to produce the site suitability map.

2. METHODS & MATERIALS

2.1. Study Area

The study area is Tanjero, which is one of the two subdistricts of the Sulaymaniyah Central District, located in northeastern Iraq, southeast of the Kurdistan Region and Sulaymaniyah city. The total area of the Tanjero Subdistrict is about 463 km², lies between 35° 17' - 35° 34' N latitudes and 45° 24' - 45° 43' E longitudes. It is bordered to the north by Sitak Subdistrict, to the northeast, east and southeast by Saidsadiq District, to the south by Sharazoor District, to the southwest by Qaradagh District, and to the northwest by Bakrajo Subdistrict. Figure 1. shows the geographical location of the study area.

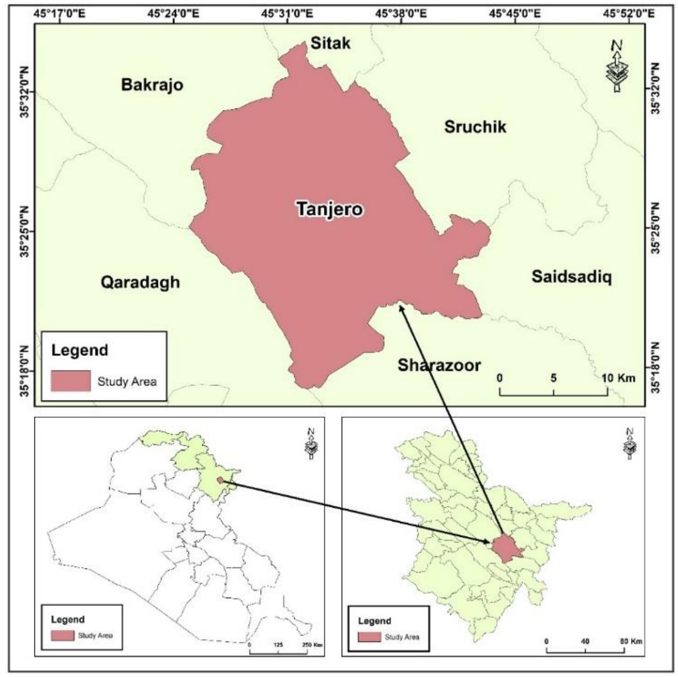

Figure 1. Map Showing the Location of the Study Area

2.2. Methods & Criteria Weighting

The scope of this study is to determine the most suitable sites for installing solar power plants in the Tanjero subdistrict, aiming to produce electricity efficiently with minimal cost and environmental impact. The study focuses on solar radiation as a primary source of clean energy. Therefore, to identify the most suitable sites for establishing solar power plants in the research area, this study employs advanced Geographic Information System (GIS) and remote sensing techniques. Specifically, utilizing GIS_based Multi Criteria Decision Making (MCDM) approach using the Analytic Hierarchy Process (AHP) techniques as a method to assess the suitability of potential sites. AHP-MCDM method was developed by Thomas L. Saaty in 1971-1975, while he was at the Wharton School (Saaty, 1987: 161), this method is a multi-criteria decision approach which it based on a pairwise comparison between a criteria using a standardized rating scale of nine levels which it called names Saaty's scale. Mentioned rating scale is shown in Table 1. AHP depends on evaluation square matrix to determine the weights of used criteria, which it is necessary to normalize the evaluation matrix (Table 4). Then the results are mathematically validated using the consistency ratio (CR). If the result of pairwise comparison exceeds (0.1), the scores must be revised. Otherwise, the results are considered to be acceptable (Stoilova, 2018: 3). Accordingly, in this study, the obtained consistency ratio for the Analytic Hierarchy Process (AHP) was 0.08, which is below the acceptable threshold 0.1, This indicates that the weight assignments for the criteria used were both reliable and consistent. The

CR value is calculated using the equation below:
{CR= CI/RI ≤ 0.1}

- CR= Consistency Ratio
- CI= Consistency Index
- RI= Random Index

The Consistency Ratio (CI) is determined using the following equation:
CI= (λmax-n)/(n-1)

- n= number of used criteria
- λmax= average (weighted sum vector / sum of criteria weight)

The (RI) is the Average random consistency index, which developed by Saaty. The RI values for different numbers of criteria (N) is shown in Table 3.

