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GIS-Based Approach for Determining Optimal Solar PV Farm Locations in Erbil City Using the ASR and MCDM Analysis

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Abstract: The increasing demand for clean energy sources has driven widespread studies to find the best locations for solar photovoltaic farms. Finding appropriate locations presents challenges due to environmental and technical factors. This study determines the optimal locations for solar PV farm installation in Erbil City using the Area Solar Radiation (ASR) tool in ArcGIS Pro 3.1.5 combined with multicriteria decision-making analysis. This study represents the first application of the ASR tool in this region to enhance solar insolation assessments by incorporating atmospheric parameters, terrain characteristics, and environmental variables. An analytical hierarchy process weighs the criteria and computes a land suitability index. Nine critical criteria were utilized: area solar radiation, land use land cover, slope, proximity to transmission lines and roads, distances to urban and rural areas, soil types, and temperature. The ASR tool calculates the solar insolation across the study area, with the Average ASR for Erbil City at 1,306,742 Wh/m² annually. Thematic maps and a pairwise comparison matrix assign weights to each criterion, creating a comprehensive suitability index. The study revealed that solar development can occur in 60.89% of the area, mainly in Erbil's western region, but remains restricted to 39.11% of the area. A small segment (6.24% or 169.92 km²) is the most suitable and is capable of producing more than 10,000 MW of clean power. While providing important data to legislators and investors to forward sustainable energy policies and lower reliance on fossil fuels, the results show great chances for the development of solar power.

Keywords: *Solar PV Farm; Renewable Energy; GIS; Area Solar Radiation (ASR); Analytical Hierarchy Process (AHP); Erbil City*

1. Introduction

Increasing global energy needs and environmental sustainability concerns have accelerated the efforts to find renewable energy solutions. At the same time, solar photovoltaic (PV) technology is also a viable option for clean energy generation. Due to its renewable nature and environmental benefits, solar energy is a viable alternative to fossil fuels. Its characteristics render it an efficient instrument in mitigating greenhouse gas emissions and climate change prevention [1]. Based on semiconducting materials, solar photovoltaic (PV) technologies directly transform sunlight into electricity. PV cells are made in different designs to achieve higher efficiency, offering a sustainable and renewable energy source with minimal maintenance needs [2]. Solar PV systems' efficiency is significantly affected by geographic, climatic, and environmental conditions. Site selection is thus necessary to ensure maximum energy output and economic feasibility [3].

In this context, Geographic Information Systems (GIS) combined with multi-criteria decision analysis (MCDA) techniques, like the Analytic Hierarchy Process (AHP), have become extensively utilized instruments for determining the most appropriate location for the mounting of solar farms [4]. Effective utilization of solar PV farms relies on a structured methodology that consolidates GIS and decision-making techniques, particularly when electricity demand rises and solar energy potential widens in Erbil City.

Several studies have used GIS and MCDA methods for determining optimal locations for solar PV farms. [5] identified the most suitable locations for solar power plants in the Erbil Governorate of Iraq using GIS with Boolean logic and AHP. The technique assigns weights to different environmental, financial, and climatological factors in a multicriteria spatial analysis. [6] Using ArcGIS Pro 3.1.5, the Area Solar Radiation tool, this study evaluates Vranje, Serbia's potential for solar energy. Roof suitability for the installation of solar panels and energy production was evaluated on the basis of terrain, climate, and land use.

Similarly, [7] used Geographic Information Systems and the Analytical Hierarchy Process to determine the most suitable locations for large solar photovoltaic farms in Saudi Arabia from environmental, technical, and economic factors. [8] uses Expert Choice software combined with the Analytical Hierarchy Process to evaluate potential locations for solar power plants in Iran based on meteorological parameters such as rainfall, humidity, sunny days, and solar radiation. The most suitable locations for the installation of photovoltaics in Iran's Kurdistan Province were established in a study [9], it estimated the financial and environmental benefits of the solar PV farm installation by applying GIS-based multi-criteria decision analysis techniques like AHP, ANP, and TOPSIS.

Additionally, [10] A fuzzy-logic GIS approach was presented to assess the solar power potential in Erbil City. The methodology takes into account numerous factors, including proximity, elevation, and slope, and verifies its findings based on case study data. Despite uncertainties and limited data bringing difficulties, the approach determines the best locations.

Numerous studies have examined the potential of solar energy. However, most of them concentrate on vast regions and employ generalized metrics, such as sunshine duration, solar irradiance, Direct Normal Irradiance (DNI), and Global Horizontal Irradiance (GHI) [8, 11, 12]. The indicators usually fail to reflect the intricacies of urban environments. In Erbil City, there remains a large shortage of research endeavours seeking to employ high-resolution geospatial data in the optimization of solar PV siting. This research tries to bridge this gap by applying, for the first time in Erbil, the Kurdistan Region of Iraq, the Area Solar Radiation (ASR) Tool in ArcGIS Pro 3.1.5. This is a quick and dependable tool to calculate solar radiation from terrain, slope, and shadow. This study offers a robust and scientifically appropriate approach to the selection of solar PV locations by integrating GIS, MCDA, and AHP.

The terrain examination was complemented by utilizing high-resolution (12.5m) Digital Elevation Model (DEM) information for accurate location determination. Furthermore, the integration of nine major criteria, including soil type, addresses a significant shortage of renewable energy planning and provides a comprehensive basis for informed decision-making. This multidisciplinary endeavour facilitates an evidence-based transformation to solar energy in Erbil City and beyond by creating a pioneering benchmark for spatial decision-making in renewable energy planning and providing insightful information to investors, policymakers, and urban planners.

This study aims to identify the most appropriate sites for solar PV farm installation in Erbil City, Kurdistan Region, Iraq, and the key features of a multicriteria decision process, namely GIS, the AHP method, and the ASR tool. Nine primary criteria will be utilized to evaluate and rank prospective sites: area solar radiation, land use and land cover, slope, distance to transmission lines, distance to roads, distance to urban and rural settlements, soil types, and temperature. This approach aligns with the Kurdistan Regional Government's commitment to generating 3,000 megawatts of solar electricity over the next decade.

2. Methods and Materials

2.1 Study Area

Erbil City, located in the northern part of the Kurdistan Region of Iraq, is positioned at 36°11'27″ N latitude and 44°0'33" E longitude [13], with an elevation of 264–1104 m above sea level (Figure 1). The total study area was about 2727 km2. Erbil City, situated in northern Iraq, experiences a semiarid continental climate. This climate zone is characterized by significant temperature variations between summer and winter, as well as between day and night. The summer months (June to September) are typically hot and dry, whereas winter (November to February) is cold and wet. Rainfall is limited and occurs primarily between October and November. During the peak summer, daytime temperatures can soar to 50°C, whereas in winter, nighttime temperatures may drop as low as −5°C. Humidity levels fluctuate significantly, reaching an average of 80% in winter and dropping to around 20% in summer [14]. The Kurdistan Regional Government (KRG) is reinforcing its focus on renewable energy as part of its broader strategy to shift towards sustainable power sources. Erbil has been identified as one of the most favourable locations for the development of solar photovoltaic (PV) farms. The Department of Renewable Energy, within the Ministry of Electricity, reports that the KRG aims to generate 3,000 megawatts of solar power over the next decade.

