Land Suitability Mapping for Solar Power Plant Using Remote Sensing, GIS-AHP and Multi-Criteria Decision Approach: A Case of Karbala, Iraq

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Abstract

The attention of developed countries is turning to the use of renewable energy sources, especially after the fossil fuel crises and environmental pollution caused by power plants, solar energy is a more effective renewable resource for use today, especially in areas with high solar energy. Solar cells convert solar radiation into an electrical energy source for domestic and industrial use. In this study we used remote sensing and Geographic information systems (GIS) to identify potentially suitable areas for solar power plants in the holy city of Karbala, Iraq.

After determining the necessary criteria and collecting their data via the satellite images of Landsat 8 for the year 2022 and analyzing them by ArcGIS, the analytical hierarchy process (AHP) and the Multi-Criteria Decision-Making Process (MCDA) were used to determine the best land for the installation of solar cells

The results showed that the areas that are suitable and very suitable are (15.41%), equivalent to (775.76607 Km2) of the total area of Karbala governorate (5033 Km2). As a result, this model is suitable for setting the selected criteria to identify the most promising sites in Karbala governorate that can achieve the research objectives, this study helps urban planners, designers and investors to implement and develop solar power plants within the governorate.

1. Introduction

The world population is constantly increasing and this growth requires more energy to meet daily needs [1], so the demand for fossil fuels is increasing, which is the most common type of fuel for the operation of power plants, In addition, energy manufacture from fossil fuels is the largest source of conservatory gas emissions into the atmosphere that have caused worldwide climate change[2], This has led to a focus on the use of renewable energy sources, as they are generally considered spotless, with a significantly lower influence on the environment than other energy sources[3]. Solar energy is a renewable and additive energy source that is gradually replacing non-renewable energy sources. Solar power generation has become one of the fastest growing energy sources as the cost of solar panels decreases[4], The average monthly solar radiation values for the region, which depends on the number of sunny days and the length of daylight hours, is one of the most important criteria for determining the installation areas of the solar system[5]. Based on previous studies in this field, the most important criteria have been identified that make the area suitable or unsuitable for the installation of solar cell stations, namely solar radiation, Elevation , slope, Aspect, land cover/ use, distance to power lines and main roads[6]

Remote sensing is a multi-scale and multi-temporal approach that provides important data about objects and atmosphere at or near the surface of the Earth based on radiation reflected or emitted from objects or regions. Remote sensing techniques use satellite or airborne sensors to gather information about specific objects or areas. They therefore depend on physical, chemical, biological and/or geological properties [7, 8]. The geographic information system creates, manages, analyzes and maps all types of data. It is an organized set of programs and data designed to capture, store, update, process, analyze and display all forms of geographically referenced information efficiently [9], Technological innovations in the fields of Remote Sensing (RS) and Geographic Information Systems (GIS) Providing timely, accurate and high quality input for decision making while improving sustainable use and conservation practices of natural resources has opened a new dimension for addressing the broad scientific problem of land-use classification of land cover. Satellite imagery provides qualitative information over large geographic areas and reduces the complexity of field operations. Suitable remote sensing data for image classification are selected by analyzing the strength and limitations of the various types of available sensor data. Land use/land cover classification can be determined by measuring, analyzing and interpreting satellite imagery collected by satellite sensors [10].

MCDM (Multiple Criteria Decision Making) technique is applied to make the most suitable optimal among the replacements offered under multiple criteria and different targets[11] The analytical hierarchy process (AHP) was developed in 1980 to solve unstructured problems by Saaty and is considered one of the most important MCDM methods used to determine the best choice amongst a set of alternative choices based on multiple criteria. AHP is one of the powerful and useful MCDM technologies that enables multifaceted problems for decision makers and provides high suppleness and reliability with a usable structure[12] The AHP technology includes important steps to enumerate the components in the pairwise comparison approach and the decision-making criteria technique, the hierarchy process determines the weighted scores of the criteria by applying the pairwise comparison technique to homogenize the effects on the total unit [13], suitability analysis in a GIS context is a geographic or GIS-AHP-based process used to determine the appropriateness analysis of a given area for a particular use. The basic premise of GIS suitability analysis is that each aspect of the landscape has intrinsic characteristics that are in some degree either suitable or unsuitable for the activities being planned [14]. The integration of MCDM techniques with GIS has considerably advanced the conventional map overlay approaches to the land-use suitability analysis mapping and analysis .GIS-based MCDA can be thought of as a process that combines and transforms spatial data into resultant decision [15]. This study aims to provide a GIS-based methodology for making the decision to install solar cells in Karbala governorate, and this proposed methodology was implemented using the ArcGIS program to calculate solar radiation and also analyze and classify land cover / use.