Although, this method has its pros and cons, many researchers have used AHP as one of the techniques in Multi-Criteria Decision Making for selecting suitable sites (Demirci, 2019: 47). As stated above, this method involves some criteria and alternatives to address and rank

problems (Matpay, 2024: 9). For this purpose, in the first step, the essential criteria were determined based on a comprehensive literature review and guidance from experts. According to this method, after comparing all criteria, their weights are determined and they are ranked based on importance and priority (Arca, Çıtroğlu, 2022: 21). In other words, conducting a suitability analysis requires assigning relative weights to the used criteria. The weights obtained from the pairwise comparison matrix (Table 2) is ordered from highest to lowest. These weights quantitatively reflect the consistency of value judgements made between pairs of factors (Effat, 2013: 211). Finally, to normalize the pairwise comparison matrix, each criterion's weight was divided by the sum of all criteria weights within the same column, as shown in table 3.

Table 1
Saaty's Rating Scale

Importance	1	3	5	7	9	2, 4, 6, 8
Definition	Equal Importance	Moderate importance	Strong importance	Very strong importance	Extreme importance	Intermediate values

Source: Saaty, Vargas, 2012: 6.

Table 2
Saaty's Pairwise Comparison Matrix

Criteria	A	B	C	D	E	F	G	H	Weight
A	0.33	0.39	0.39	0.33	0.29	0.19	0.20	0.18	0.29
B	0.17	0.19	0.26	0.22	0.19	0.14	0.17	0.14	0.18
C	0.11	0.10	0.13	0.22	0.19	0.14	0.13	0.12	0.14
D	0.11	0.10	0.06	0.11	019	0.23	0.17	0.18	0.14
E	0.11	0.10	0.06	0.06	0.10	0.23	0.20	0.18	0.13
F	0.08	0.06	0.04	0.02	0.02	0.05	0.10	0.10	0.06
G	0.06	0.04	0.03	0.02	0.02	0.02	0.03	0.10	0.04
H	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.02
Sum	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Table 3
Random Consistency Index

Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Solar Radiation (**A**)	1	2	3	3	3	4	6	9
Proximity to Power Transmission Lines (**B**)	1/2	1	2	2	2	3	5	7
Proximity to Power Distribution Units (**C**)	1/3	1/2	1	2	2	3	4	6
Slope (**D**)	1/3	1/2	½	1	2	5	5	9
Aspect (**E**)	1/3	1/2	½	1/2	1	5	6	9
LULC (**F**)	1/4	1/3	1/3	1/5	1/5	1	3	5
Road (**G**)	1/6	1/5	¼	1/5	1/6	1/3	1	5
River (**H**)	1/9	1/7	1/6	1/9	1/9	1/5	1/5	1
Consistency Ratio = 0.08								

Source: Saaty, Vargas, 2012: 9.

Table 4
Normalization of Parameters & Priority Calculation

Number of (N)	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.52	0.89	0.11	1.25	1.35	1.40	1.45	1.49

Source: derived from Table 2.

Table 5
AHP Consistency Verification & Lambda Max Calculation

Criteria	A	B	C	D	E	F	G	H	**Sum**	**Weight**	**Sum/ Weight**
A	0.29	0.37	0.43	0.43	0.39	0.24	0.23	0.16	2.53	0.29	8.86
B	0.14	0.18	0.28	0.29	0.26	0.18	0.19	0.13	1.65	0.18	8.99
C	0.1	0.09	0.14	0.29	0.26	0.18	0.16	0.11	1.32	0.14	9.25
D	0.1	0.09	0.07	0.14	0.26	0.3	0.19	0.16	1.31	0.14	9.15
E	0.1	0.09	0.07	0.07	0.13	0.3	0.23	0.16	1.15	0.13	8.94
F	0.07	0.06	0.05	0.03	0.03	0.06	0.12	0.09	0.5	0.06	8.43
G	0.05	0.04	0.04	0.03	0.02	0.02	0.04	0.09	0.32	0.04	8.21
H	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.02	0.15	0.02	8.3
λmax											**8.77**

Source: derived from Table 2 & 4.

