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Estimate Suitable Location of Solar Power Plants Distribution by GIS Spatial Analysis

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Abstract

This study proposes a model for the best investment in renewable energy plants that uses DEM, Spatial Analysis, and analysis of indicator weights by AHP to choose a suitable place to locate the solar plants, which increases their efficiency. This is because renewable energy is the most important component of future sustainability. In addition, the cities of Iraq, including Babylon, have increased the proportion of the population, which has led to high rates of urbanization and a lack of services. In particular, the need for services increased, especially electric power, which is characterized by its inefficiency and insufficiency. Yet, the governorate is a good source of solar energy and regular radiation. Therefore, the trend to use renewable energy is the optimal solution, and this manuscript proposes multiple criteria that can determine the optimal locations for building solar energy farms. So methods of analysis are the Digital Elevation Model (DEM), the slope of the earth, efficient distances from the city center, the main road networks and electricity distribution networks, and average solar brightness (hours/day) quantity. Finally, the spatial analysis of all indicators shows eight sites. By using criteria of analysis based on AHP analysis, the result is that six represent suitable sites chosen as sufficient space to locate solar plants. Consequently, the results of this manuscript for solar energy collection projects show percentages ranging between 2% and 37%, with areas starting with 10 km^2 and gradually rising towards the largest proposed area of 155 km^2, distributed over the province so that the total proposed areas for solar energy collection projects will be about 422 km^2. All that aim to achieve the best service in quality and quantity of renewable energy to establish sustainability and efficiency economic modeling in addition to increasing production efficiency.

Keywords: Spatial Distribution; Solar Power Plants; Suitability Location; GIS; AHP.

1. Introduction

Climate change is one of the most critical challenges of the present time. It represents the interests of all developed and developing countries, Individual international texts like the report of the International Panel on Changes in Climate. It is also a goal of sustainable development. Yet, the environmental problems resulting from the emission of carbon dioxide are serious and have a direct impact on climate change [1–3]. Iraq is one of the nations threatened by climate change, according to a conference of the UN [4]. Therefore, it has become necessary to think about renewable energy because it is one of the focus areas for sustainable future life due to its inexhaustible and important properties. Presently, renewable energy replaces many types of fossil fuels and mainly relies on renewable natural resources that was less polluting to the environment and more durable [5-8]. Many advantages make it promising for the future. In addition to its importance in preserving the environment, Renewable energy is less expensive than energy produced from fossil fuels while the expenses are limited to the tools and equipment used and maintenance costs [9].

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Renewable energy will contribute to preserving the ecosystem by reducing emissions at the local and global levels. Our study is important because of solar energy, which is it available in Iraq almost throughout the year. According to radiation, it is one of the indicators for the analysis. Due to the large number of studies that dealt with clean energy in terms of environmental and economic aspects, our study indicates that determining the appropriate location is more efficient and less costly. It represents the knowledge gap that the paper will address [10–13].

The problem appears in the following question: Is it possible to locate the appropriate spatial analysis of solar energy construction to achieve the highest efficiency in generating electricity from renewable energy in the environment of Babylon Governorate?

*Hypothesis***:** Can appropriate spatial selection of solar energy by several criteria elements achieve the highest efficiency in generating electric power from renewable energy in Babylon Governorate?

Importance of the study: The research attempts to build an analytical model by analyzing several spatial analysis criteria to achieve the highest efficiency in supplying electrical energy from solar energy applied anywhere in the world.

2. Renewable Energy Sources

Burning fossil fuels is one of the most important factors that change the Earth's climate and lead to rising greenhouse gas emissions, which increase the average temperature all over the world [14].

Therefore, the worldwide trend is to increase the usage of renewable energy at the expense of fossil fuels in order to combat the threat of climate change. For this reason, many nations have backed the utilization of renewable energy via research and development to lower carbon emissions as well as overall use of renewable energy sources to lower the price of utilizing these energy sources and increase their efficiency [15, 16]. This is what prompted us to write this manuscript. There may not be a single solution to the energy needs of the community. Yet, there is a set of integrated technologies to meet these needs and the community's need for clean energy resources in its area and to develop plans to achieve energy sustainability accordingly [17]. Therefore, in the present investigation, seek to provide energy power totally with percentage net utilizing solar energy.

2.1. Solar Energy

Solar energy is the energy generated from sunlight, and it is also possible to convert sunlight into other forms of energy using multiple conversion processes. For example, solar energy can be converted to generate electrical or thermal energy with photovoltaic cells or photothermal transfer agents [18]. Solar energy technologies mean the design and construction of systems that collect and convert solar energy into another form of energy that can be used for applications like industrial, commercial, residential, and other purposes [19]. Solar energy utilization will soon be a reality and could provide people a way to live sustainably in the decades to come.

2.2. Solar Radiation

The main source of energy in the atmosphere was solar radiation, from which 99.98% of energy comes from it that has been exploited on the surface of the earth [20]. The main differences that occur from one place to another are in the availability of solar energy. Due to this, the Earth's orbit is circular in form as its center variation is smaller than 0.01675.

In another word, an amount not exceeding 1.65% must exist to detect a simple shift in the distance around our planet and the solar system. Early January is the shortest period while late July shows the maximum of this region. The angular diameter transforms from (31′ .25) to (32′ .30). When, the planet's orbit reaches and arrives away from the solar system. As a result, there exists a little variation in the amount of illumination the sun transfers that is believed to be 3.3%, nearly a full percentage seen over a distance [21].

3. The Practical Aspect

3.1. Case-Study (Babylon Governorate)

Babylon is one of the provinces of the Middle Euphrates. Its geographic area is limited between the two latitudes (32° 7′–33° 8′) north and between the longitudes (45°42′–45°50′) east. It is adjacent to the provinces of Baghdad, Wasit, Al-Qadisiyah, Al-Anbar, Karbala, Al-Naja). The governorate looks like a triangle with the base to the south, and the governorate's land narrows in its northern parts. As for its longitudinal extension from north to south, it is 120 km, and its area is 5,119 km^2, as shown in Figure 1 [22, 23].