2. Study area

Karbala is located in the Mesopotamian plain 92km away from Baghdad in the southwest direction and occurs between Eastern Longitude (44° 25’ 00- 43° 45’ 00) and Northern latitude (32° 40’ 00-32° 20’ 00), it has an area of about 5 thousand square kilometers which represent about 1.2% of Iraq total area. It’s inhabited by more than 1.2 million residents and host millions during religious events like the Ashura and the Arba’ee [16, 17]

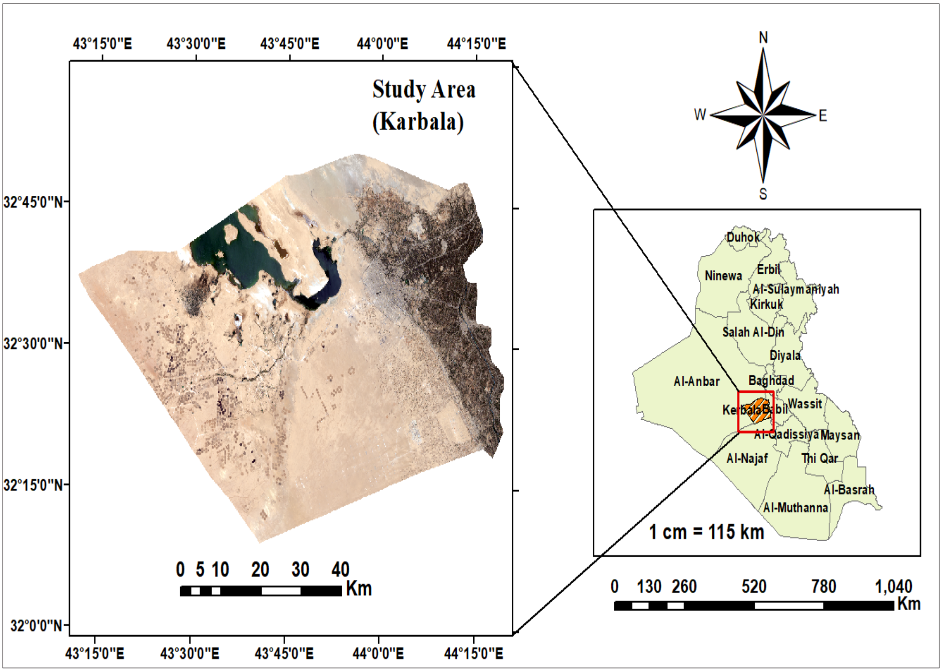

Figure 1.Study area location

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3. Methodology

3.1. data acquisition

The criteria were derived from various data sources, including satellites, classification and websites. As shown by Table No. 1

Table 1.Site suitability criteria for solar PV installation

criteria	Reference	Unit
global horizontal irradiance (GHI)	ALOS PALSAR satellite image (DEM) processed with ArcGIS	(WH/m^2)
elevation	ALOS PALSAR satellite image (DEM) (ASF) processed with ArcGIS	m
Slope	ALOS PALSAR satellite image (DEM) (ASF) processed with ArcGIS	Degree
Aspect	ALOS PALSAR satellite image (DEM) (ASF) processed with ArcGIS	Degree
Land cover/use	Landsat 8 OLI/TIRS (USGS)	Unitless
Distance from power lines	Open street map	m
Distance from major roads	World Bank Data Catalog	m

The study relied on GIS-based combination with the AHP method as a methodology to acquire ideal sites of solar farms in the study area. Figure 2 shows a flowchart of the methodology.