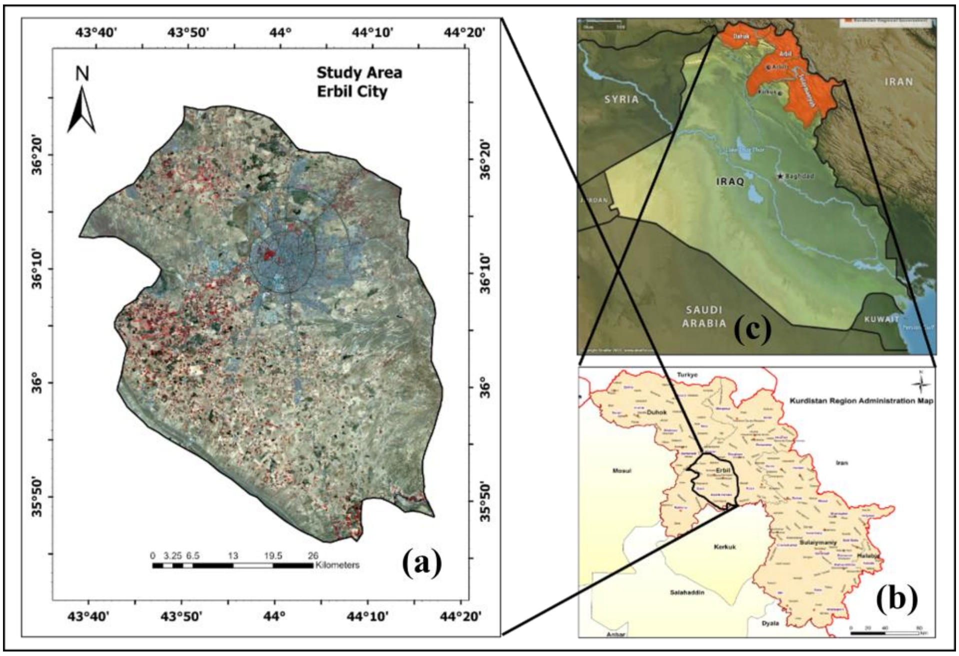

Figure 1: Study area: city of Erbil (a), Kurdistan Region (b), Iraq (c).

2.2 Dataset

The process of selecting a site for solar power plants requires thorough evaluation to determine the most optimal location. This selection must align with government regulations while minimizing economic, environmental, and social challenges. While selecting a suitable site for a solar power facility, it's important to consider various criteria. Despite the Technical requirements of photovoltaic cells, selecting a location that optimizes solar panel performance is important. Detailed analysis of all the factors is very crucial in order to increase the precision of site selection and thus avoid wastage of precious resources like land and financial resources [5].

This study extracted land use land cover (LULC) data and distances to urban and rural areas using Sentinel Level-2A satellite imagery with a 10-meter spatial resolution. The data were obtained from the European Union's Copernicus program (Copernicus.eu). The Alaska Satellite Facility (ASF) provides a pre-processed digital elevation model (DEM) with a resolution of 12.5 meters sourced from the ALOS PALSAR satellite. The flow accumulation, slope, and area solar radiation (ASR) were derived from the DEM. The road network was acquired in shapefile (vector) format from OpenStreetMap. A soil map from the Ministry of Agriculture in Baghdad was used to generate the soil-type data for the study area. Transmission line data were obtained from the General Directorate of Electricity in Erbil, Kurdistan Region, Iraq. Temperature data for 2023 was collected from the General Directorate of Meteorology and Seismology in Erbil. A summary of the datasets and their sources is presented in Table 1.

Table 1: Characteristics of the dataset used in this study.

Datasets	Date	Format/ Resolution	Generated thematic maps	Source
Soil data	1957	Raster image	Soil map	Ministry of Agriculture, Baghdad. (Buringh 1957)
DEM	2006 - 2011	12.5 m	Slope, Area Solar Radiation	https://asf.alaska.edu/
Sentinel 2 imagery	8, August 2024	RGB, NIR: 10 m	Land Use Land Cover, distance to urban and rural area	https://copernicus.eu
Temperature	2023	Daily data	Temperature map	The General Directorate of Agriculture in Erbil, Kurdistan Region of Iraq.
Roads	2024	Vector data (shapefile)	Distance to Road	Open Street Map
Transmission line	2024	Vector data (shapefile)	Transmission line proximity	General Directorate of Electricity in Erbil, Kurdistan Region of Iraq.

2.3 Solar PV Technology

Solar photovoltaic (PV) technology is one of the most well-known and consistent renewable energy sources currently available. Operating on the photovoltaic effect, which allows semiconductor materials to convert sunlight into electrical power, mono- and polycrystalline silicon are two of the many available PV materials, and their excellent efficiency and long-lasting performance make them extensively used in the industry. Thin-film solar cells, such as cadmium telluride (CdTe) and copper indium gallium selenide (CIGS), which, despite their reduced efficiency, provide cost-effective manufacturing options, have also recently advanced PV technology [15].

The performance of PV systems is highly affected by factors such as material selection, temperature, and incident sunlight intensity. Because of their exceptional efficiency, silicon-based solar cells are most often utilized, and recent developments have made single-junction cells [16]. to 25% efficiency, respectively. With the aim of obtaining better efficiency while lowering manufacturing costs, emerging technologies, such as organic solar cells and nanocrystalline cells, are being investigated to solve the constraints of conventional solar cells.

A major obstacle still exists in the high production costs and the need for efficient energy storage technologies to offset the intermittent nature of solar power, notwithstanding ongoing developments.

Nonetheless, developments in PV integration, such as floating PV systems and building-integrated photovoltaics (BIPV) are increased the feasibility of major PV acceptance [16].

3. Methodology and Criteria

3.1 Analytical Method (AHP)

Selecting optimal sites for solar power plants requires the application of multi-criteria decision-making (MCDM) techniques [8]. One of the most commonly used methods is the Analytic Hierarchy Process (AHP), which offers effective solutions to complex decision-making challenges by evaluating multiple criteria. This approach involves assigning relative importance to various factors based on their significance. AHP allows decision-makers to express clear preferences, ideal for personal or corporate scenarios. However, it assumes criteria independence and cannot handle criteria dependency or correlation. Also, its subjectivity may cause inconsistent results, especially for complex problems affecting many people. It works best with fewer than ten criteria.AHP utilizes pairwise comparisons to derive each criterion's weight by comparing it to the other, finally determining the relative significance of each factor in order to guide the decision-making process [17].