2.3. Criteria

In the process of determining the most suitable site for installing solar power plants to ensure the highest accuracy, the required data must be provided in an appropriate manner. The layers that are commonly used in other studies, and suitable for the study area have been included after being synthesized from scholarly sources (Arca, Çıtroğlu, 2022: 19). Accordingly, this study considers several parameters, including solar irradiation, distance from power transmission lines, distance from power distribution stations, slope, aspect, landuse/land cover and distance from major roads and rivers. In addition, the required raw data (Geographical features) have been obtained from several reliable sources, including USGS Earth Explorer, Alaska Satellite Facility (ASF) > High Resolution AlosPalsar Dem 12.5m, WorldCover V2, Copernicus Open Access Hub Sentinel 2 Data Collection and the Tanjero Power Station Directorate. The used parameters are explained below.

2.3.1. Solar Irradiation

Solar irradiation is the most important factor in determining suitable site for installing solar power plants, since it directly impacts on amount of electricity produced by solar cells. Hence, nearly all solar site suitability studies consider solar irradiation as the most fundamental decision criterion (Al Garni, Awasthi, 2018: 65). Solar irradiation maps can be generated in ArcGIS using the "spatial analyst > solar irradiation" tool. This tool allows users to map solar irradiation for a specific time period within a geographical area using Digital Elevation Model (DEM). It accounts for changes in the sun's azimuth and position, as well the effects of surface objects or topography-dependent shading on the input DEM (Kocabaldır, Yucel, 2020: 350). In this study, the research area was divided into five groups and represented using a color gradient ranging from blue to red, as shown in Figure 1. Blue areas indicate where the least solar radiation is received, while red areas show where the highest levels are recorded. As a result, the red zones are considered the most suitable locations for installing solar power plants.

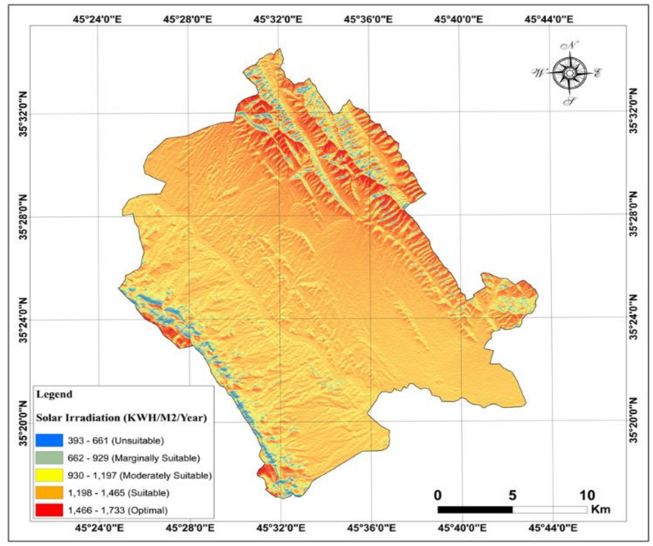

Figure 2. Solar Irradiation Map

2.3.2. Proximity to Power Transmission Lines & Substations

Distance form power lines and substations is an important factor when selecting locations for installing solar power plants, when a power plant is close to transmission lines & substations it helps reduce power loss during transmission and avoid high costs of installing new power lines (Rusol, Al-Timimi, 2024: 28, Kocabaldır, Yucel, 2020: 350). It also ensures adequate access to power transmission grids (Al Garni, Awasthi, 2018: 67). In this study, the ArcGIS Euclidean Distance tool was used to calculate the distance form power lines and substations, then areas located closest to power transmission lines and substations were identified as the optimal location for installing solar power plants, while more distant areas were considered economically unsuitable for such installation, as shown in Figure 3 & 4.