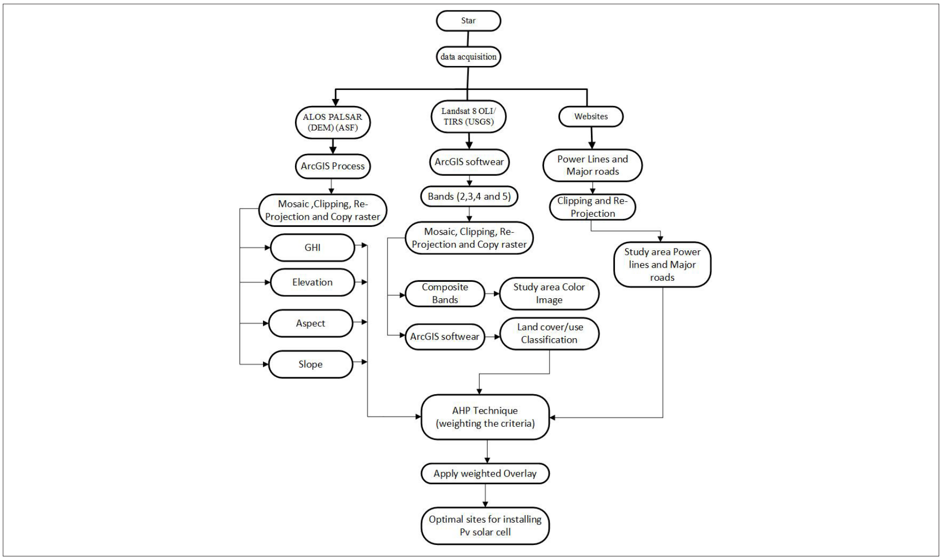

Figure 2 .Flowchart of proposed methodology

3.2. Data preparation

After obtaining the data, the data is prepared using the ArcGIS program in order to obtain accurate results. Satellite images are combined using (Mosaic to new raster tool) to get a satellite image that covers the entire area of the study area. The second step is to subtract the study area from the satellite image produced by the Mosaic tool by a mask that represents the boundaries of the study area so that the results are focused only on it. The third step is to correct the spatial reference of the satellite image in this study, the spatial reference used is (UTM Zone 38n) , The last step is to get rid of the NoData Value and the Background values of the satellite image. After these steps, the data is ready for analysis

3.3. calculate criteria

Global Horizontal irradiation (GHI): It represents the amount of solar radiation that the Earth's surface receives. This value is of great importance in the installation of photovoltaic plants, and includes both direct radiation and reflected radiation as shown in Figure 3. This criteria calculated using (Areal solar radiation tool) contained in the ArcGIS program using ALOS PALSAR satellite images As shown in Table 2

Table 2.ALOS PALSAR satellite images DEM data

Scene	Band	Path/Frame	Resolution (m)	Spatial reference
Scene 1	L-band	585/640	12.5	UTm_Zone_38n
Scene 2		585 /630		
Scene 3		586/640		
Scene 4		586/630		
Scene 5		587/640		
Scene 6		587/630		