In this study, nine main criteria areas: solar radiation (ASR) , land use/land cover (LULC), slope, proximity to transmission lines, distance to roads, distance to urban and rural areas, soil types, and temperature form the basis of Erbil City assessment. ArcGIS Pro 3.1.5 facilitated the data processing and map extraction. Figure 2 shows the flowchart of the methodology used in this study. The weights presented in Tables 4 and 5 were determined through consultations with university lecturers, professors, and relevant stakeholders. Their expert opinions guided the decision-making process to ensure the weights accurately reflect practical and academic considerations.

An essential measure of the reliability of decisions taken during pairwise comparisons of criteria is the consistency ratio (CR). Generally, a CR value less than 0.1 (or 10%) is considered acceptable [18]. An essential component of the Analytic Hierarchy Process (AHP), a disciplined approach for arranging and evaluating difficult decisions by combining psychological and mathematical ideas, is a Pairwise Comparison Matrix. In AHP, the matrix enables pairwise comparisons between several alternatives or criteria, enabling decision makers to methodically assess their relative importance or preference[12, 19]. The consistency ratio was calculated for the pairwise comparison matrix (Table 5), and the result is 1.9%.

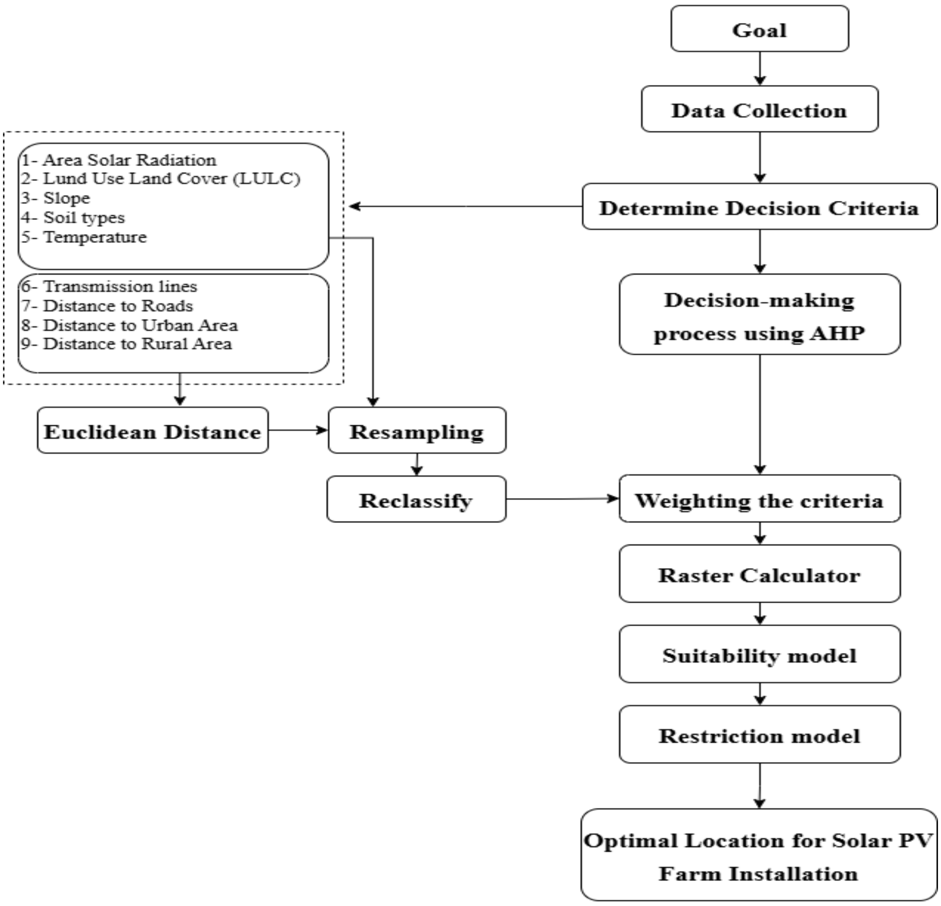

Figure 2: Flowchart of the study.

This procedure assigns every criterion a particular weight. The pairwise comparison matrix in AHP depends on expert opinions from decision makers [5]. It is significant that it can contain some degree of subjectivity. As shown in Table 2, the AHP approach identifies nine scales of importance. The experts provided their responses based on their experiences, resulting in varying answers. Irregular responses were excluded to ensure a more consistent average importance [12].

The CR is given by $\frac{CI}{RI}$, where RI is the random consistency index that varies according to the number of criteria in a comparison (n). The consistency index (CI) is calculated using eq (1)

$$CI = \frac{(\lambda \max - n)}{(n-1)} \quad (1)$$

Where $\boldsymbol{\lambda\, max}$ is the maximum eigenvalue of the comparison matrix [7].

Table 2: Importance scales according to the AHP method [8].

Importance Scale	Definition of Importance Scale
1	Equally
3	Moderately
5	Strongly
7	Very Strongly
9	Extremely
2,4,6, and 8	Preferences between the above values

3.2 Area Solar Radiation (ASR)

The Solar Radiation tool in ArcGIS Pro 3.1.5 Spatial Analyst Toolbox computes solar radiation across a geographic region or for specific point locations (latitude–longitude), utilizing the hemispherical viewshed algorithm [20, 21]. This tool incorporates the location, elevation, slope, orientation, and atmospheric transmission as essential inputs. The total radiation for a specific location is quantified as the global radiation (energy), measured in watt-hours per square meter (Wh/m^2) [21]. Direct radiation is received directly from the sun along an unimpeded path, whereas diffuse radiation is scattered by atmospheric components such as clouds and dust. Direct radiation contributes the most to total solar radiation, followed by diffuse radiation. The tool calculates incoming solar radiation using a raster surface such as a digital elevation model (DEM) [22].

DEM was employed to produce slope and land aspect layers, ensuring coherence among the integrated layers. The model utilized three map layers to calculate solar irradiation: a viewshed map, a sky map, and a sun map. The diffuse proportion variable spans from 0 to 1, where elevated values signify a clear sky. Transmittivity denotes the ratio of energy received by the Earth's surface to that received by the upper atmosphere, with values ranging from 0 (no transmission) to 1 (complete transmission). This study adopted a value of 0.5 [7]. The parameters used in the ArcGIS Pro 3.1.5 Solar Analyst are listed in Table 3. The calculation was performed for each pixel in the provided elevation model, and the results were presented as a raster map showing the values of incoming solar radiation [22].

The average annual ASR for Erbil City is 1,306,742 Wh/m^2. This criterion is a key factor in determining the optimal location for solar PV farms, and is classified into three categories, as shown in Figure 3(a). Based on the pairwise comparison (PC) matrix in Table 5, the overall weight assigned to this criterion is 21%.

Table 3: Parameters used in the ArcGIS Pro 3.1.5 solar analyst tool.

