Land suitability for solar power plants in Karbala, Iraq using MCD and AHP-GIS

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Abstract. The attention of developed countries is turning to utilizing renewable energy sources, especially after the fossil fuel crises and environmental pollution caused by power plants, Solar cells are considered one of the main sources of energy in smart cities, which are especially focused on the roofs of houses and the unused area that provide a continuous source of energy and reduce polluting emissions to the atmosphere, solar energy is a more today's efficient renewable resource, especially in areas with high solar energy. Solar cells turn solar energy into a source of electricity for domestic and industrial use. In this study we used using geographic information systems (GIS) and remote sensing to potentially appropriate locations for solar power plants in the holy city of Karbala, Iraq, which makes religious tourism in this city the most distinctive because it is a significant religious hub that draws many visitors from both inside and outside of Iraq. Despite other historical, cultural, heritage, and tourist attractions in the province. 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 ideal land for the installation of solar cells was chosen using the Multi-Criteria Decision-Making Process (MCDA) and the Analytical Hierarchy Process (AHP). 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 parameters chosen to choose 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, Additionally, the main source of energy comes from the production of fossil fuels It is the main source of greenhouse gas emissions that have contributed to global climate change [2, 3], This has caused a focus on using renewable

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energy sources, which are generally thought of as clean and having a far smaller impact on the environment than other energy sources. [4, 5]. A renewable and supplementary energy source that is gradually displacing non-renewable energy sources is solar energy. Due to falling solar panel prices, one of the energy sources with the quickest growth is solar power generation.[6], 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[7]. 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[8]. Renewable energy is the basis of smart cities to achieve a sustainable, healthy and efficient environment by reducing emissions and pollution and reducing costs by improving energy distribution and reducing waste[9]

Remote sensing is a multi-scale and multi-temporal approach that provides important data around objects and atmosphere at or close the surface of the Earth depending on radiation that is reflected or released from certain areas or objects. Satellite or airborne sensors are used in remote sensing techniques to obtain data on particular items or regions. As a result, they are dependent on geological, biological, chemical, and/or physical characteristics [10]. All forms of data are created, managed, analyzed, and mapped by the geographic information system. It is a structured collection of applications and information created to efficiently collect, store, update, process, analyze, and present all types of spatially linked data, The broad scientific issue of land-use classification of land cover has taken on a new dimension as a result of technological advancements in the fields of remote sensing (RS) and geographic information systems (GIS), which provide timely, accurate, and high quality input for decision-making while enhancing sustainable use and conservation practices of natural resources. Large geographic areas may be covered by satellite images, which also makes field operations less complicated. Analyzing the strengths and limits of the various forms of accessible sensor data allows for the selection of suitable remote sensing data for picture categorization. Satellite imagery captured by satellite sensors can be measured, analyzed, and interpreted to classify land use and land cover.

MCDM (Multiple Criteria Decision Making) technique is employed to determine which replacements given under various parameters and varied aims are the most suited, best 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. The AHP technology includes important steps to enumerate Using the pairwise comparison technique to homogenize the impacts on the entire unit, the hierarchy process combines the elements of the pairwise comparison approach and the decision-making criteria technique to determine the weighted scores of the criterion. In a GIS context, suitability analysis is a geographic or GIS-AHP-based procedure used to assess if a specific location is suited for a given use. Every part of the landscape has intrinsic qualities that are, to some extent, either appropriate or unsuitable for the planned activities. This is the fundamental tenet of GIS suitability analysis. The typical map overlay approaches to the mapping and analysis of land-use suitability have significantly been advanced by the combination of MCDM techniques with GIS.A method that aggregates and converts spatial data into a final decision might be conceived of as GIS-based MCDA. 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.

Karbala is positioned in the Mesopotamian plain 92km away from Baghdad in the southwest route and take place 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 characterize 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 Karbala province is considered one of the important tourist sites where thousands of visitors go throughout the year for religious tourism, as the city contains the shrine of Imam Hussein and the shrine of his brother Imam Abbas, who represent great religious importance for Shiite Muslims. Karbala governorate is also considered one of the historical cities because it contains historical monuments such as (Al-Ukhaidir Fortress) and tourist places such as (razarze Lake and Ain Al-Tamr), so it is considered a destination for visitors to archaeological tourism.

