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# The Optimum Site Selection for Solar Energy Farms using AHP in GIS Environment, A Case Study of Iraq

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**Abstract**

Recently, renewable energy (RE), such as solar energy, sources have proven their importance as an alternative source of fuel. The utilizing of solar energy can contribute to move the world towards relying on clean energy to curb global warming. However, the placement of solar farms is a major priority for planners as it is a critical factor in the succession energy project. This study combines one of the multi-criteria decision-making techniques Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) to assess the suitability of land for establishing solar farms in Iraq. Numerous climatic, geomorphological, economic, and environmental criteria and some exclusionary constraints have been adopted in modeling process. It is supported by expert knowledge and a comprehensive literature review. The results showed that approximately 19% of the study area are optimal areas for installing solar farms. The southern, southeastern, and a few western regions obtained the largest part of the suitable lands. Furthermore, this approach can be adapted easily to cover different criteria and different weights in order to assist planners in deciding solar farm locations.

**Keywords:** GIS; Multi Criteria Decision Making; AHP; Solar farm; Site Selection

# اختيار الموقع الامثل لمزارع الطاقة الشمسية باستعمال عملية التحليل الهرمي في بيئة نظم المعلومات الجغرافية، العراق كمنطقة دراسة

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**الخلاصة**

في الآونة الأخيرة ، أثبتت مصادر الطاقة المتجددة مثل الطاقة الشمسية أهميتها كمصدر بديل عن الطاقة الناجمه من حرق الوقود الاحفوري. يمكن أن يساهم استعمال الطاقة الشمسية في دفع العالم نحو الاعتماد على الطاقة النظيفة للحد من ظاهرة الاحتباس الحراري. ومع ذلك ، فإن وضع المزارع الشمسية يمثل أولوية رئيسية للمخططين لأنه عامل حاسم في نجاح مشاريع الطاقة. تجمع هذه الدراسة بين إحدى تقنيات اتخاذ القرار متعددة المعايير (Analytical Hierarchy Process) وأنظمة المعلومات الجغرافية (GIS) لتقييم الأرض

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الملائمة لإنشاء مزارع شمسية في العراق. تم تبني العديد من المعايير المناخية والجيومورفولوجية والاقتصادية والبيئية وبعض القيود الإقصائية في عملية النمذجة. علاوه على ذلك، تم دعم المعايير بمشورة الخبراء ومراجعة شاملة للأدبيات السابقة. أظهرت النتائج أن حوالي 19٪ من مساحة الدراسة هي مناطق مثالية لتركيب مزارع الطاقة الشمسية. حصلت المناطق الجنوبية والجنوبية الشرقية وعدد قليل من المناطق الغربية على الجزء الأكبر من الأراضي المناسبة. بالاضافه الى ذلك يمكن تكييف هذا النهج بسهولة لتغطية معايير مختلفة وأوزان مختلفة من أجل مساعدة المخططين في تحديد مواقع المزارع الشمسية .

## 1. Introduction

1.1. Overview

The various energies available in nature are the main artery of the economy of countries all over the world. For decades, the focus has been on fossil fuels in the production of 80% of human primary energy needs. However, the global stock of fossil fuels is running out and its production costs will be the highest in the future. In addition, energy production from fossil fuels is the largest source of greenhouse gas emissions into the atmosphere that have caused global climate change [1], [2], [3], [4]. Today, the global trend to take advantage of renewable energy, especially solar energy, is increasing due to its potential to solve many economic and environmental problems. According to estimations by the International Energy Agency (IEA), 11% of the world's electricity will be produced using solar energy by 2050. This step depends on the number of countries that encouraging plans to develop solar energy in the future [2], [5]. Therefore, there is an urgent need for human societies to learn about renewable energies and harness them.

Solar farms are one of the clearest examples of renewable energy available throughout the year, renewable through natural processes, and do not cause significant effects on the environment [6]. Solar farms are usually built on large areas of carefully selected land, where thousands of photovoltaic panels are installed to collect energy and support the main electricity network. Solar farms vary in size, ranging from a few megawatts to hundreds of megawatts [7]. However, the trend towards constructing solar farms with high production capacities close to Gigawatt has started as a result of the development and low cost of producing solar panels. For example, the Bunyan Solar Farm in Egypt is being constructed on an area of 37 square kilometers with a production capacity of 1.5 Gigawatt [8]. Giant solar farms need more space than just solar panels. With space between rows of panels and all other equipment, a 1 megawatts solar farm needs about 2 hectares of surface area, according to green-tech media (GMT) research.