Parameter	Value	Parameter	Value
DEM	Resolution of 12.5 m	Slope and aspect input type	From DEM
Latitude	36.09	Calculation directions	32
Sky size	300	Zenith divisions	8
Time Configuration	Whole Year (2024)	Azimuth divisions	8
Day interval	7	Diffuse model type	Uniform Sky
Hour interval	2	Diffuse proportion	0.3
Z factor	0.00001112	Transmissivity	0.5

3.3 Slope

Slope is a crucial factor in determining the suitability of sites for solar power farm installation [5]. Ideally, a site with a minimal slope is preferred for installing solar photovoltaic (PV) systems, as it facilitates easier setup and maintenance of panels [23]. Locations with steep slopes are generally unsuitable for solar power generation. The most favourable sites for solar energy installations are those with slopes less than 5% [5, 7]. Areas with steep terrain, such as valleys and mountainous regions, should be avoided because of the infeasibility of construction or the significantly increased costs associated with necessary installation modifications [24].

A slope thematic map was produced using the ArcGIS Pro 3.1.5 slope tool derived from a digital elevation model (DEM). This map categorizes slopes into five distinct classes, with flatter regions categorized as lower slopes and receiving the highest suitability score of 5. Conversely, slopes exceeding 20% were considered least suitable, as shown in Figure 3(b). The slope factor was assigned a weight of 12%, based on the pairwise comparison (PC) matrix in Table 5.

3.4 Land Use Land Cover (LULC)

Land use and land cover (LULC) play a crucial role in determining the optimal locations for solar farm installation. Since photovoltaic (PV) power plants typically require a large land area, the availability of suitable land is a primary factor in site selection [25]. LULC imagery for the study region was derived from Sentinel 2 satellite data and classified into three categories: built-up areas, green areas, and barren land. The Support Vector Machine (SVM) algorithm in ArcGIS Pro 3.1.5 was employed to generate the LULC map. SVM is a widely used, accurate, non-parametric supervised machine-learning technique that classifies data by identifying and defining a maximum margin between distinct classes [26]. Barren land was assigned the highest suitability ranking of 5, which is considered the most appropriate for solar PV farm development, whereas green areas were ranked lower at 2. As shown in Figure 3(c), the built-up areas were deemed unsuitable. The overall weight assigned to the LULC factor, as determined by the pairwise comparison (PC) matrix in Table 5, was 15%.

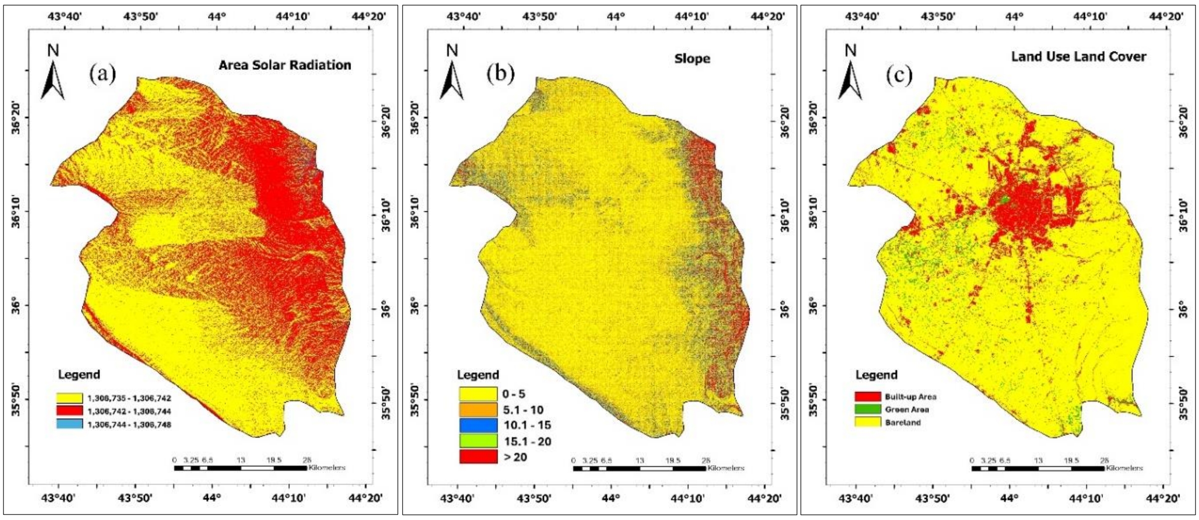

Figure 3: (a) Solar Radiation, (b) Slope, and (c) Land use land cover maps of Erbil city.

3.5 Temperature

The average annual temperature is a critical component that must be addressed to enhance the dependability and efficiency of large-scale solar panels [25]. Although it might be unexpected, increases in temperature can have a detrimental effect on the performance of photovoltaic (PV) modules [27]. The optimal temperature range for the installation of solar farms is 22–26 °C [12]. Data for this analysis were collected from eight stations across Erbil City. Daily temperature averages were recorded to calculate the annual mean temperature. This study used actual measurements to interpolate the annual average temperature for the entire region in 2023. The map was categorized into three temperature classes, with the highest temperatures assigned a ranking of 5, as shown in Figure 4(a), and the lowest ranked as 3. Given the relatively minor temperature variations across Erbil due to the limited size of the study area, this classification method was applied. The weight of the temperature was set at 5%, as determined through the pairwise comparison (PC) matrix in Table 5.

3.6 Transmission lines

Transmission lines play a crucial economic role in determining the optimal location for solar power installations and should be carefully considered [5, 28] primarily to reduce the cost of power delivery to users. At present, solar generation projects are often located in high-solar areas that are in close proximity to existing power lines, with adequate capacity and lower energy costs. In the absence of nearby transmission lines, new power lines must be constructed, which significantly increases the overall cost of establishing solar power plants [5, 23]. The Euclidean distance method was employed to calculate the straight-line distance between the points to determine the nearest source. Proximity to such infrastructure is vital for the development of a distributed generation network and the integration of grid-connected photovoltaic (PV) solar systems [7]. This analysis categorizes proximity into five classes, as shown in Figure 4(b), with an overall weight of 13% based on the pairwise comparison (PC) matrix in Table 5.

3.7 Distance to Road

This criterion is concerned with the construction expenses for building a road from a selected site to the nearest existing roadway. Similar to the distance to transmission lines, this factor is also directly related to the cost [29]. The distance to the road was determined using Euclidean distances with data sourced from the Open Street Map. The proximity was classified into five categories, as shown in Figure 4(c), and was assigned an overall weight of 12%, as indicated in the pairwise comparison (PC) matrix in Table 5.