3.2. Solar Brightness in Babylon Governorate

The Babylon Governorate receives a large amount of solar radiation, and this quantity varies between theoretical solar radiation and actual solar radiation. Table 1 and Figure 2 show that the annual average of theoretical solar brightness hours is 7.1 hours/day. Also, the duration of theoretical solar luminosity varies in Babylon between the months of the year, where it recorded the highest monthly averages of theoretical solar radiation in the months (March, June, and July), which amounted to 5.13, 14, and 2.13 hours/day, respectively. As for the lowest monthly averages of theoretical solar brightness, from November and December, about (10 hours/day) for each month, as shown in Table 1 and Figure 2.

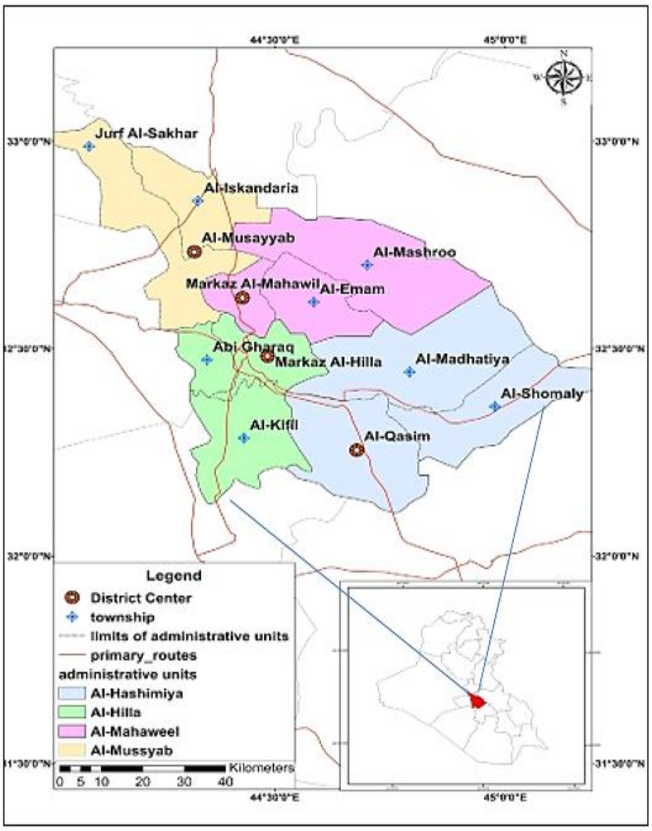

Figure 1. The location of Babylon Governorate and its districts. By Arc GIS 10.8

Table 1. Monthly and annual averages for theoretical and actual solar brightness (hours/day) in Babylon Governorate from (1988-2017) [24]

Months of the year	Actual solar brightness rate (hour/day)	Theoretical solar brightness rate (hour/day)
January	6.1	10.1
February	7	11
March	7.7	12
April	8.3	13
May	9.2	13.5
June	11.4	14
July	11.3	13.2
August	11.2	12.2
September	9.9	11.2
October	8.2	10.3
November	6.9	10
December	6	10
Annual Rate	8.6	11.7

The annual averages of actual solar radiation in Babylon province were 6.8 hours/day, and the duration of the actual solar brightness varies between the months of the year in the province, where the highest averages were recorded during the months (June, July, and August) at averages of 4.11, 3.11, and 2.1 hours/day, respectively. The reason for this is due to the incidence angle of the sun's rays being vertical or almost vertical.

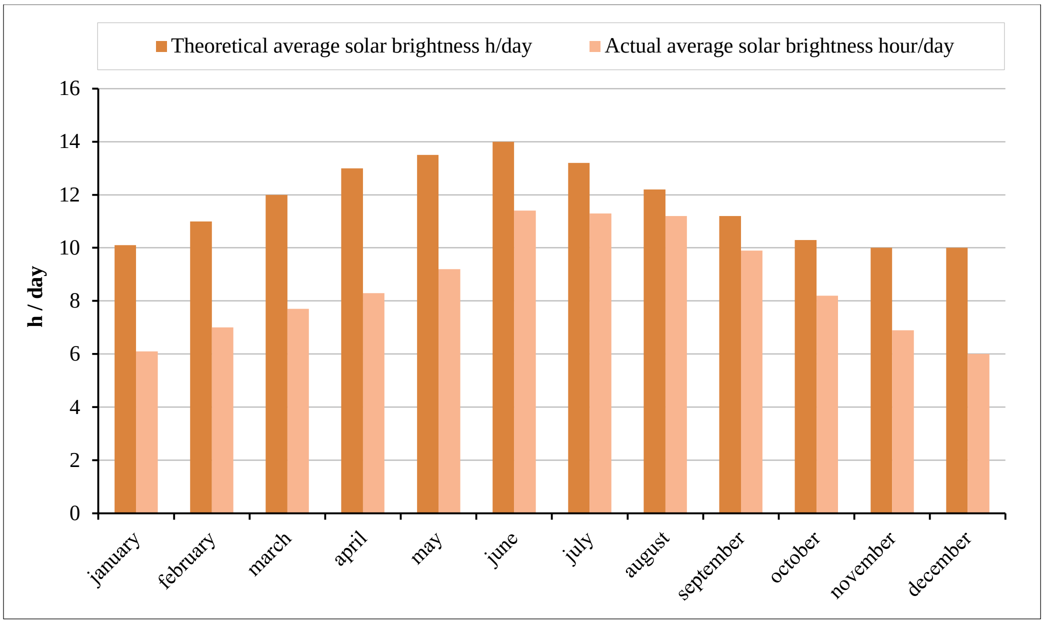

Figure 2. Monthly and annual averages for theoretical and actual solar brightness (hours/day) in Babylon Governorate form (1988-2017)

3.3. Analysis and Observations

This manuscript used GIS to analyze the case study, which depends on sources for data processing. The primary data was:

- Digital Elevation Model (DEM);
- Topographic Figures of Babylon Province;
- Data on solar radiation;
- Electricity network distribution Figure.

Digital Elevation Model (DEM) indicates that Babylon Province is one of the plains, which is flat in most of its areas, with elevations in the north of the governorate. It crosses the end of the region to the wavy area and the start of the alluvial plain area, which is characterized by its lowness and flatness (Figure 3).