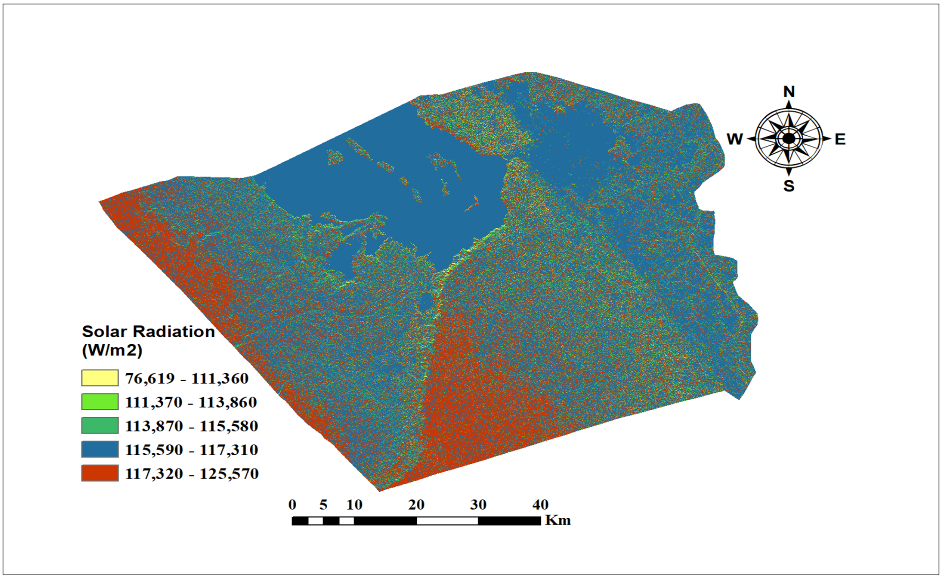

Figure:3.Annual Solar Radiaiton map for Karbala 2022

The areas with red color represent the highest values of solar radiation during the year and are considered the best areas for installing photovoltaic plants, which recorded the highest value of 125570 (WH/m2) and the values are graduated as shown in Figure 3 to reach the lowest value of 76619 (WH/m2) (areas in yellow).

- **Elevation:** High-altitude areas receive more solar radiation than low-lying areas, where they receive the lowest values of solar radiation, as shown in figure 4, the highest value of altitude reaches 156 (m) and gradually decreases until it reaches the lowest area with a value of 22 (m).

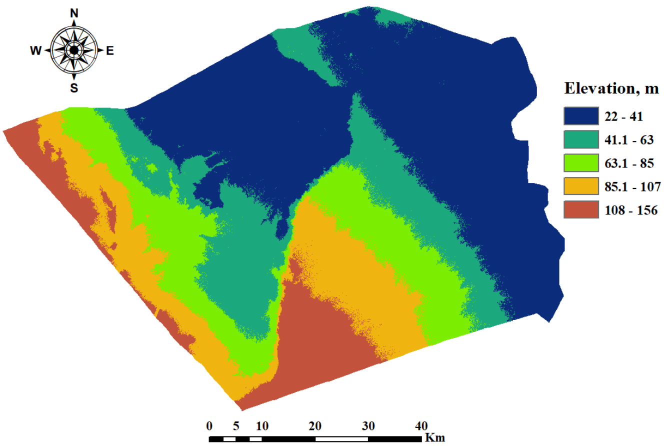

Figure 4. Elevation values in Karbala

- **Slope and Aspect:** The slope and Aspect of the study area are important criteria for choosing a suitable location for photovoltaic systems. Where it is determined by the amount of solar radiation received by solar panels. The figure 5 and figure 6 represent the Slope map and Aspect map respectively of Karbala