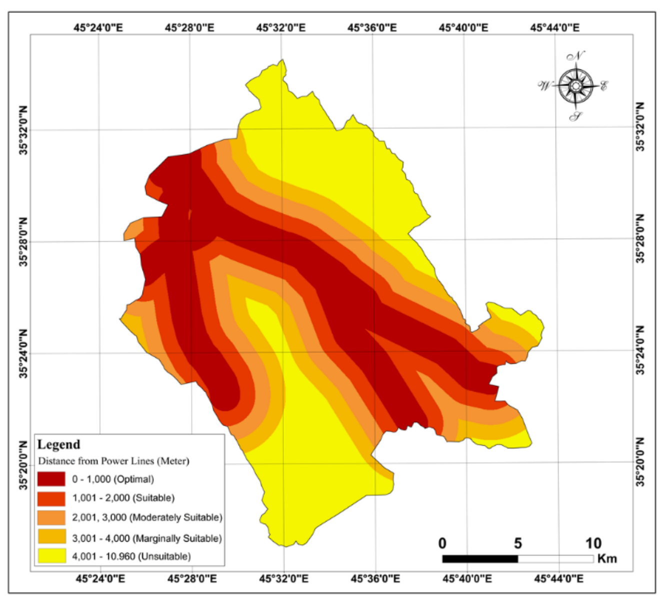

Figure 3. Distance from Power Lines Map

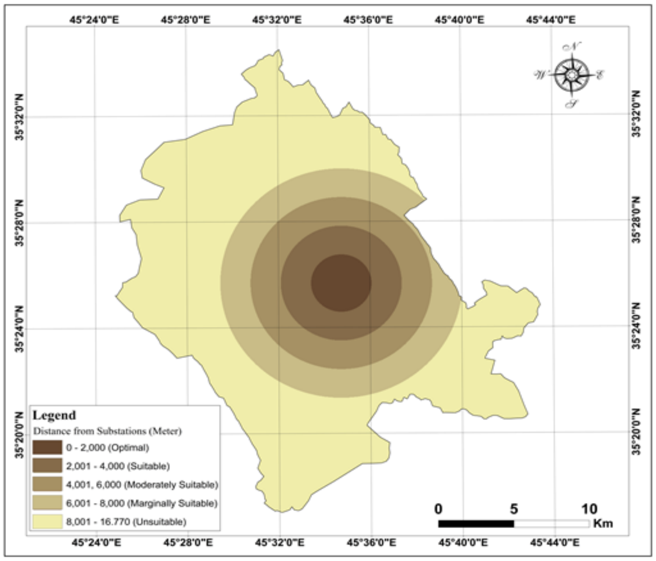

Figure 4. Distance from Substations Map

2.3.3. Slope & Aspect

Topography plays a crucial role in determining the spatial variability of incoming solar radiation. Variation in slope angle and aspect of slope influence the amount of radiation received at different locations (Effat, 2013: 209). In simple terms, the slope and aspect of the land surface play a key role in how much solar energy potential a site has for electrical power generation (Ahmed, 2023: 2). In light of this, it is preferable to install solar panels in locations with a flat or nearly flat surface, since installing solar panels on steep slopes can cause them to cast shadows on each other, reducing their efficiency. Similarly, soil erosion and soil creep on sloped terrain compromise the structural stability of solar panels and increase operating costs. Furthermore, sloped land can hinder transportation and significantly increase the cost of transporting and installing solar panels. Although there is no the definitive definition of suitable slope degree for installing solar power plants, but areas with slopes between 0-16° as shown in figure (5), are generally considered appropriate (Matpay, 2024: 13). Besides this, the aspect is another important factor to consider when installing solar power plants. The orientation of the solar panels is determined by the location where the system will be installed. In areas located in the Northern Hemisphere, such as the study area, solar panels are typically oriented toward the south and southwest (Aykaç, 2020: 25), because south and southwest facing lands receives the most solar radiation. Northeast and southeast orientations are the second and third best respectively. While north and northwest facing lands have low suitability (Effat, 2013: 210, Kocabaldır, Yucel, 2020: 350). As shown in figure 6.