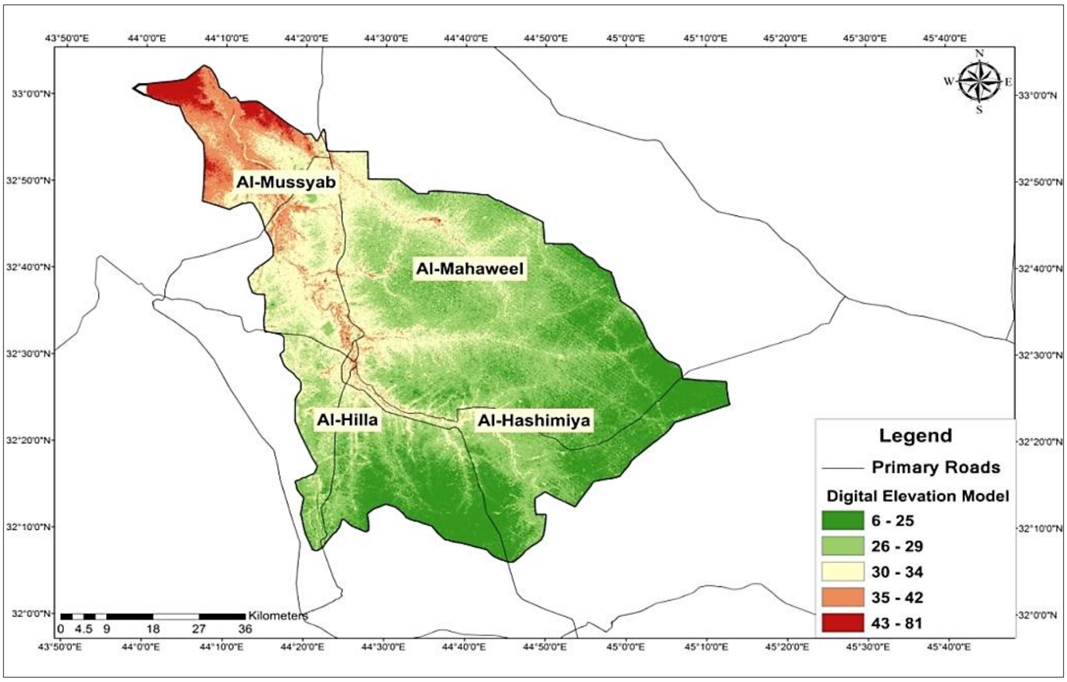

Figure 3. The ground levels in Babylon based on DEM STRM3 data by Arc GIS v.10.8 program

Land elevation values in Babylon Province are mostly lower. The reason was that the province is located in the Euphrates basin. It is characterized by equanimity and a lack of individual elevations from the south-eastern side, with elevations from 43–81 due to undulation. The region borders Babylon Governorate from the north. After knowing the height values of the land, it must be exploited to find out the trends of the land and the degree of slope for Babylon Governorate, as it was found that the degree of slope ranges between (0-0.7) as shown in Figure 4.

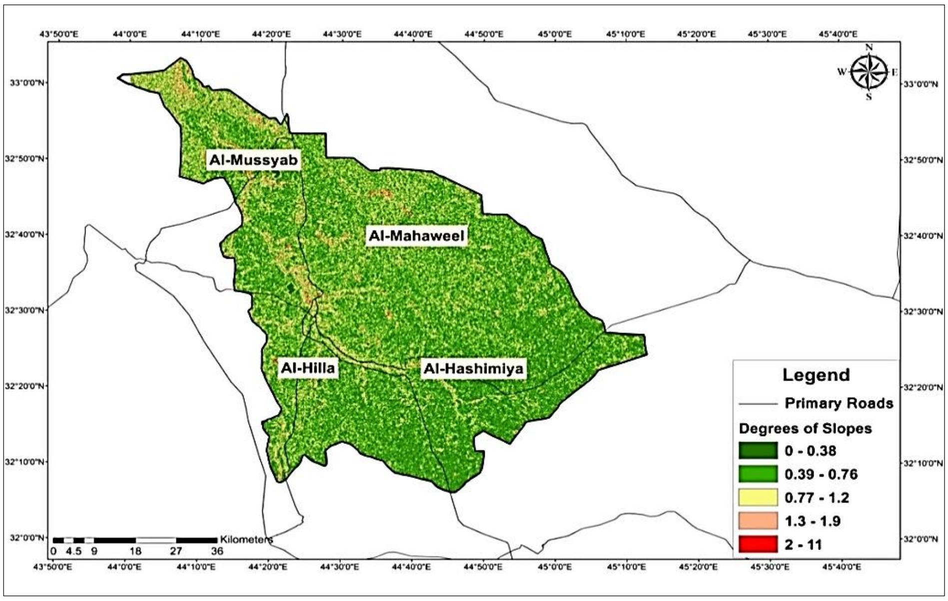

Figure 4. The slopes of the earth's surface in Babylon Governorate. Based on DEM data by Arc GIS 10.8 program

The degree of slope in Babylon province ranges between 0-0.75, and this is considered an advantage for the lands of the province, where it will not constitute an obstacle to the establishment of projects that need appropriate slopes. It is almost flat land to suit the standards established for the planned project. Also, a set of topographic figures and multiple satellite visuals were used in numbering several linear layers representing the locations of the road network, major cities, and electricity distribution lines as shown in Figure 5.