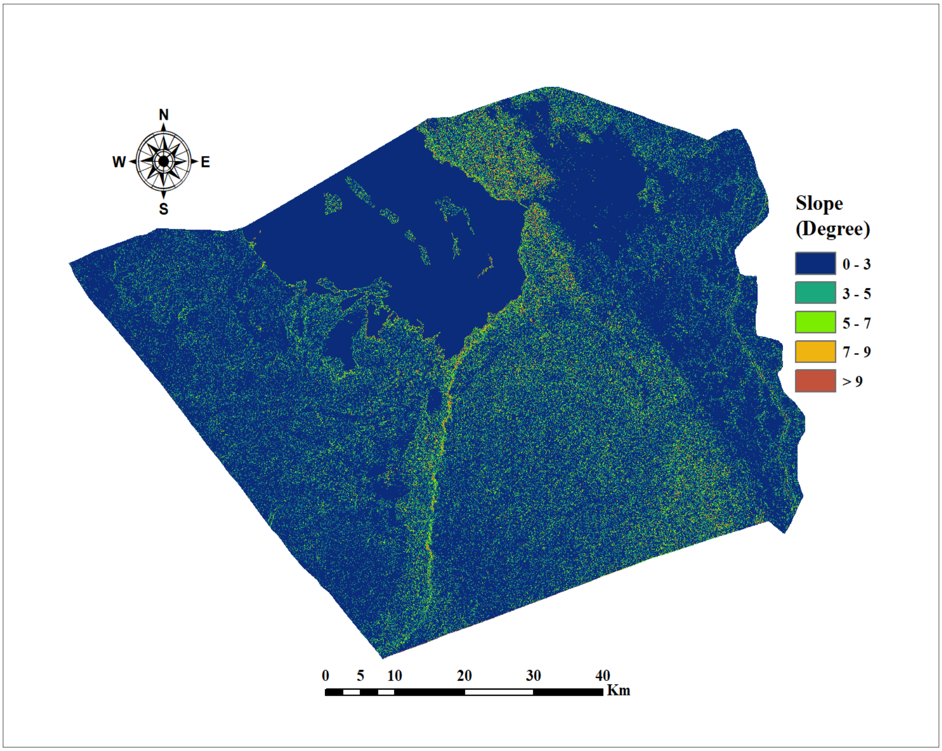

Figure 5.Slope map of Karbala

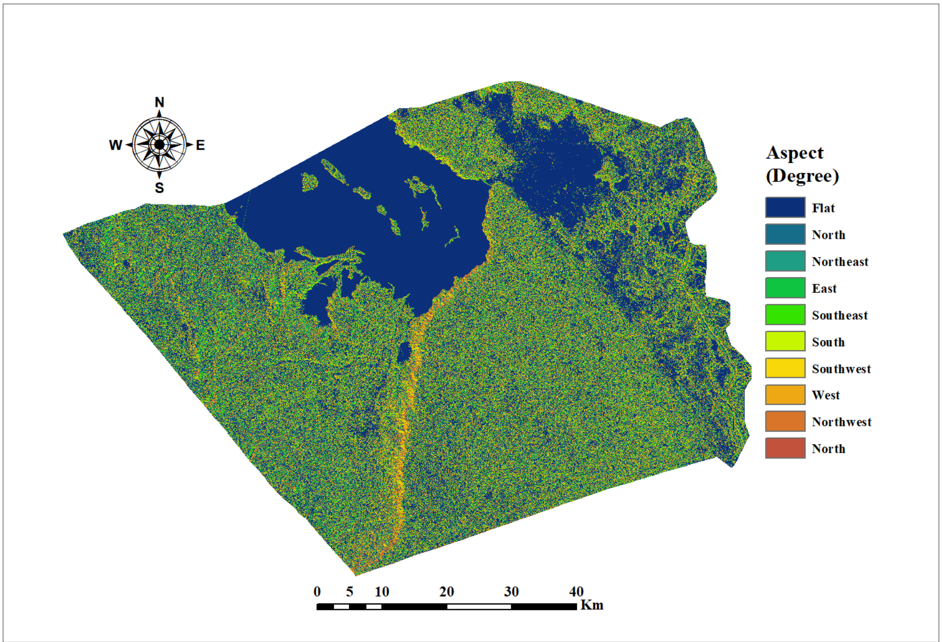

Figure 6. Aspect map of Karbala

- **Land cover :** Not all lands are suitable for the installation of photovoltaic panel systems, the best candidate areas for this purpose are bare lands and pastures. The ground cover of the study area derived from the Landsat 8 satellite as shown in Table 3. The land cover is classified into 6 varieties, which are barren lands, rangelands, Crops, Built area, forest evergreen and water

Table 3.Landsat 8 OLI Spectral Bands

Landsat 8 Sensors	Band	Band Name	Wavelength (μm)	Resolution (m)
Operational Land Imager (OLI)	2	Blue	0.450-0.515	30
	3	Green	0.525-0.600	
	4	Red	0.630-0.680	
	5	Near Infrared (NIR)	0845.-0.885	

Table 4. Land cover classes' details

Class	Area (Km)	Percentage %
Barren lands	3185.568	62.90
Rangelands	65.644	1.29
Crops	356.243	7.03
Built area	819.513	16.18
forest evergreen	388.712	7.67
water	248.186	4.90