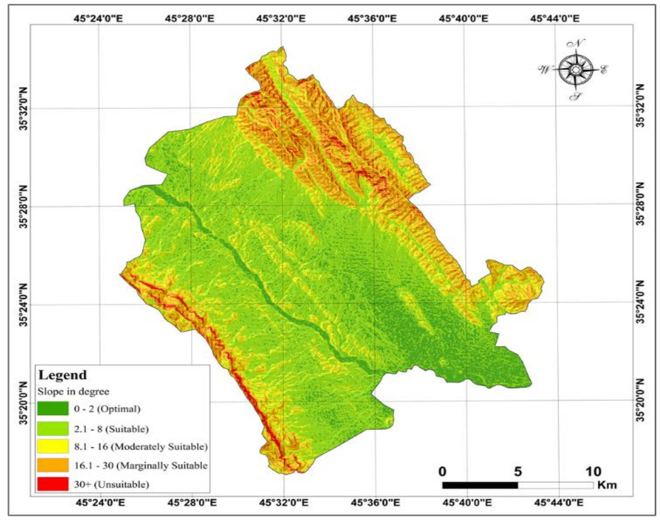

Figure 5. Slope Map

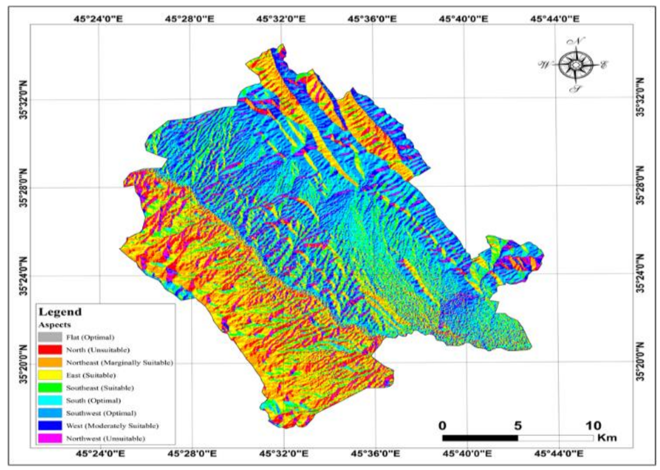

Figure 6. Aspect Map

2.3.4. Landuse/ Landcover (LULC)

LULC is the major consideration in suitable site selection for solar power plants studies (Oluseye1, Usman, 2022: 684). In other words, Land use is considered one key environmental issue in selecting a suitable site. Accordingly, in this study LULC was categorized into seven types: tree cover, shrubland, grassland, cropland, built-up area, bare land and water body. Following a thorough review of the existing literature on the subject, we assigned scores to the study area on a scale from 1 to 5 to evaluate the suitability of different locations within the study area. Therefore, areas marked with a score of 5 were identified as the most suitable sites, whereas a score of 1 indicated areas that are not suitable for installing solar power plants. As shown in figure 7, considering environmental and economic factors, bare lands were designated as the most optimal area, while grassland was found to be suitable. However, croplands and shrublands were classified as marginally suitable. Water bodies, tree-covered areas, and built-up lands were categorized as unsuitable.