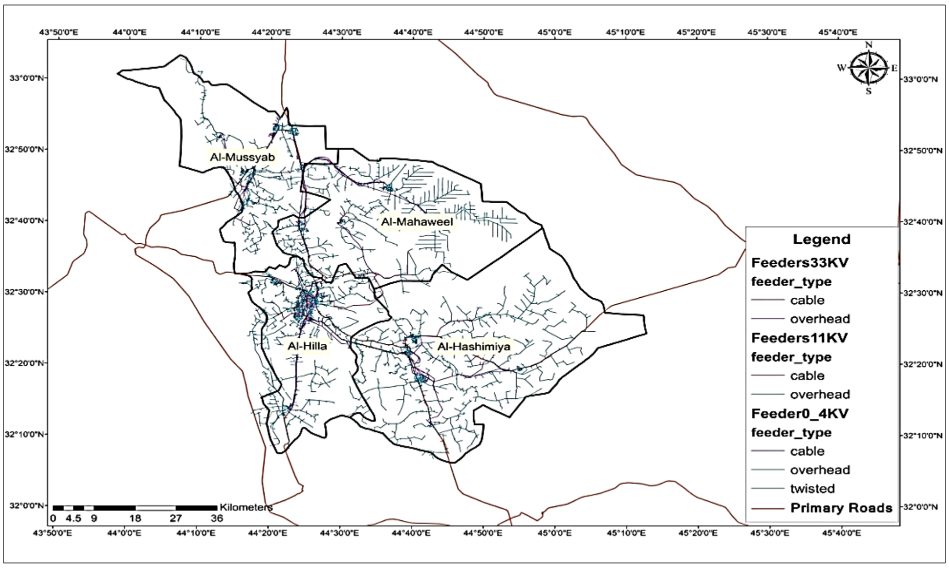

Figure 5. The electricity distribution network and the main road network in Babylon

The figure shows the types of electric power transmission lines, lifting stations and lowering stations, as well as high-voltage and low-voltage feeder paths, and the types of cables that transmit them, which are underground or by high towers. As for the amount of solar radiation, it was done using the tool of solar radiation on altitude layers in the Arc GIS 10.8 program (Figure 6).

In Figure 6 of the spatial variation for the average degrees of solar radiation in Babylon Governorate, there is a balance in the average radiation due to the proportion of the slope that was characterized equally in most parts of the Governorate, which made the sun's rays be equal.

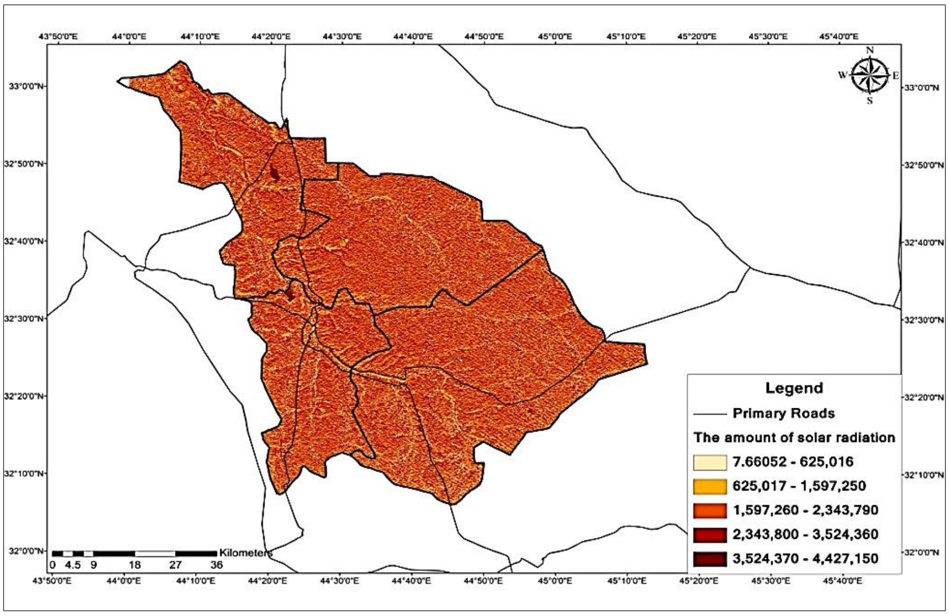

Figure 6. The solar radiation for Babylon province. By Arc GIS 10.8 program

3.4. Spatial Suitability of Solar Power Plants

Three criteria were adopted; the first one was the technical criterion that amounted to solar radiation. Secondly, inclinations to the surface of the governorate affect the equipment and the installation of devices and equipment necessary for the project. Third, a greater amount of energy will be lost during the transmission process by the electricity distribution network, as will the cost of energy transmission. Taking into consideration the environmental aspect represented in the criterion of distance from city centers as a basic matter, the distance from major roadways is an important factor while choosing the most suitable sites for renewable solar energy sources [23]. A set of technical and economic criteria has been selected (Table 2), specifying two criteria to prevent locating these projects inside metropolitan areas or on agricultural lands, that must be available in the most suitable sites for solar energy projects. The relative weights were determined to elements of criteria as shown in the last column of the table. In Figure 7, for each of the stated criteria, a network layer reflecting the categorization of the criterion's values into categories was developed, and the data processing procedures included reclassifying each category's values through certificates on a scale that ranged from (1 -10) for efficiency of analysis and purpose. It then applied the specified weights (Equation No.1) to arrive final fit model. Figures 8 and 9 give examples of categorization layers for the criteria that were derived from distances to the major cities, the electrical grid, and the principal transportation network.

Table 2. Criterion for identifying the best locations for solar power plant collecting

Standard Type	Standard	Categories	Weight
Technical	Solar radiation	>8 6-8 4.5-6 <4.5	High Medium Low Not suitable
	Earth's surface inclination in (degree)	0-3 3-5 5-10 >10	High Medium Low Not suitable
	Distance from the electricity distribution network	0 – 5 5-10 10 – 12 >20	High Medium Low Not suitable
Economic + Environmental	Distance from the road network	<5 >5	Suitable Unsuitable
	Distance from cities center	<5 >5	Suitable Unsuitable
Technical	Residential Compounds Boundaries	-	Unsuitable
	Agricultural lands	-	Unsuitable

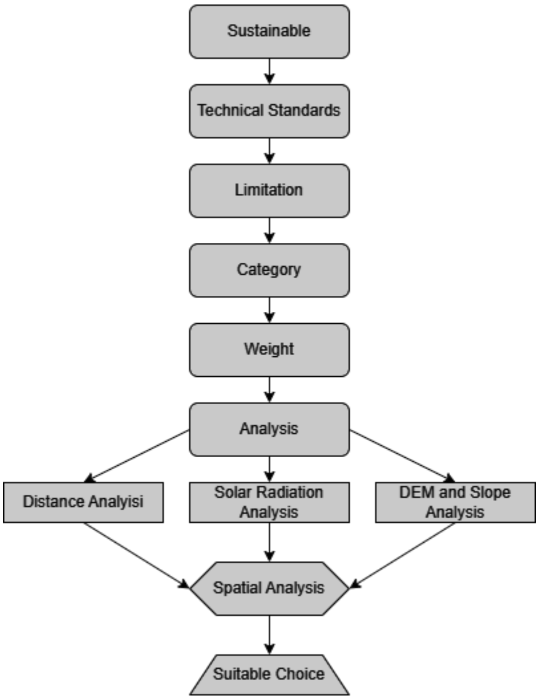

Figure 7. The methodology for preparing the used database: Depending on weights, the appropriate weights