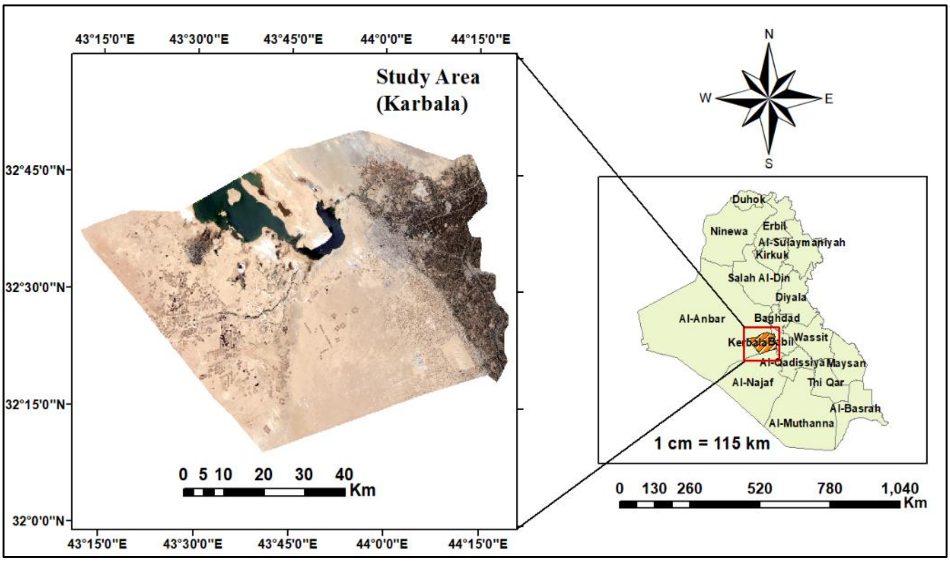

Fig. 1. Study area map.

2 Materials and Methods

2.1 Smart city and PV station

To facilitate the necessary transition to more energy-efficient cities, methodological approaches that employ alternative urban models are needed to address the expanding urbanization process and the ensuing energy demand. Maximizing the solar photovoltaic potential on appropriate rooftops and enhancing the energy balance across a smart grid are the goals of solar smart city planning. However, through integration and intensification, urban planning can play a significant role in managing energy production by utilizing solar potential on well-constructed roof and facade areas.

2.2 Data acquisition

The criteria were resulting from various data sources, including satellites, classification and websites. As shown by Table 1.

Table 1. Site criteria for installing solar power plants.

Criteria	Reference	Unit
global horizontal irradiance (GHI)	ALOS PALSAR satellite image (DEM) processed with ArcGIS	(WH/m2)
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

In order to find the best locations for solar farms in the study area, the study used a methodology based on GIS in conjunction with the AHP method. Figure 2 shows a flowchart of the methodology.

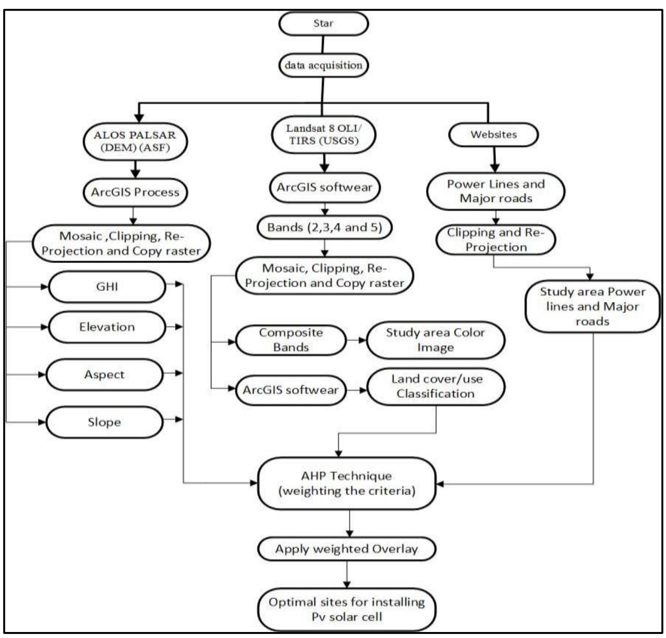

Fig. 2. Methodology flowchart for Land suitability of solar cell site selection.

2.3 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

2.4 Calculate criteria

- Global Horizontal irradiation (GHI): It represents the quantity 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 criterion 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.

Scenes	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		

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/m^2) and the values are graduated as shown in Figure 3 to reach the lowest value of 76619 (WH/m^2) (areas in yellow).