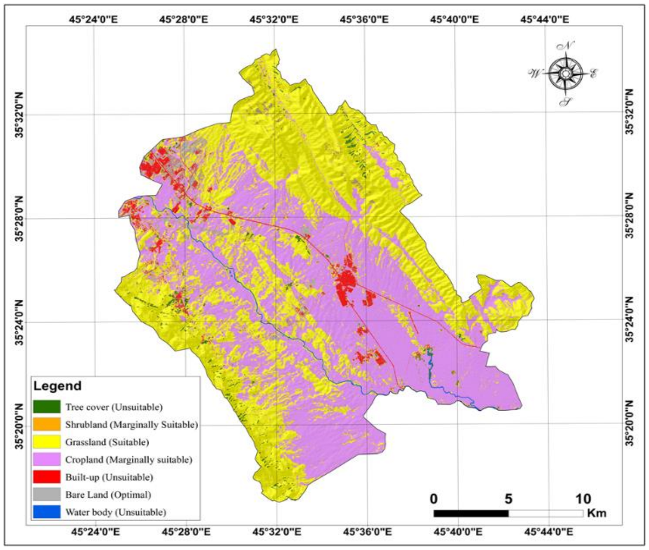

Figure 7. Landuse\Landcover Map

2.3.5. Distance from Roads

In terms of economic and maintenance, proximity to major roads can provide an indication of the installation costs for solar panels (Uyan, 2013: 15). In other words, a distance to a road is also a cost-related criterion, like a distance to power transmission lines. The cost of installing and maintaining of solar panels increases linearly with distance from the major roads (Dinçer, Demir, Yılmaz, 2025: 5). Overall, proximity to major roads influences the positioning of solar panels due to safety considerations and ease of access (Rusol, Al-Timimi, 2024: 28). Therefore, in this study areas located within 0 to 100 meter of major roads were determined to be optimal for establishing solar farms, areas between 101 and 500 meters were still considered highly suitable, while those between 501 and 1,000 meters were deemed moderately suitable. Areas falling between 1,001 to 2,500 meters were classified as marginally suitable, and areas beyond 2,500 meters were not recommended for such installation, as shown in figure 8.

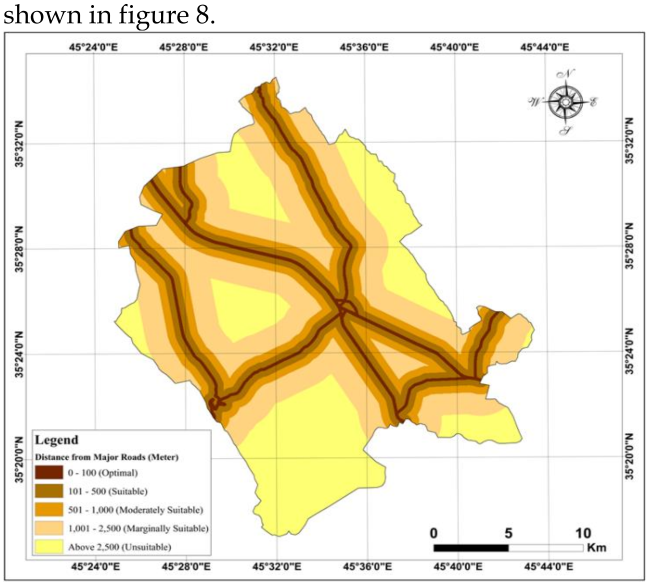

Figure 8. Distances from Major Roads Map

2.3.6. Distance from Rivers

Distance to rivers and streams should be considered to minimize the risk of seasonal floods impacting solar power stations. That's why, it is very important to place solar plants, this helps to protect them from flooding and to ensure ease of access (Uzar, Koca, 2020: 16). However, because panel cleaning requires water, locations that are too far from water resources are not considered desirable for installing photovoltaic panels (Kocabaldır, Yucel, 2020: 350). Based on the aforesaid reasons, the study area was divided into five buffer zones. A score of 1 (unsuitable) was assigned to the 400-meter buffer zone, while areas beyond 3,201 meters were classified as marginally suitable and assigned a score of 2. The 401–800-meter buffer zone was given a score of 5 (optimal), the 801-1,600-meter buffer zone was scored as 3 (suitable), and 1,601-3,200-meter buffer zone was assigned a score of 2 (moderately suitable), as illustrated in figure 9.