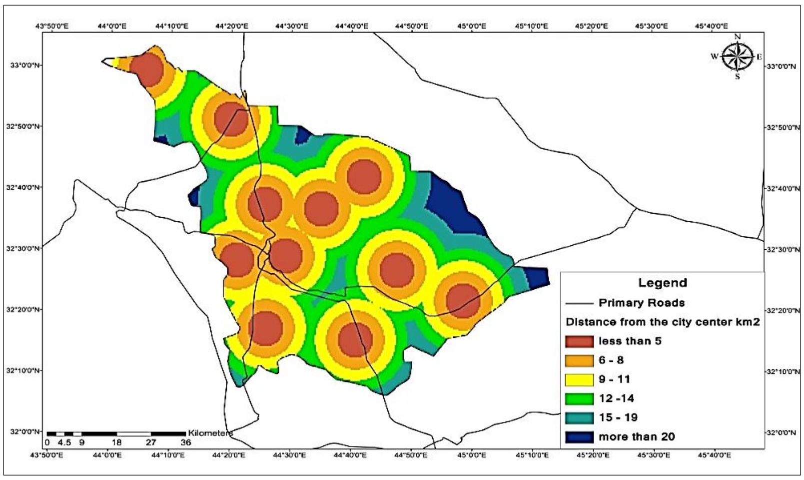

Figure 8. The zones from cities center in six classifications by distance

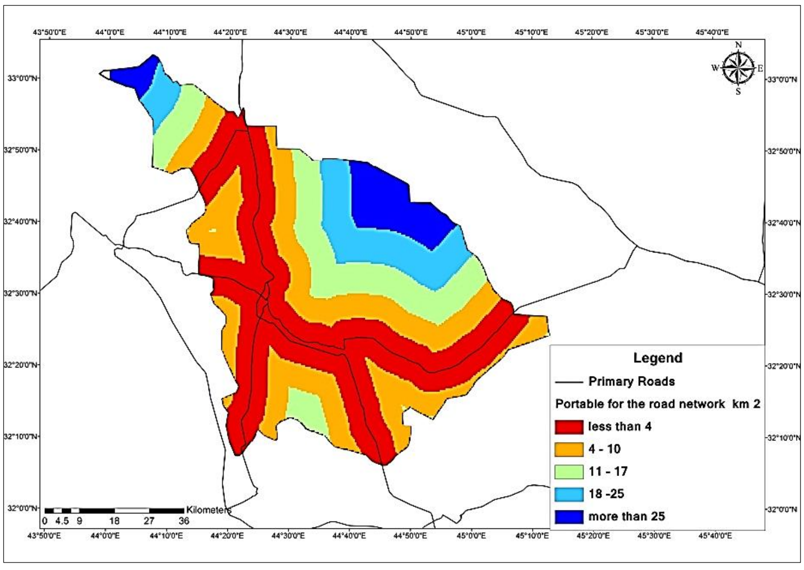

Figure 9. The zones to distance from the main roads

The appropriate weights were determined for each of the above-mentioned criteria. They are illustrated by the following [25–29] . Mathematical equations present the calculated weights to choose the appropriate weights:

$$S = \sum_{i=1}^{n} {w_i x_i}/{\sum w} \quad (1)$$

where S is suitability coefficient, W_i is weight per standard, X_i is standard coefficient number i, and n is the number of applicable standards.

According to the environmental and economic standards of analysis of distance from the city center, the red zones are inappropriate where they are less distant from the city center. Then the orange color, which is also inappropriate but to a lesser extent, may require the use of it with strict precautions. After the yellow zones, which are appropriate, the green zones are considered appropriate zones. The project may be resorted to if the rest of the criteria are met. Finally, the blue zones presented the best areas to construct the project.

The distance from the main roads is one of the important criteria because it is related to the cost of transportation and the subsequent losses. In this issue, the red zone with a distance of less than 5 km is considered one of the best places to reduce transportation and other costs. It is followed by the orange zones with a good advantage, and then the green zones may be appropriate, but with an increase in the cost and loss ratio with each scale because of the inverse relationship between the distance from the main roads, transportation costs, and distance from the market.

To reclassify the tool, every element of criteria is converted to a new layer representing the spatially suitable zone, as shown in Figures 10 to 15.