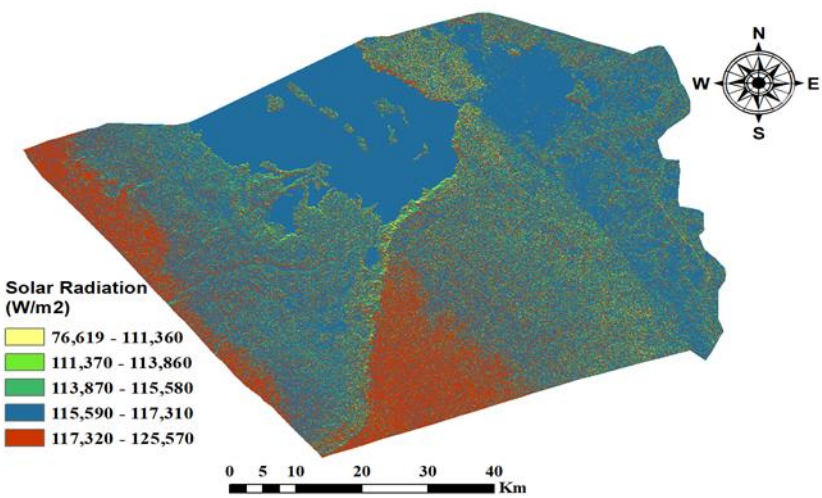

Fig. 3. Annual Solar Radiation map for Karbala 2022.

- 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).

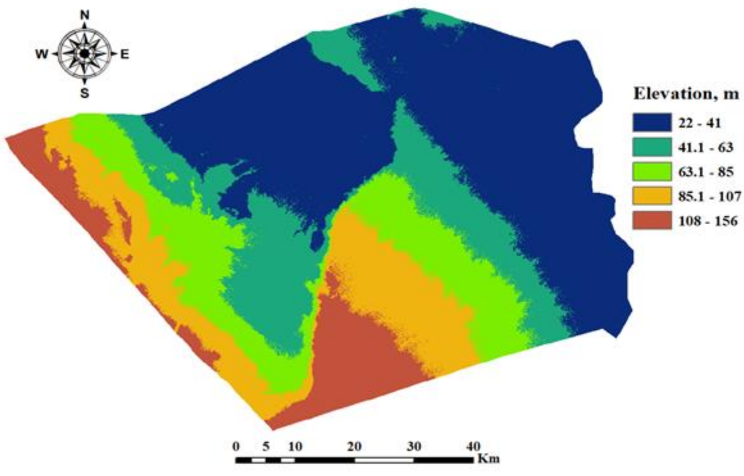

Fig. 4. Elevation values in Karbala 2022.

- Slope and Aspect

The slope is a crucial factor that needs to be properly taken care of. It illustrates how sloping or level the land is. Sitting PV solar systems are better suited to flat terrain with extremely small slopes. Because locations with extreme slopes will cast shadows on the solar panels next to them, the amount of electricity produced will be reduced. The Aspect similarly to slope indicates the steepness of the surface but with an expansion of exhibiting the direction of the slope of the surface with the accompanying angles. Although the south, southeast, and southwest directions have been selected as the most favourable for sitting PV solar power plants.

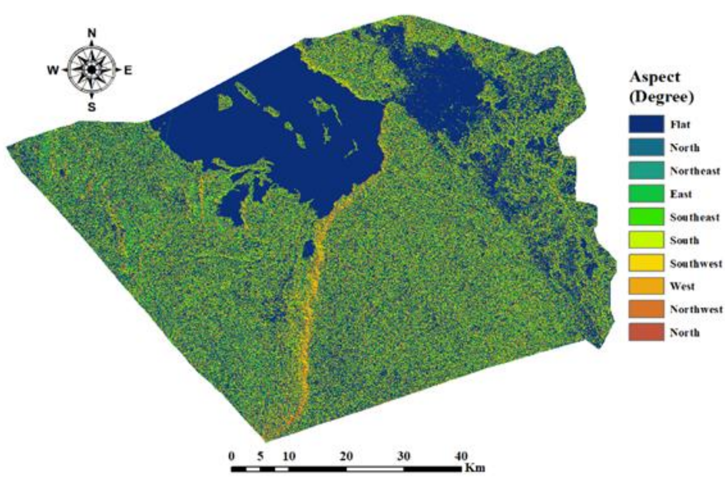

Fig. 5. Aspect map of Karbala.