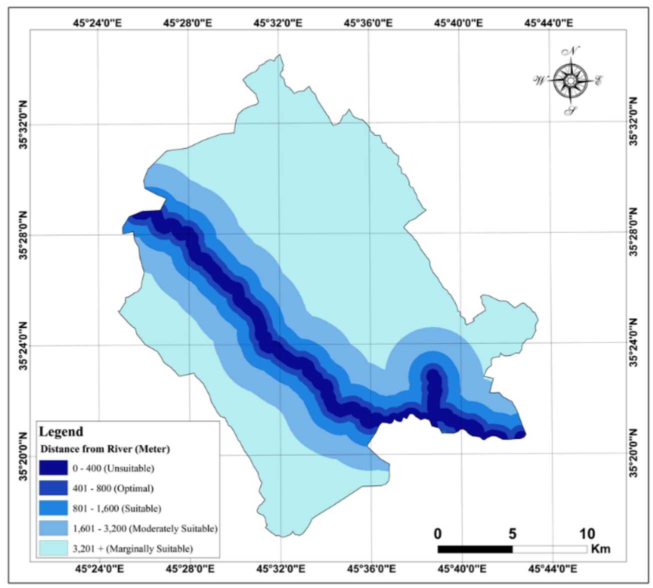

Figure 9. Distances from Rivers Map

3. SUITABILITY MAP CREATION PROCESS

After preparing all the criteria using ArcGIS (10.8) software, they were reclassified (Figure 10) and ranked on a scale from 1 to 5. As previously stated, score of 1 was assigned to unsuitable area, while a score of 5 represented the most optimal area for establishing solar power plants. Subsequently, site suitability map was generated using Weighted Overlay tool in ArcMap, in this phase all selected criteria were combined and assigned relative weights (as percentages), and the total weight of all criteria must be equal to %100, as shown in table 6.

Table 6
Weight Distribution of Criteria in ArcGIS Weighted Overlay Analysis

No	Criteria	Weight (%)
1	Solar Radiation	29
2	Proximity to Power Transmission Lines	18
3	Proximity to Substations	14
4	Slope	14
5	Aspect	13
6	Landuse\ Landcover (LULC)	6
7	Distance from Major Roads	4
8	Distance From Rivers	2

Source: Derived from Table 4.

As shown in table 5, solar radiation is given the highest weight (29%), followed by proximity to power transmission lines (18%), proximity to substations (14%), slope (14%), aspect (13%), LULC (6%), distance from major roads (4%), and distance to rivers (2%) respectively. Consequently, to generate the site suitability map, all the weighted criteria were integrated using Weighted Overlay tool.