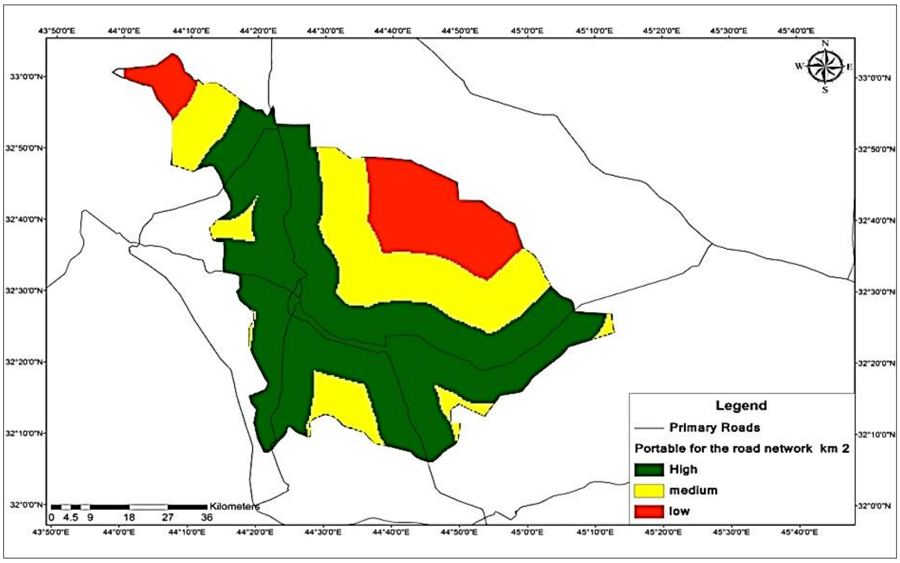

Figure 10. The adequacy of the road network in km²

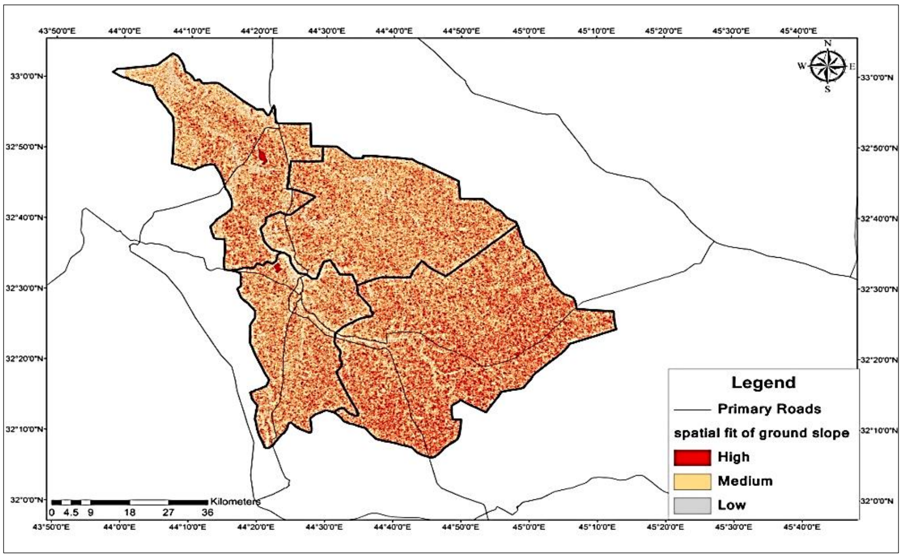

Figure 11. The suitability to the slope of the ground

In order to obtain the best site for collecting solar cells, it is necessary to process the data and make models that are combined according to the appropriate equations to get the proposed areas (Figure 10). We find the degrees of suitability for the distance from the main road network, and its priority is the green color because it has the best suitability, followed by the yellow band, and the last is the red color, which is considered to be of low suitability. The suitability of the tendencies of the earth's surface is very important (Figure 11). The inclinations of the earth are of great importance in determining the optimal location of the project without the occurrence of future risks or problems, in addition to the application of previously prepared conditions and standards. We find that most of the governorate's lands possess a high degree of suitability, which makes establishing a solar cell assembly project possible.

The distance from the city center is suitable (Figure 12). The suitability ranges from places with poor weight and gray color that do not match the standard and have a significant negative impact and risks that cannot be treated. It is considered outside the suitability scales due to the brown color, which is good within the criteria analysis.

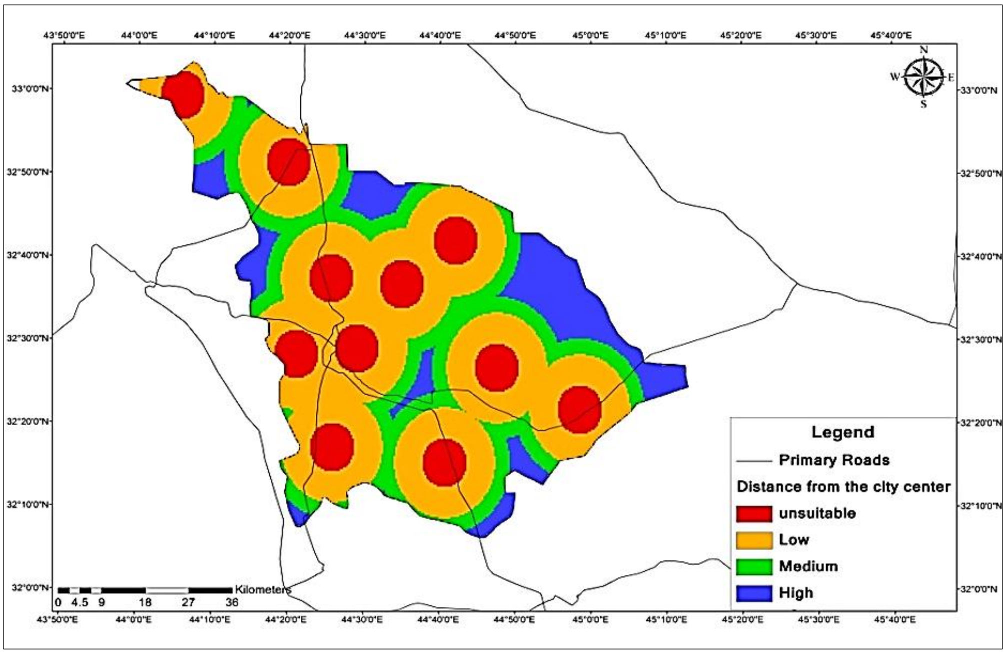

Figure 12. The suitability of distance from the city in km²

The study area is characterized by balanced solar radiation in most of its areas (Figure 13). Because of the few areas with strong solar (red) radiation, places with medium suitability are the optimal places.