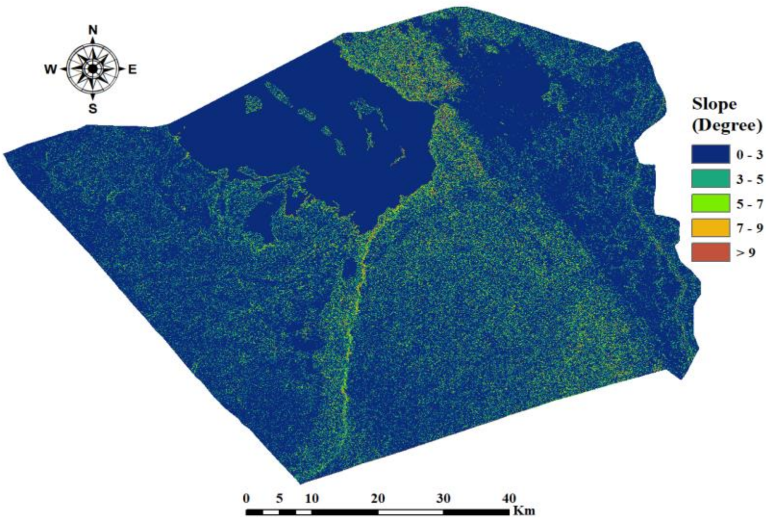

Fig. 6. Slope map of Karbala 2022.

- 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 resulting 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

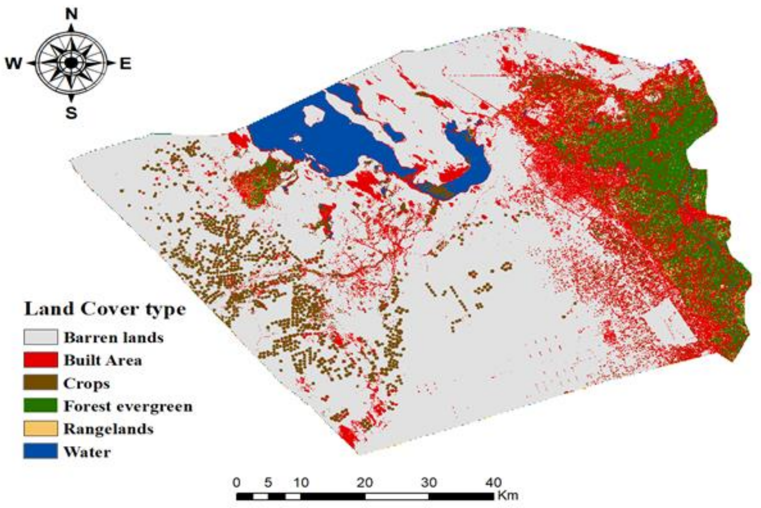

Fig. 7. Karbala Land cover Classification.

- Major roads and Power lines

Proximity to major roads and major energy transmission lines affects the cost of organization construction and the related environmental damage. Figure 8 and Figure 9 represent the map of the main roads and the map of the main power lines in order

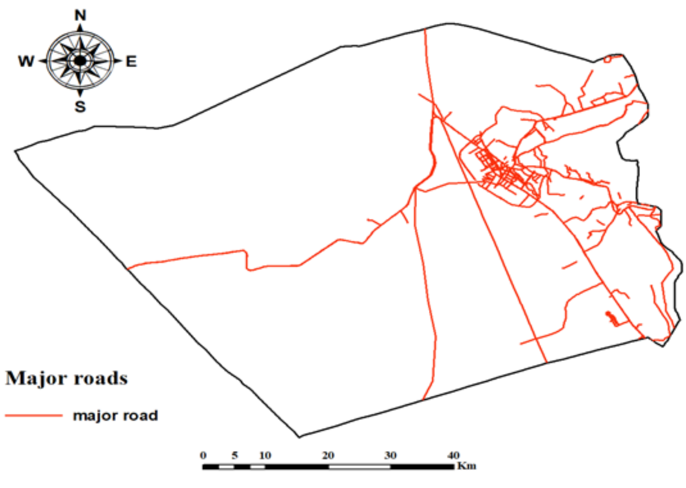

Fig. 8. Major roads Map of Karbala.

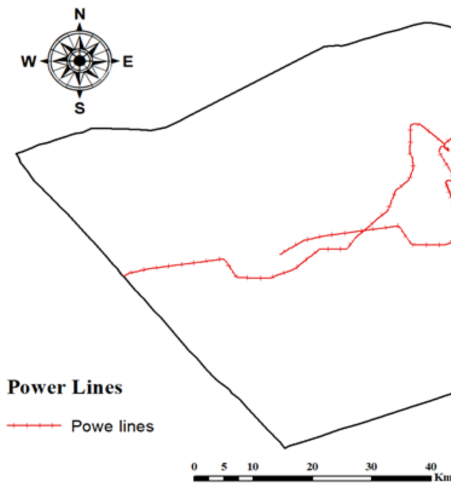

Fig. 9. Major power transmission lines.