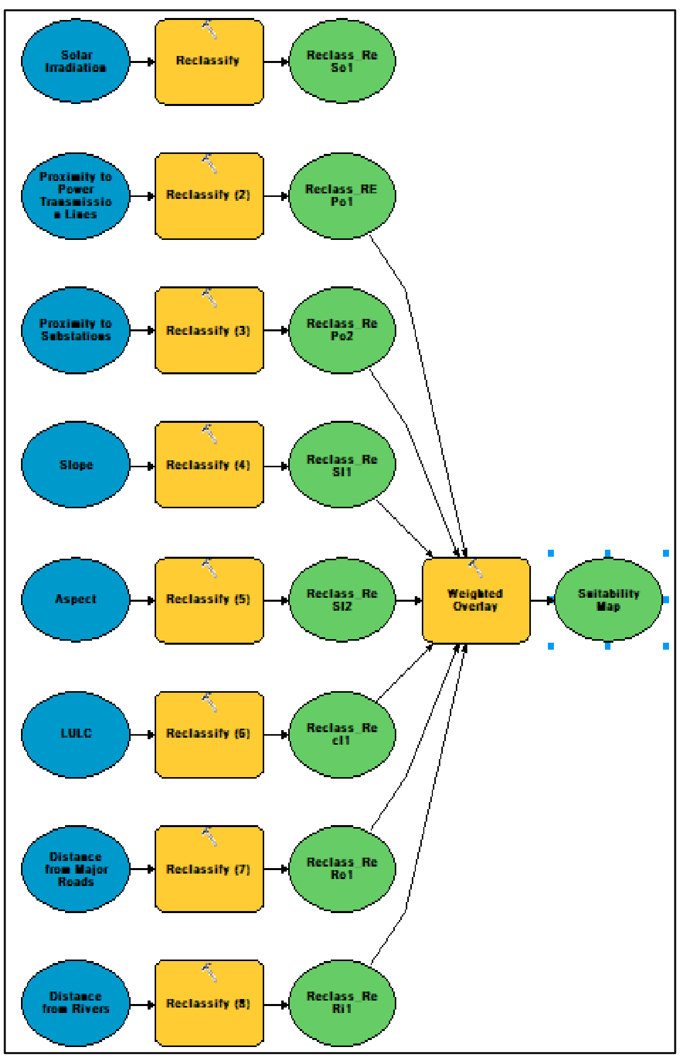

Figure 10. Suitability Analysis Workflow Diagram

4. FINDINGS AND DISCUSSION

The results of Weight Overlay analysis indicated that 0,43% of the study area is optimal for generating electricity form solar radiation. In addition, 29.37% is still considered suitable, 51.62% is moderately suitable, 17.28% is marginally suitable, while the remaining %1.30 is classified as unsuitable, as shown in figure 11. In other words, about 30% of study area (equivalent to 138 square kilometers), which mostly covers the central part of the study area and extends form northwest to southeast, is appropriate for installing solar power plants. This is a promising sign for promoting solar energy as an alternative to generators for addressing the electricity deficit in the Tanjero subdistrict.

The main reason some areas were identified as highly suitable or optimal for installing solar power plants is the presence of several favorable characteristics, such as: receiving high levels of solar radiation and being located close to transmission lines and substations, which helps minimize energy losses. These areas also have gentle slopes, advantageous aspects, and extensive bare land, making them ideal for solar panels installation without affecting residential or agricultural lands. Also, their proximity to major roads facilitates maintenance, and being at a safe distance from rivers and streams reduces the risk of flooding. In contrast, areas that lack these characteristics are considered less suitable or unsuitable for solar power development.

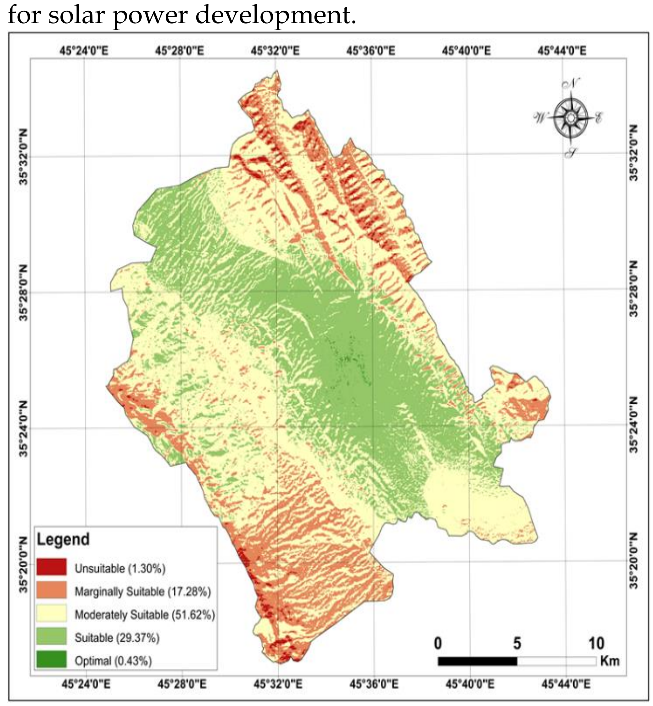

Figure 11. Site Suitability Map

5. CONCLUSION

This study highlights the role of integrating spatial analysis with Multi Criteria Decision Making analysis to determine suitable sites for solar power plants in Tanjero subdistrict. By employing the Analytical Hierarchy Process within a GIS environment, several parameters such as solar radiation, proximity to power transmission lines, proximity to substations, slope, aspect, LULC, distance from roads and distance from rivers were evaluated and pairwise compared. The results indicate that approximately 138 square kilometers (equivalent to 30%) of the study area are appropriate for installing solar power plants. Notably, if just 0.1% of this area is used for generating electricity from solar panels, it would be enough to meet local electrical energy demands. Moreover, this approach not only offers a sustainable solution to the electricity shortfall but also helps reduce environmental pollution caused by generators, particularly in terms emissions of toxic gases and disruptive noise. Despite all that, this study provides a practical framework to assist planners, decision makers and investors in identifying optimal sites for solar energy projects. Ultimately, this study contributes to the broader field of the Geography of Energy by showing how spatial analysis can inform cleaner, more resilient and eco-friendly energy strategies.

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