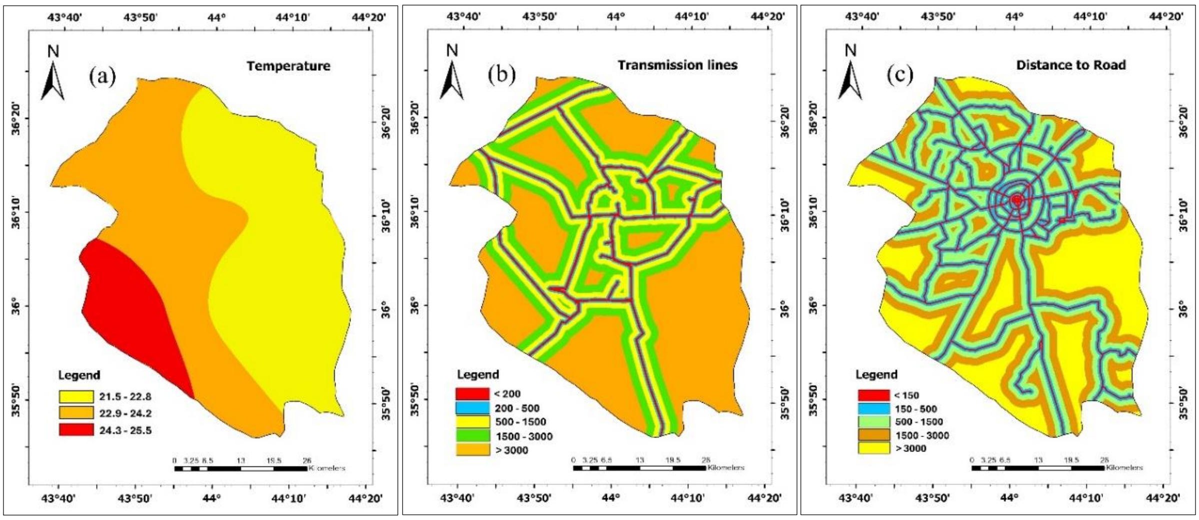

Figure 4: (a) Temperature, (b) Transmission lines, and (c) Distance to Road maps of Erbil city.

3.8 Distance to urban and rural areas

The social impacts of solar power, particularly in urban and rural areas, are often regarded as critical constraints [5]. Proximity to these areas is essential for reducing the cost of delivering the electricity generated to consumers. Using the Euclidean distance tool in ArcGIS Pro 3.1.5, these areas were categorized into six groups as shown in Figures 5(a) and 5(b). The pairwise comparison (PC) matrix in Table 5 shows that the distances from urban and rural areas have overall weights of 10% and 8%, respectively.

3.9 Soil types

To prevent erosion and minimize its possible effects, photovoltaic (PV) system installation requires careful study of soil types [30]. The effective planning and execution of solar energy projects depend significantly on geotechnical assessments. Determining the suitability of a site, planning suitable foundation systems, and guaranteeing the long-term stability and performance of both solar panels and their supporting construction depend on these evaluations [31]. Using the data supplied by the Ministry of Agriculture in Baghdad, Erbil City was classified into three soil types to produce a soil map, as shown in Figure 5(c). The pairwise comparison (PC) matrix in Table 5 reflects the weight assigned to the soil type as 4%.

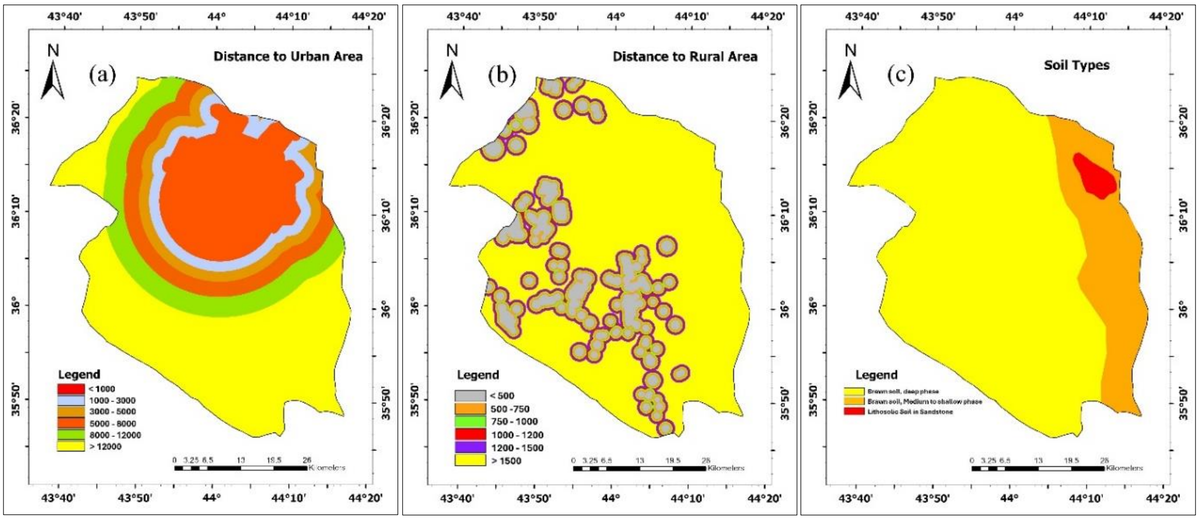

Figure 5: (a) Distance to Urban area, (b) Distance to Rural area, and (c) Soil types maps of Erbil city.

Table 4: Criteria used in the solar power selection model

Criterion	Sub criteria	Rating	Criterion	Sub criteria	Rating
Area Solar Radiation (Wh/m^2)	1,306,735 - 1,306,742	3	Land Use and Land Cover	Built-up Area	Restriction
	1,306,742 - 1,306,744	4		Green Area	2
	1,306,744 - 1,306,748	5		Bare land	5
Distance to Road (m)	0 - 150	Restriction	Transmission lines (m)	0 - 200	Restriction
	151 - 500	5		201 - 500	5
	501 - 1500	4		501 - 1500	4
	1501 - 3000	3		1501 - 3000	3
	> 3000	2		> 3000	2
Distance to the Urban area (m)	0 - 1,000	Restriction	Distance to Rural area (m)	0 - 500	Restriction
	1,001 - 3,000	1		501 - 750	1
	3,001 - 5,000	2		751 - 1,000	2
	5,001 - 8,000	4		1,001 - 1,200	3
	8,001 - 12,000	5		1,201 - 1,500	4
	> 12,000	3		> 1,500	5
Temperature (C^o)	21.5 - 22.8	3	Soil Types	Deep phase	5
	22.9 - 24.2	4		Medium to shallow	3
	24.3 - 25.5	5		Lithosols Soil in Sandstone	1
Slope %	0 - 5	5			
	5.1 - 10	4			
	10.1 - 15	3			
	15.1 - 20	2			
	>20	1			

3.10 Restriction model

Restrictions should be appropriately defined in light of the site's circumstances. The government imposes some restrictions. However, experts have specified certain limitations based on safety, economic, and environmental concerns [23].

This phase was necessary to overcome the limitations of this study. In particular, the study did not include sites where solar photovoltaic (PV) farms had identified developmental restrictions [5]. The restriction layers shown in Figure 6 were combined into a single layer, incorporating the required buffer zones. These layers were then given a binary scale (1 and 0), where "1" denotes the absence of constraints, so indicating the feasibility of project development, while "0" indicates the presence of constraints, thereby implying that the project cannot be developed in these areas [7].