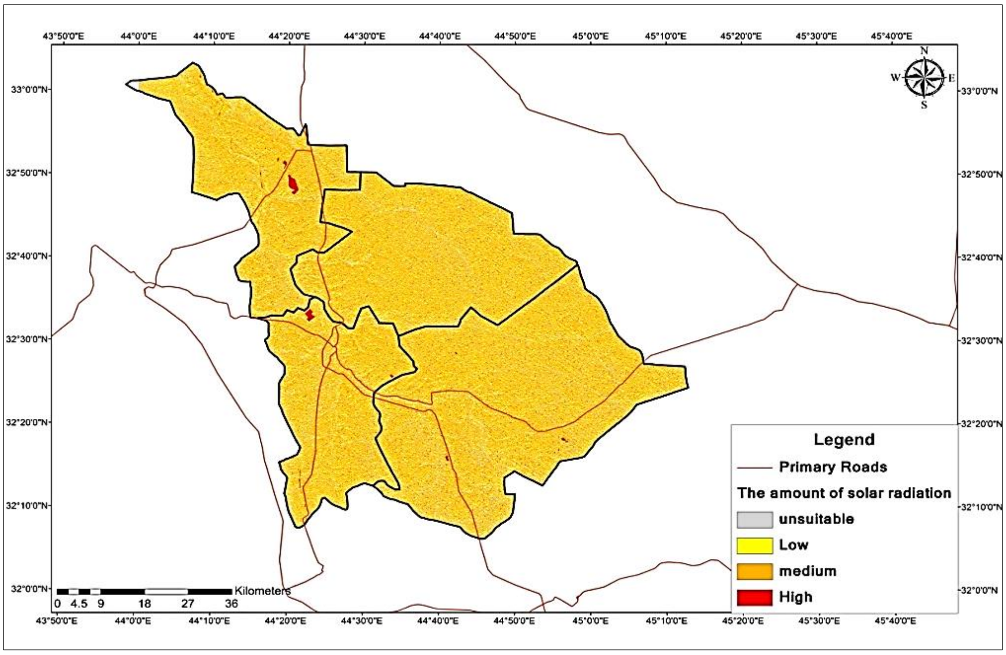

Figure 13. The solar radiation analysis

Finally, by analyzing all the models after installing them all to find the appropriate site, the result is as shown in Figures 14 and 15. Then the location was analyzed in the field through the site criteria to achieve the suitable area for Solar Power Plant.

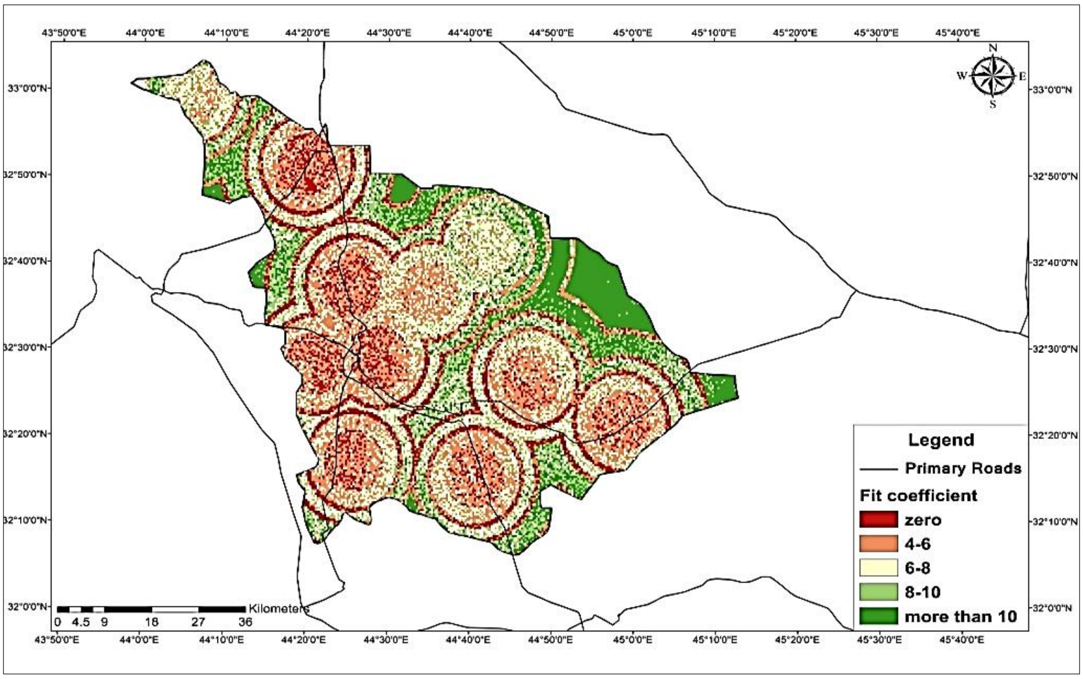

Figure 14 . The suitability factor for solar collecting stations

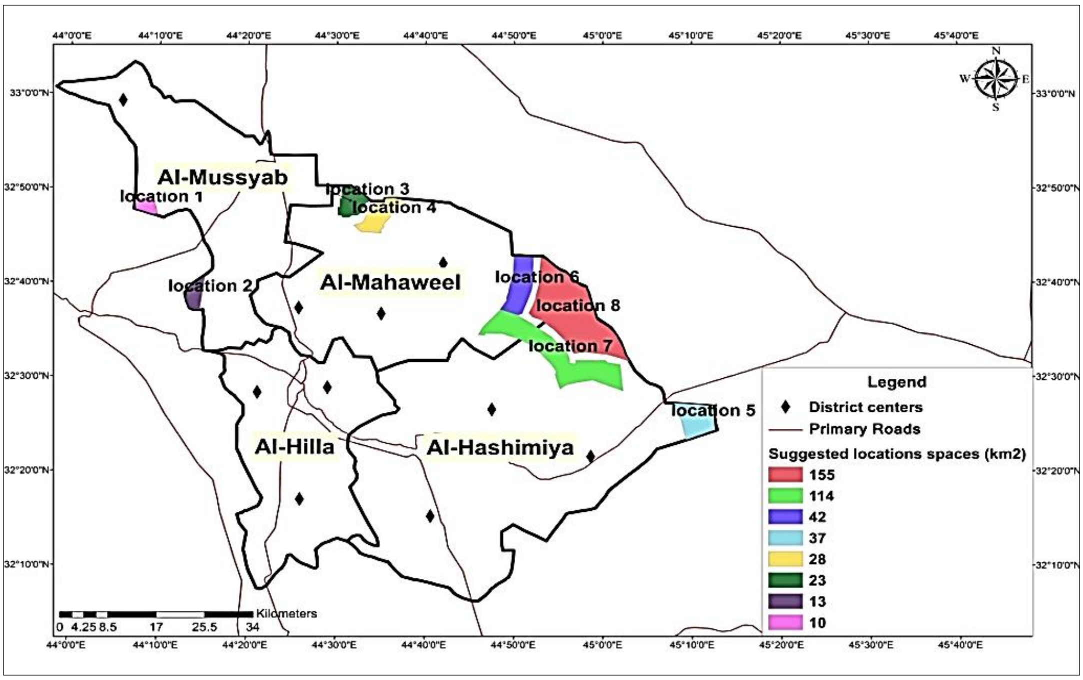

Figure 15 . The result of proposed areas for Solar Power Plants

Based on the data analysis steps and the weights for each of the criteria, we confirm the availability of spaces suitable to a very high degree for the establishment of photovoltaic power generation projects after the models were subjected to spatially appropriate equations. Yet the small areas that could not be used for the solar energy collection project were neglected. We see the availability of six sites with areas starting at 10 km^2 and ending at 155 km^2, bringing the total proposed area to 422 km^2 (Figure 16).