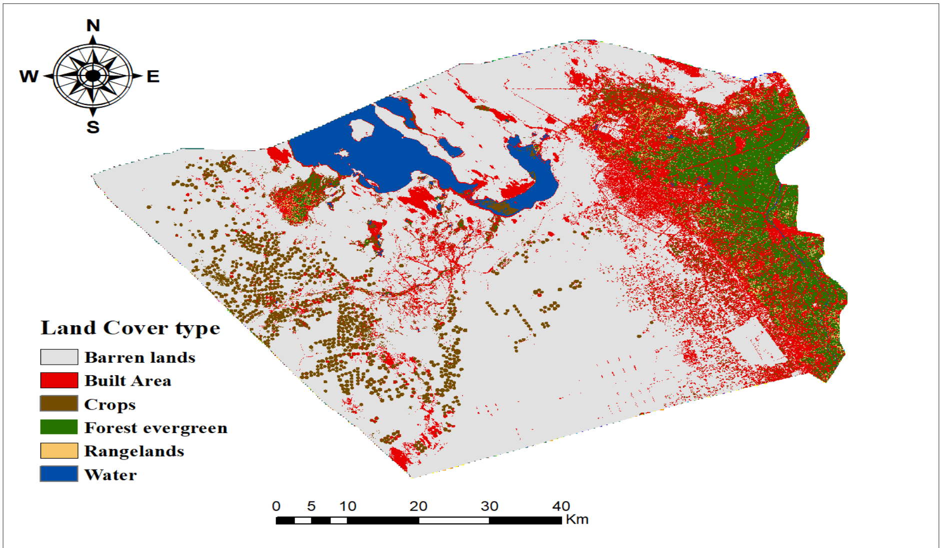

Figure 7.Karbala Land cover Classification

- **Major roads and Power lines:** Proximity to major roads and major energy transmission lines affects the cost of infrastructure construction and the associated environmental damage. Figure 8 and Figure 9 represent the map of the main roads and the map of the main power lines in order