The installation of solar PV farms is prohibited in built-up areas to prevent conflicts with land use, as these regions are characterized by high population density. Such restrictions aim to preserve space for essential services, mitigate concerns related to aesthetics, and protect property value. Distance regulations around transmission lines and roads are enforced for safety reasons, ensuring easy access for maintenance and emergency interventions, while minimizing disruptions to existing infrastructure. In densely populated urban areas, a setback of 1000 meters helps reduce glare, safety risks, and negative impacts on properties. In contrast, rural areas require a 500-meter buffer to safeguard agricultural land and residential quality without causing excessive disturbance. Over 39% of Erbil City falls under restricted zones, including built-up areas, regions near roads and transmission lines, and both urban and rural areas, as outlined in Table 4.

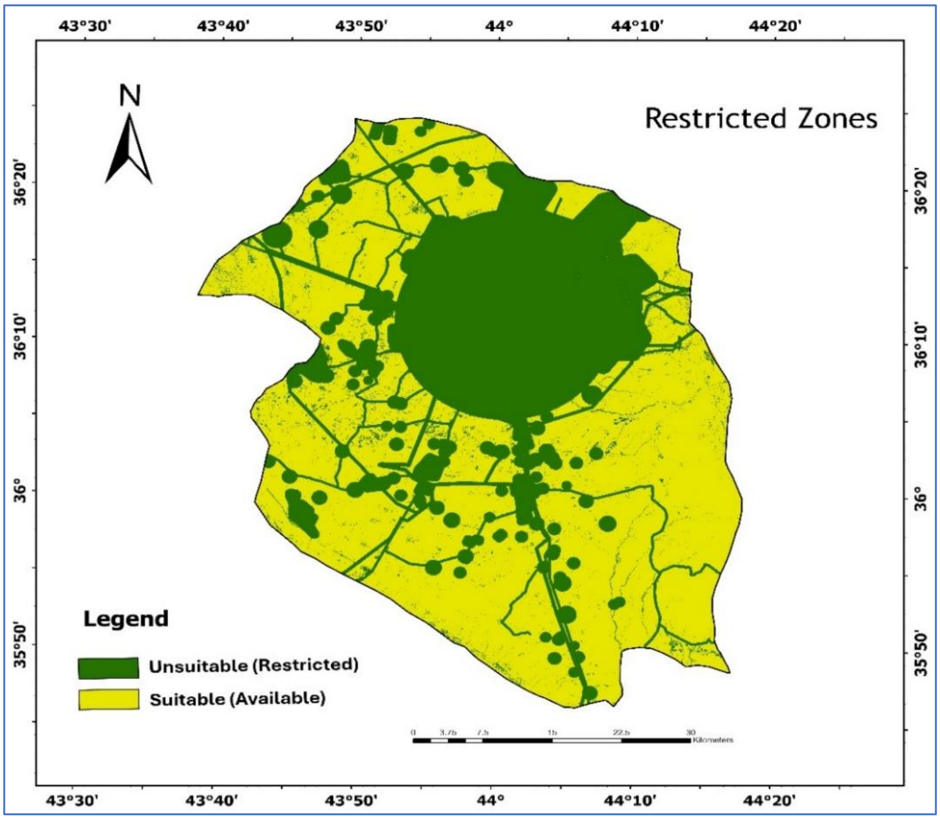

Figure 6: Thematic map of restricted and suitable zones.

Table 5: Pairwise comparison matrix for nine criteria

Factors	ASR	Trans.	LULC	Dist. to Road	Slope	Dist. To Urban	Dist. to Rural	Temp.	Soil types	Sum	Weight %
ASR	1.0	1.0	1.0	2.0	2.0	3.0	3.0	3.0	5.0	21.00	21
Trans.	1.00	1.0	1.0	1.0	1.0	1.0	1.0	3.0	3.0	13.00	13
LULC	1.00	1.00	1.0	1.0	1.0	2.0	2.0	3.0	3.0	15.00	15
Dist. To Road	0.50	1.00	1.00	1.0	1.0	2.0	2.0	2.0	2.0	12.50	12
Slope	0.50	1.00	1.00	1.00	1.0	1.0	2.0	2.0	3.0	12.50	12
Dist. To Urban	0.33	1.00	0.50	0.50	1.00	1.0	1.0	2.0	3.0	10.33	10
Dist. to Rural	0.33	1.00	0.50	0.50	0.50	1.00	1.0	1.0	2.0	7.83	8
Temp.	0.33	0.33	0.33	0.50	0.50	0.50	1.00	1.0	1.0	5.50	5
Soil types	0.20	0.33	0.33	0.50	0.33	0.33	0.50	1.00	1.0	4.53	4

4. Results and Discussion

This study introduces a comprehensive GIS-based framework that merges the Area Solar Radiation (ASR) tool with the Analytical Hierarchy Process (AHP) to assess the suitability of solar photovoltaic (PV) sites within Erbil City. The resulting suitability map classifies the area into six categories, indicating that 60.89% of the region is suitable for solar PV installations, while 39.11% faces limitations owing to infrastructural or environmental constraints (see Figure 7 and Table 6).

Table 6: Classification of Suitability Levels for Solar PV Farms in Erbil City.

Classes	Percentage of suitability	Area (km²)	Area %
Unsuitable (Restrictions)	0 %	1064.75	39.11
Least Suitable	1% - 19%	166.31	6.11
Marginally Suitable	20% - 39%	397.75	14.61
Moderate Suitable	40% - 59%	534.86	19.65
Highly Suitable	60% - 79%	388.81	14.28
Most Suitable	80% - 100%	169.92	6.24

Although solar radiation is consistently high across Erbil, this study highlights that factors such as land use, slope, and proximity to critical infrastructure significantly affect site suitability. In particular, the western part of Erbil stands out as the most favourable region, characterized by relatively flat terrain, lower urban development, and closer proximity to transmission lines and roads. However, the southern regions, which are rich in solar energy potential, are less suitable because of the absence of necessary infrastructure. This multi-criteria approach demonstrates that while solar insolation is a key resource, the effective deployment of solar PV systems relies on a comprehensive evaluation of both accessibility and land availability.

A key innovation in our methodology is the integration of the ASR tool with high-resolution digital elevation models, which capture solar insolation variation across space with remarkable precision. This method not only enhances the accuracy of solar radiation measurements but also strengthens the overall multi-criteria decision-making process, setting a new standard for solar PV site selection that surpasses conventional approaches.