2.5 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/m^2 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.

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 (DFP) and C7: Distance from major roads (DFR)

2.6 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.

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

With this approach, difficult choices are reduced to a series of side-by-side comparisons. By constructing an equal comparison matrix (A), the method also enables testing the decision's reasoning, which reduces bias in decision-making. as shown by equation No. 1. If n is the number of inputs, then the size of the array is n×n

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

The Matrix A is combined by dividing each column's elements by the sum of the same column's elements in order to weight each condition. The new matrix's average row value establishes the relative weights that the criterion must have. The consistency ratio (CR), a metric for assessing the consistency of the weights, is a component of the AHP. The consistency index (CI) must first be calculated before the CR can be determined. (Equation (2))

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

Where: *λmax* means the Subjective value of the pairwise comparison matrix, *n* is the number of the input criteria, The CR is ultimately determined by divided the CI by the random consistency index (RI). Saaty reported the RI values for the proper n values. To determine CR's value, Equation (3) is used.

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

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

	GHI	**Slope**	**Land Cover**	**Aspect**	**Elevation**	**DFP**	**DFR**
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
DFP	0.142857	0.285714	0.428571	0.571429	0.714286	1	1.285714286
DFR	0.111111	0.222222	0.333333	0.444444	0.555556	0.777777778	1

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

	GHI	Slope	Land Cover	Aspect	Elevation	DFP	DFR	Weight
GHI	0.394119	0.394119	0.394119	0.394119	0.394119	0.394119487	0.394119487	0.394119
Slope	0.19706	0.19706	0.19706	0.19706	0.19706	0.197059744	0.197059744	0.19706
Land Cover	0.131373	0.131373	0.131373	0.131373	0.131373	0.131373162	0.131373162	0.131373
Aspect	0.09853	0.09853	0.09853	0.09853	0.09853	0.098529872	0.098529872	0.09853
Elevation	0.078824	0.078824	0.078824	0.078824	0.078824	0.078823897	0.078823897	0.078824
DFP	0.056303	0.056303	0.056303	0.056303	0.056303	0.056302784	0.056302784	0.056303
DFR	0.043791	0.043791	0.043791	0.043791	0.043791	0.043791054	0.043791054	0.043791

2.7 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 km^2) while the last category is the red color class with a high level of suitability (3.075711 km^2). The presence of more than one Suitable site for the installation of solar photovoltaic power plants near the Holy Shrine, which can supply the electric power grid with energy, especially that it receives thousands of visitors throughout the year and millions of pilgrims on the anniversary of the Arbaeen.

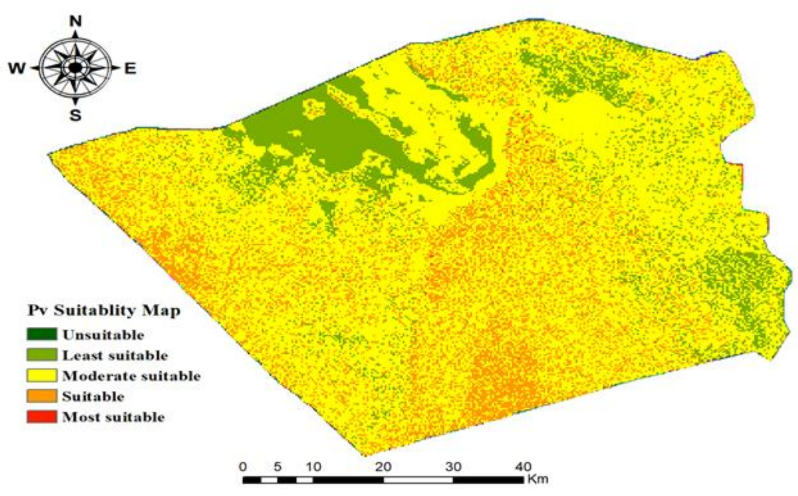

Fig. 10. Results of suitable areas for installing solar farms.

3 Results and conclusions

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 km^2), suitable areas (772.690359 km^2) and the moderate suitable areas are (3606.027189 km^2) and the least suitable area is (650.790079 km^2) and finally, the unsuitable area is (0.424565 km^2).

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