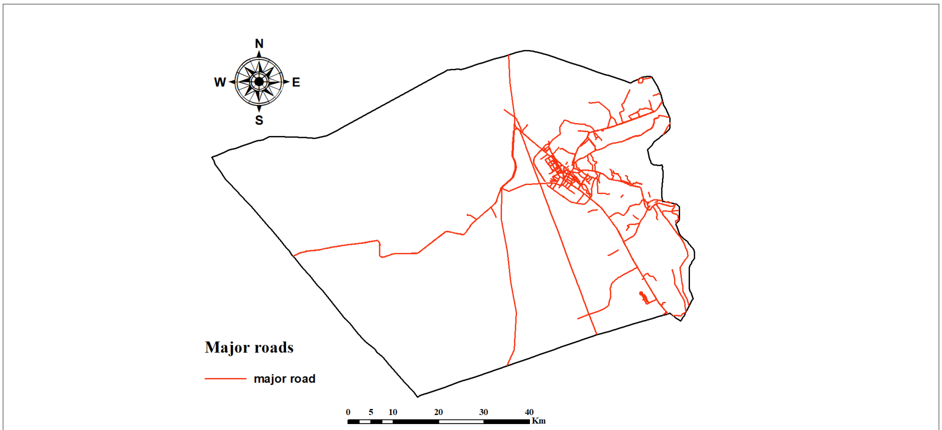

Figure 8.Major roads Map of Karbala

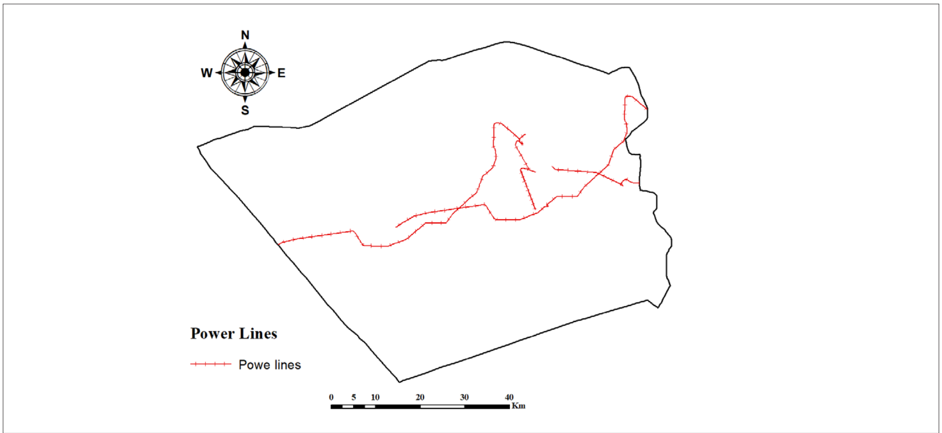

Figure 9.Major power transmission lines

3.4. Criteria Reclassify

After calculating the values of the criteria used in this study. We classify the values of the standards based on their suitability for the installation requirements of photovoltaic regulators from 1 to 5 ratings, where Rating 1 represents the least suitability and Rating 5 the highest suitability, Photovoltaic plants require at least 4 WH/m2 solar radiation for daily use and according to the efficiency of the system. Studies on the suitability the site for photovoltaic systems confirmed that the best slope values are less than <3%, but values exceeding them are Unsuitable, and the Aspect in the south and Southeast is very convenient. As for the land cover, barren lands and rangelands represent the best places to install photovoltaic plants, in addition to their proximity to energy transmission lines and Main Roads [18-20].

Table 5. Suitability rating criteria

C1	C2	C3	C4	C5	C6	C7	Rating
76619-111360	>9	Water	Flat	22-41	<1	1	1
111374-113860	7-9	Built Area/ Forest Evergreen	N, NE, NW	41.1-63	1-3	3	2
113870-115580	5-7	Crops	E, W	63.1-85	3-6	6	3
115590-117310	3-5	Rangelands	SE, SW	85.1-107	6-9	9	4
117320-125570	<3	Barren Lands	S	107.1-156	>9	>9	5

Where: C1: GHI, C2: Slope, C3: Land cover/use, C4: Aspect, C5: Elevation, C6: Distance from Power lines and C7: Distance from major roads

3.5. Criteria Rating

Pairwise comparison is essential in the use of AHP, criteria are prioritized by importance by judging them in pairs and then a pairwise comparison matrix is created. Judgments that are represented by numbers according to the Saaty scale are used for comparison[21]

Table 6.Pairwise Comparison scale

Saaty scale	Definition
1	equally important
3	moderately more important
5	strongly more important
7	very strongly more important
9	Extremely more important
2,4,6,8	Intermediate values

This method turns complex decisions into a series of side-by-side comparisons. In addition, the method allows checking the logicality of the decision, thereby reducing bias in decision-making by creating an equal comparison matrix (A), as shown by equation No. 1. If n is the number of inputs, then the size of the array is n×n

$$A = \begin{bmatrix} 1 & a & b \\ \frac{1}{a} & 1 & c \\ \frac{1}{b} & \frac{1}{c} & 1 \end{bmatrix} \qquad (1)$$

To weighting each criterion, The Matrix A is unified by dividing the elements in each column by the sum of the elements in the same column. The average of the rows in the new matrix determines the relative weights required for the criteria. The AHP includes the consistency ratio (CR), which is a parameter to evaluate the weights' consistency. To calculate the CR, the consistency index (CI) must be first Calculated (Equation (2))

$$CI = \frac{\lambda max - n}{n-1} \qquad (2)$$

Where: λmax denotes the eigenvalue of the pairwise comparison matrix, n is the number of the input criteria, In the end, the CR is calculated by dividing the CI by the random consistency index (RI). The RI values for the appropriate n values were reported by Saaty.

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To obtain the value of CR, Equation (3) is used [22]

$$CR = \frac{CI}{RI} \qquad (3)$$

Table 7. The pairwise comparison matrix for the multi-criteria decision analysis (MCDA)

	GHI	Slope	Land Cover	Aspect	Elevation	Distance from major power line	Distance from main road
GHI	1	2	3	4	5	7	9
Slope	0.5	1	1.5	2	2.5	3.5	4.5
Land Cover	0.333333	0.666667	1	1.333333	1.666667	2.333333333	3
Aspect	0.25	0.5	0.75	1	1.25	1.75	2.25
Elevation	0.2	0.4	0.6	0.8	1	1.4	1.8