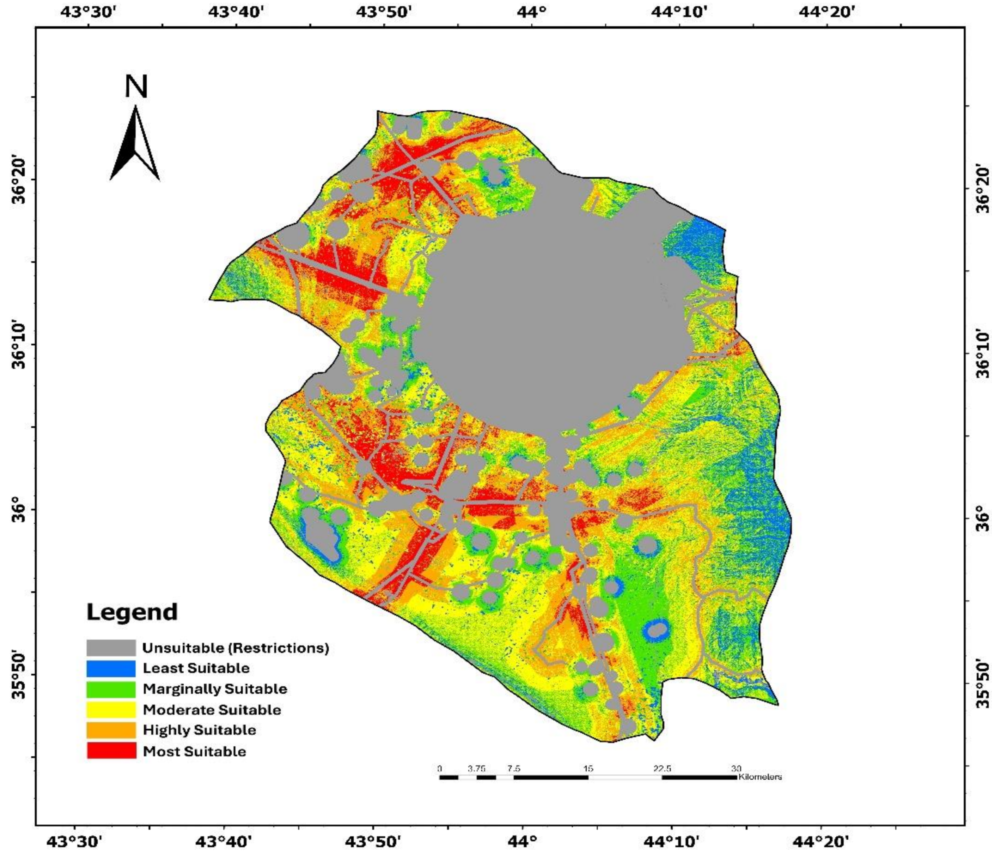

Figure 7: The Suitability Map of Erbil City for Solar PV Farms Installation.

The "most suitable" category, comprising 6.24% of the total area (169.92 km²), holds substantial potential for large-scale solar energy projects. Given the requirement of approximately 15,000 m² per 1 MW of capacity [23]. This area could theoretically accommodate installations of over 10,000 MW if optimally utilized. Such development would not only enhance local renewable energy generation but also significantly reduce fossil fuel consumption and greenhouse gas emissions. Additionally, solar PV systems typically have minimal water requirements compared with traditional thermal power plants [32], offering a distinct advantage in the arid climate of Erbil. This shift toward solar energy would contribute to improved air quality and align with the broader sustainable development objectives.

These findings offer valuable insight into regional energy planning. The concentration of the most suitable sites in the western portion of Erbil suggests that policymakers should prioritize these areas for future solar projects.

Proximity to current road networks and transmission infrastructure minimizes the necessity for additional investment, and the financial feasibility and viability of such initiatives are thereby enhanced. Moreover, the method described in this study offers a repeatable model that can be implemented in other areas with similar infrastructure and climates.

Despite the strengths inherent in this method, there are several limitations that need to be mentioned. Firstly, while the AHP method successfully incorporates varied criteria, the weights given may be prone to bias due to expert judgment. Future studies can look into the utilization of other multi-criteria decision-making (MCDM) methodologies such as fuzzy logic models or TOPSIS to cross-check and enhance the weighting procedure. Second, the model's predictive accuracy may be increased by including dynamic factors, such as real-time weather data and grid connectivity, as the current analysis depends on static datasets. Finally, socioeconomic factors and land ownership issues need to be the focus of future studies because they are key to the successful deployment of large solar PV projects.

5. Conclusion

This study provides Erbil City with the most suitable site for solar photovoltaic (PV) farm installations. A comprehensive and methodical approach based on this study offers a data-driven framework that maximizes the use of the given land for solar energy development by including a Geographic Information System (GIS), the Analytical Hierarchy Process (AHP), and the Area Solar Radiation (ASR) tool. The results demonstrate that the western region of Erbil is most suited for solar PV installations; thus, 60.89% of the study area is viable. With the potential to generate over 10,000 MW of clean electricity, 6.24% of the area (169.92 km²) was found to have the most suitable conditions for solar power generation, which greatly contributed to the renewable energy capacity of the region.

This study indicates a correct fit by combining high-resolution spatial data with a strong multi-criteria evaluation model. Solar radiation, land use land cover (LULC), slope, proximity to transmission lines, road access, distance from urban and rural areas, soil type, and temperature nine key factors were considered in the analysis. The AHP approach was essential for allocating exact weights to these criteria and balancing technical feasibility, environmental impact, and economic viability. The study reveals that solar radiation and land availability are the most important determinants of suitability, but infrastructure accessibility remains pivotal to the effective deployment of solar projects.

The findings highlight the huge potential of Erbil City for the development of solar energy, therefore offering valuable insights to urban planners, lawmakers, and investors. Highly suitable areas identified clearly suggest room for targeted solar photovoltaic development, in line with the Kurdistan Regional Government's (KRG) vision to achieve 3,000 MW of solar energy over the coming decade. The decision-making model based on GIS that has been created in this study is a flexible and expandable site selection system that continues to be relevant to other regions with comparable climatic and infrastructural characteristics.

Beyond its immediate significance to Erbil, this study also lays the basis for an approach that can be used in other geographical locations. To optimize further the site selection process, additional studies should examine other factors like the economic feasibility of solar projects, land ownership issues, environmental impact assessments, and grid connectivity. Predictive modelling and real-time monitoring could also be a significant consideration in making solar PV farms viable in the long term, thereby guaranteeing their efficiency and performance throughout the years.

In conclusion, this study shows that GIS, AHP, and ASR tools can find optimal sites for solar PV projects in Erbil City. The results not only stress the enormous potential of the region for renewable energy but also present a strategic analysis that can potentially catalyze the adoption of solar energy in Erbil and the wider Kurdistan Region. This study promotes the transition from fossil fuels by enabling sustainable energy practices through technical analysis and policy suggestions. Moreover, the approach shown here can be a template for comparable energy evaluations in other areas, thus supporting worldwide dedication to a more resilient energy future.

Conflict of Interest

The authors declare no conflict of interest.

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References

[1] Owusu PA, Asumadu-Sarkodie S. A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Engineering. 2016 ;3(1):1167990. https://doi.org/10.1080/23311916.2016.1167990

[2] Hudedmani MG, Soppimath V, Jambotkar C. A study of materials for solar PV technology and challenges. European Journal of Applied Engineering and Scientific Research. 2017;5(1):1-3.

[3] Uyan M. GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey. Renewable and Sustainable Energy Reviews. 2013;28:11-7. https://doi.org/10.1016/j.rser.2013.07.042

[4] Şen Z. Solar energy fundamentals and modeling techniques: atmosphere, environment, climate change and renewable energy. London: Springer; 2008.