*1.2. GIS-based MCDM*

Suitable site selection for solar farms is the most important step towards successful investment in this growing industry. There is a wide range of climatic, geographic, economic, and environmental criteria for determining the optimal locations for installing solar panels. Furthermore, each main criterion contains a set of sub-criteria that influence the decision-making of site selection. It is significant to note that the types and importance of these criteria vary from country to country depending on geography, energy policies, and some other possible factors [9], [10]. Therefore, it is highly recommended to obtain expert advice on determining the influencing criteria and their weights.

Multi Criteria Decision Making (MCDM) methods are often adopted as a very popular approach to renewable energy site planning due to their ability to handle expert opinions and a plurality of criteria [11], [12], [13]. One of the MCDM methods mostly used in renewable energy studies and research is the Analytic Hierarchy Process (AHP), which is often used in conjunction with GIS [11], [14]. The AHP method, proposed by Thomas Saaty in 1980, helped capture decision objectivity by reducing the number of complex decisions and turning them into a series of pairwise comparisons and collecting results. It is also a useful technique for checking the consistency of results and reducing decision bias [15]. Meanwhile, Geographic Information Systems (GIS) have been introduced for the purpose of integration with (MCDM) to determine the appropriate site [16]. After that, GIS became indispensable for the purpose of site optimization. The use of GIS allows researchers to reduce the field of study by eliminating areas that do not meet the criteria required to establish solar farms.

In this paper, a combination of GIS and AHP technique was performed to assess the suitability of the land for establishing solar farms in Iraq. Numerous climatic, geomorphological, economic, and environmental criteria and some exceptional limitations have been adopted in the modeling process supported by expert knowledge and a comprehensive literature review.

*1.3 Previous Studies*

During the past decades, countless researches had been devoted to solar energy development strategies. Studies concluded that assessing the land suitability for the installation of solar panels is very beneficial in the success and sustainability of photovoltaic projects [17], [18]. In addition, a review of the literature revealed that many studies in various fields such as planning for renewable energies, energy management, and assessment of energy production have applied different techniques for decision-making [19]. The researchers have examined the potential of some MCDM methods that investigate inter-correlation and influence the weights of criteria controlling site selection [9], [20], [21]. However, several studies had found that a GIS-based AHP approach is a mature multi-constraint decision-making technique for studying land suitability [22], [23], [24], [25].

In a study performed by Noorollahi, 2016 to reveal the suitability of Iranian regions for the utilization of solar farms, a GIS-based Fuzzy AHP (FAHP) approach was used. This study has found that 14.7% of Iran's entire lands have a high suitability level, 17.2% a decent level, and 19.2% at a reasonable level, 11.3% at a medium level, and 1.8% at the lowest level of suitability for installing solar panels [26]. In another study, Dawod and Mandoer, 2016 focused on using the Multi criteria analysis (MCA) to determine optimal sites for solar power projects in Egypt within a GIS environment. The results of the research had found that the entire Egyptian regions with varying suitability index are almost suitable for solar energy harvesting. The suitability index varies from 4.5 to 9.3, with an average of 7.4 on a scale of 10 [27]. Likewise, Al Garni and Awasthi, 2017 had combined GIS and MCDM in order to evaluate and select the most appropriate site in Saudi Arabia for PV investments. The results of the spatial analysis had concluded that the northwestern part of the study area is the most suitable area, while the central areas are home to many sites of moderate suitability [28].

On other hand, studies had varied regarding to the number and type of criteria that affect the assessment of land suitability for solar farms due to differences in study areas and energy policies. However, these studies shared some significant criteria such as the amount of solar radiation, temperature, and aspects which have a clear influence on decision-making in this regard. In 2015, Tahri et al have conducted a study to determine the suitability of implementing a renewable energy project in the southern region of Morocco (Ouarzazate). The study had adopted seven criteria for selection: landuse, slope, slope direction (aspect), distance to city, distance to road, solar radiation, and surface temperature of the earth, while the AHP method was used to determine the weights of the relevant criteria [13]. In another study conducted by Nasehi et al in 2017, ten criteria were used relevant for planning solar farms. These criteria are divided into four categories including, environmental (distance from the fault, and land cover), climate (temperature, solar radiation), geomorphology (aspect, elevation, geology, slope), and location (distance from cities, distance from roads). In addition, city locations, roads, protected areas, and water sources were all considered restrictions [29]. Two years later, Koc et al had achieved a study on the eastern side of Turkey to find the best solar and wind energy site. This study took into account nine criteria:

elevation, topographic characteristics, solar irradiance, tilt and appearance, temperature, geology, land cover, and wind speed [25].