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Distance from major power line	Distance from main road
0.142857	0.111111
0.285714	0.222222
0.428571	0.333333
0.571429	0.444444
0.714286	0.555556
1	0.77777778
1.285714286	1

Table 8.The standardized matrix and the weighted dissemination for the multi-criteria decision analysis (MCDA)

	GHI	Slope	Land Cover	Aspect
GHI	0.394119	0.19706	0.131373	0.09853
Slope	0.394119	0.19706	0.131373	0.09853
Land Cover	0.394119	0.19706	0.131373	0.09853
Aspect	0.394119	0.19706	0.131373	0.09853
Elevation	0.394119	0.19706	0.131373	0.09853
Distance from major power line	0.394119487	0.197059744	0.131373162	0.098529872
Distance from main road	0.394119487	0.197059744	0.131373162	0.098529872
Weight	0.394119	0.19706	0.131373	0.09853

Distance from main road	Distance from major power line	Elevation
0.043791	0.056303	0.078824
0.043791	0.056303	0.078824
0.043791	0.056303	0.078824
0.043791	0.056303	0.078824
0.043791	0.056303	0.078824
0.043791054	0.056302784	0.078823897
0.043791054	0.056302784	0.078823897
0.043791	0.056303	0.078824

3.6. Suitable areas

The results of suitable areas for installing solar farms had obtained by applying the Weighted Overlay tool. The results were a raster model that was classified into five categories according to the degree of suitability, as shown in Figure 10, The first category with dark green color represent the Unsuitable area (0.424565 km2) while the last category is the red color class with a high level of suitability (3.075711 km2)

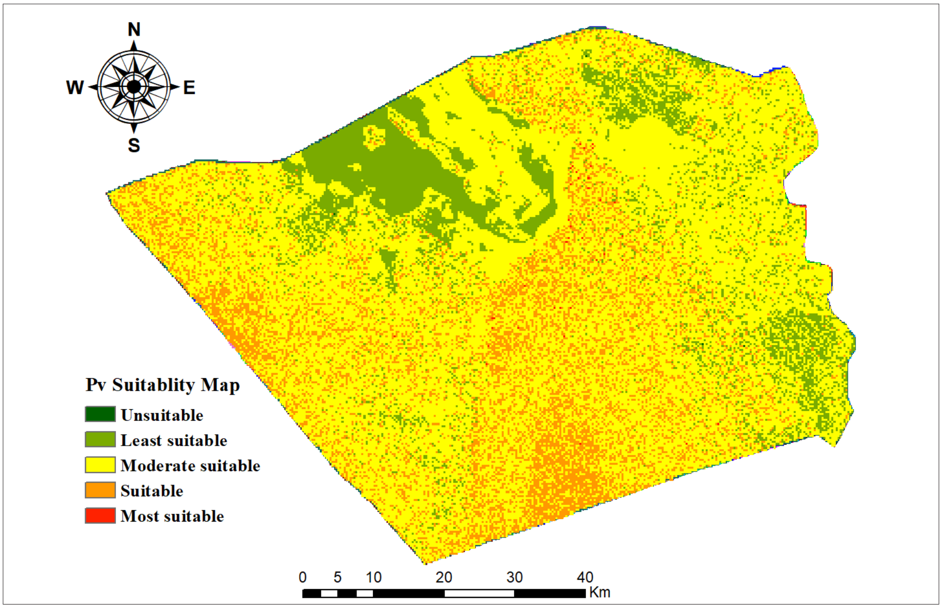

Figure 10.Results of suitable areas for installing solar farms.

Conclusion

Based on the results obtained, Karbala governorate is exposed to large amounts of solar radiation annually, which contributes to the move towards exploiting this amount of solar radiation to generate clean electric energy and reduce the environmental impacts resulting from ordinary energy sources

The results of using the solar energy project showed that the solar radiation standard, slope and type of land cover are among the most important criteria related to determining the location of solar farms

The results indicated that the most suitable areas have an area of (3.075711 km2), suitable areas (772.690359 km2) and the moderate suitable areas are (3606.027189 km2) and the least suitable area is (650.790079 km2) and finally, the unsuitable area is (0.424565 km2)

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