[5] Ibrahim GR, Hamid AA, Darwesh UM, Rasul A. A GIS-based Boolean logic-analytical hierarchy process for solar power plant (case study: Erbil Governorate—Iraq). Environment, Development and Sustainability. 2021;23:6066-83. https://doi.org/10.1007/s10668-020-00862-3

[6] Boban P, Milica P. The application of ArcGIS for assessing the potential of solar energyin urban area: The case of Vranje. In12th International Conference on Energy and Climate Change. 2019, (pp. 325-340).

[7] Al Garni HZ, Awasthi A. Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia. Applied energy. 2017;206:1225-40. https://doi.org/10.1016/j.apenergy.2017.10.024

[8] Ahadi P, Fakhrabadi F, Pourshaghaghy A, Kowsary F. Optimal site selection for a solar power plant in Iran via the Analytic Hierarchy Process (AHP). Renewable Energy. 2023;215:118944. https://doi.org/10.1016/j.renene.2023.118944

[9] Hasti F, Mamkhezri J, Pezhooli N, McFerrin R. Optimal Pv sites selection using Gis-based modelling techniques and assessing environmental and economic impacts: The case of Kurdistan. Available at SSRN 4119336. 2022. https://doi.org/10.2139/ssrn.4119336

[10] Shihab TH, AL-Hameedawi AN. Land suitability for solar energy utilization in Erbil city using fuzzy logic and GIS. InAIP Conference Proceedings 2024, (Vol. 3219, No. 1). AIP Publishing. https://doi.org/10.1063/5.0236421

[11] KEYA DR, Farangis B, Sirwan R, Behler K. Gis-based analysis of the solar radiation mapping and potential assessment for the North Iraq-Kurdistan Region. Journal of Engineering Science and Technology. 2023; 18(5):2269-80. https://doi.org/10.21203/rs.3.rs-1914165/v1

[12] Khazael SM, Al-Bakri M. The optimum site selection for solar energy farms using AHP in GIS environment, a case study of Iraq. Iraqi Journal of Science. 2021: 4571-87. https://doi.org/10.24996/ijs.2021.62.11(si).36

[13] Chomani K. Evaluating the COVID-19 Lockdown's Effects on Land Surface Temperature, NO2, and O3 in the Erbil City, Kurdistan Region of Iraq. Cihan University-Erbil Scientific Journal. 2024;8(2):84-92. https://doi.org/10.24086/cuesj.v8n2y2024.pp84-92

[14] Vatan Kaptan M. Climate-responsive design strategy for Erbil city. Archnet-IJAR: International Journal of Architectural Research. 2020;14(1):90-111. https://doi.org/10.1108/arch-04-2019-0089

[15] Vodapally SN, Ali MH. A comprehensive review of solar photovoltaic (PV) technologies, architecture, and its applications to improved efficiency. Energies. 2022;16(1):319. https://doi.org/10.3390/en16010319

[16] Singh GK. Solar power generation by PV (photovoltaic) technology: A review. Energy. 2013; 53:1-3. https://doi.org/10.1016/j.energy.2013.02.057

[17] Chomani K. Assessing the impact of urbanization on flood hazards in Ranya city, using GIS and remote sensing. EURASIAN JOURNAL OF SCIENCE AND ENGINEERING. 2023;9(3):154-65. https://doi.org/10.23918/eajse.v9i3p14

[18] Alzahmi W, Ndiaye M. A Multi-Criteria AHP Framework for Solar PV End-of-Life Management. Sustainability. 2025;17(5):1828. https://doi.org/10.3390/su17051828

[19] Ruiz HS, Sunarso A, Ibrahim-Bathis K, Murti SA, Budiarto I. GIS-AHP Multi Criteria Decision Analysis for the optimal location of solar energy plants at Indonesia. Energy Reports. 2020; 6:3249-63. https://doi.org/10.1016/j.egyr.2020.11.198

[20] Kazak JK, Świąder M. SOLIS—A Novel Decision Support Tool for the Assessment of Solar Radiation in ArcGIS. Energies. 2018;11(8):2105. https://doi.org/10.3390/en11082105

[21] Kausika BB, Van Sark WG. Calibration and validation of ArcGIS solar radiation tool for photovoltaic potential determination in the Netherlands. Energies. 2021;14(7):1865. https://doi.org/10.3390/en14071865

[22] Farnsworth C. Using GIS to estimate the Solar Power potential for rooftops within the Cleveland Park neighborhood of Washington, DC. 2023.

[23] Demir A, Dinçer AE, Yılmaz K. A novel method for the site selection of large-scale PV farms by using AHP and GIS: a case study in İzmir, Türkiye. Solar Energy. 2023; 259:235-45. https://doi.org/10.1016/j.solener.2023.05.031

[24] Sánchez-Lozano JM, Teruel-Solano J, Soto-Elvira PL, García-Cascales MS. Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain. Renewable and sustainable energy reviews. 2013;24:544-56. https://doi.org/10.1016/j.rser.2013.03.019

[25] Noorollahi Y, Senani AG, Fadaei A, Simaee M, Moltames R. A framework for GIS-based site selection and technical potential evaluation of PV solar farm using Fuzzy-Boolean logic and AHP multi-criteria decision-making approach. Renewable Energy. 2022;186:89-104. https://doi.org/10.2139/ssrn.3916212

[26] Chomani K, Pshdari S. Evaluation of Different Classification Algorithms for Land Use Land Cover Mapping. Kurdistan Journal of Applied Research. 2024;9(2):13-22. https://doi.org/10.24017/science.2024.2.2

[27] Stanka N, Aboltins A, Palabinskis J. Impact of high temperature and other factors on PV [photovoltaic] module efficiency on small farms in Latvia. InEngineering for Rural Development. Proceedings of the International Scientific Conference (Latvia). 2020 (No. 19). https://doi.org/10.22616/erdev.2020.19.tf106

[28] Rusol IA, Al-Timimi YK. Determination optimum sites for solar energy harvesting in Iraq using multi-criteria. The Iraqi Journal of Agricultural Science. 2024;55:25-33. https://doi.org/10.36103/ijas.v55ispecial.1882

[29] Demir A, Dinçer AE, Yılmaz K. A novel procedure for the AHP method for the site selection of solar PV farms. International Journal of Energy Research. 2024;2024(1):5535398. https://doi.org/10.1155/2024/5535398

[30] Farhat N, Damirji B, Fadel B. A Model Based on GIS and Climate-Criteria to Locate Optimal Solar Power Plant Sites. Journal of Agriculture and Forest Meteorology. 2023;5(180):1. https://doi.org/10.2139/ssrn.4861082

[31] Joel OT, Oguanobi VU. Geotechnical assessments for renewable energy infrastructure: ensuring stability in wind and solar projects. Engineering science & technology journal. 2024;5(5):1588-605. https://doi.org/10.51594/estj.v5i5.1110

[32] Mekhilef S, Saidur R, Safari A. A review on solar energy use in industries. Renewable and sustainable energy reviews. 2011;15(4):1777-90. https://doi.org/10.1016/j.rser.2010.12.018