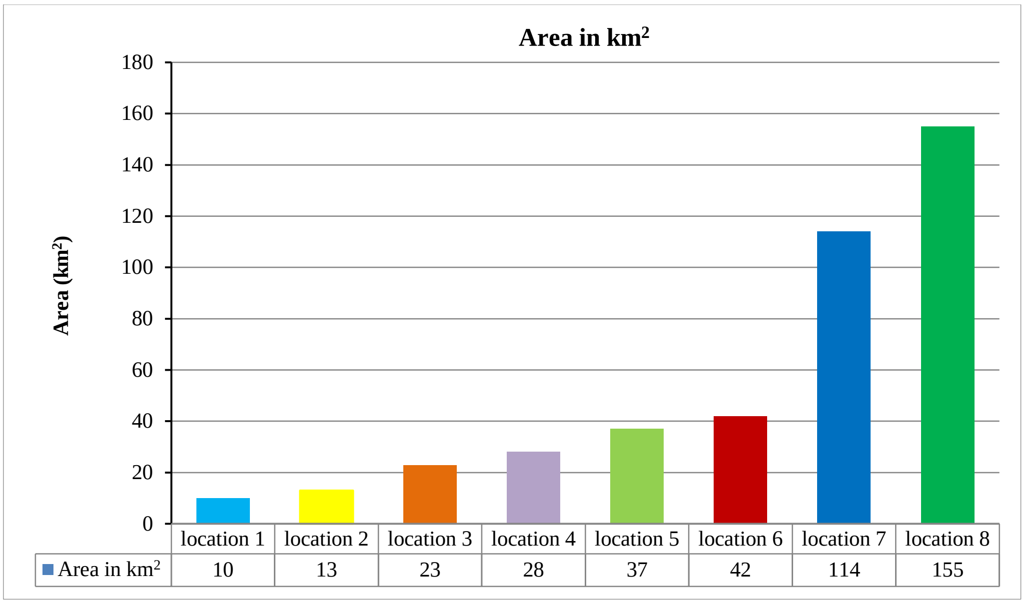

Figure 16. The areas of the proposed sites for the solar panel assembly project

4. Conclusions

The study concludes with the following:

- Spatial analysis in GIS can produce suitable areas with a high degree of efficiency and sufficiency to set up solar power plants. This work showed six sites produced with areas starting from 10 km^2 and ending with an area of 155 km^2, bringing the total proposed areas to 422 km^2, and from 2% to 36% of the total suitable area.
- Each city has its own advantage in the spatial distribution, so the results of the spatial analysis must be subjected to a field survey and a descriptive analysis.
- The economic importance of the location and the difficulty and exorbitant costs resulting from choosing the wrong place necessitated working within more than one analytical pattern, which prompted this paper. The study included spatial analysis with GIS based on a number of criteria and weights in addition to field surveys and descriptive analysis to choose the best site as a pressure for costs in addition to raising the production efficiency of solar power plants.
- The study relied on several criteria for spatial analysis, such as the distance from the city center, the slope of the land, the distance from the main roads, and the distance from the electricity network, as criteria for choosing the best location on the basis of choosing the highest appropriate weights for each criterion to achieve the best spatial analysis for choosing the locations of solar power stations.
- In addition to the expertise, large numbers of people can contribute to the operation of the solar cells that can be invested in generating electric power. However, the lack of maintenance requirements and the neglect of holding conferences and training workshops prevented the experienced people from being able to take the right direction in the projects of generating electric power by solar radiation.
- There is no clear strategic vision in Iraq, the exploitation of natural resources that are abundantly available in Iraqi lands, especially in the Euphrates basin.
- Iraq possesses sufficient natural ingredients to invest solar radiation in generating electrical energy in the proposed geographical location of solar radiation and in the angle of incidence for solar rays.
- Babylon Governorate faces a significant shortage of renewable energy supplies necessary for the continuation of life, as it is considered one of the governorates that suffer from poor management, equipment, and project organization, in addition to neglecting its nature and societal components.

4.1. Recommendations

This work recommends:

- Identifying suitable locations that receive large amounts of radiation in the city is the most important indicator that makes the selection of electric power generation projects using solar cells more efficient.
- The adoption of solar energy in electricity supply in Iraq is available throughout the year, and radiation rates are relatively high with a strong amount of solar radiation. By providing energy from multiple sources without relying on a single source.

- Shed light on renewable and clean energy to increase efficiency by choosing a suitable location in the city. It does not have pollutants that may negatively affect the surrounding environment and creates a healthy environment free of pollution.
- Spreading propaganda in the written, audio, and social media about the necessity of investing in solar cells, especially for the private sector, compensates for the shortfall and deficit in the hours of processing the national network. Also, awareness among citizens of the need to preserve and protect these solar cells needs to be raised.
- Providing technical and scientific expertise and skills related to the manufacture and management of solar energy cells through the establishment of workshops, seminars, and training conferences with countries helps to deal with solar panels, benefit from their expertise, and avoid problems that may be encountered.
- Developing plans that include a vision for the use of renewable energies contributes to the provision of electric power to remote areas far from generation and distribution stations.
- Factories and laboratories with high pollutants, especially in cities, are recommended to provide their energy needs from renewable energy sources.

5. Declarations

5.1. Author Contributions

B.A.B. and S.R.A. contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

Data sharing is not applicable to this article.

5.3. Funding

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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