Recently, the energy policy in Iraq began to tend to invest in the solar energy industry. Therefore, previous studies are few in this regard [30], [31]. Nevertheless, in 2018 Emad had conducted study to estimate the potential maps of photovoltaic systems in Iraq by calculating the solar radiation rates and determining the effective areas. The results had shown that the most effective areas for installing solar panels were the ones that provide the largest amount of exposure to solar radiation and had the lowest construction costs [32]. In another study, Kaftan 2019 had researched a determination of the optimum sites for solar farms in Najaf / Iraq based on GIS and AHP method. Kaftan had revealed that most areas of Najaf are very suitable for harvesting solar energy, especially the central regions of the governorate near Najaf airport [33].

**2. Study Area**

This study was conducted to the whole Iraq except the Kurdistan (North) region. Iraq is located between latitude (29$^{o}$ 00' to 37$^{o}$ 20') North and longitude (38$^{o}$ 45' to 48$^{o}$ 45') East. It includes 18 governorates, three constitute the Kurdistan region. Iraq has a varied topography represented in mountain ranges in the north, plateaus in the west, and alluvial plains in the center and south. The climate of Iraq is also varied due to the diversity of its terrain and the rotation of the four seasons. Iraq is known for its cold, rainy winters and hot dry summers. However, the northern parts are more moderate in temperatures, while the southern and western parts are the most exposed to solar radiation [30], [34]. Iraq is located in the global solar belt (Figure 1), so it has abundant solar energy potential with ample sunlight throughout the year. The periods of solar radiation range between 2800 to 3300 hours per year with an average amount of solar radiation at an average of 6.5-7 kWh/m$^2$ per day and this makes the study area very conducive to investment in solar farms [32], [35].

During the 1980s, Iraq developed an ambitious plan to generate electricity from solar energy. In 1982, the Renewable Energy Law was passed, and the first rooftop solar panels in the Middle East were installed on some Baghdad's buildings [36]. However, the energy shortage problem and the environmental impacts resulting from reliance on fossil fuels made the development of solar energy projects in Iraq inevitable. Moreover, the development of this promising and rapidly growing industry could contribute to the creation of the country's scientific competencies.

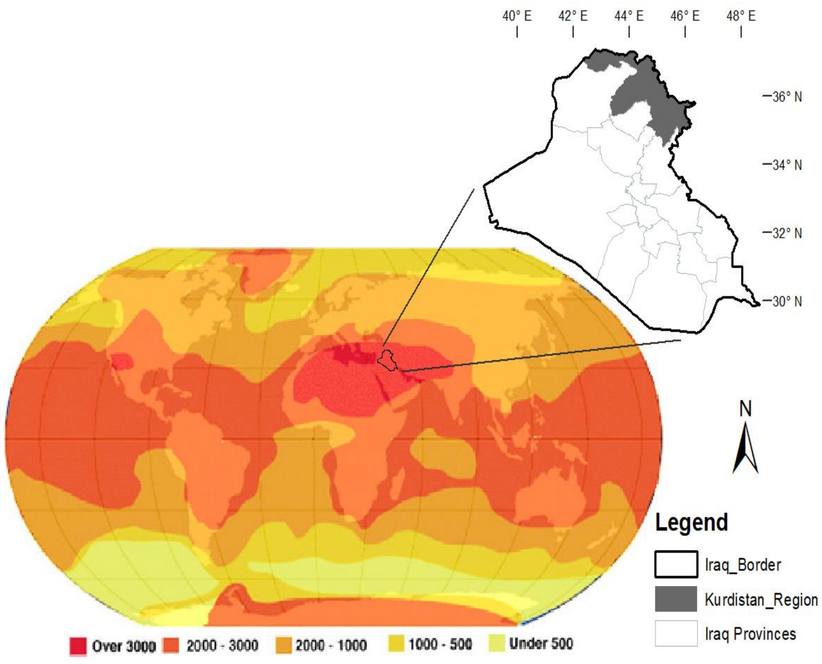


**Figure 1-**Iraq's location in the global solar belt receiving more than 3,000 hours of bright sunlight annually. [35]

## 3. Methodology

The study relied on GIS-based integration with the AHP method as a methodology to obtain optimal sites of solar farms in the study area. Figure 2 shows a flowchart of the methodology followed in this paper.

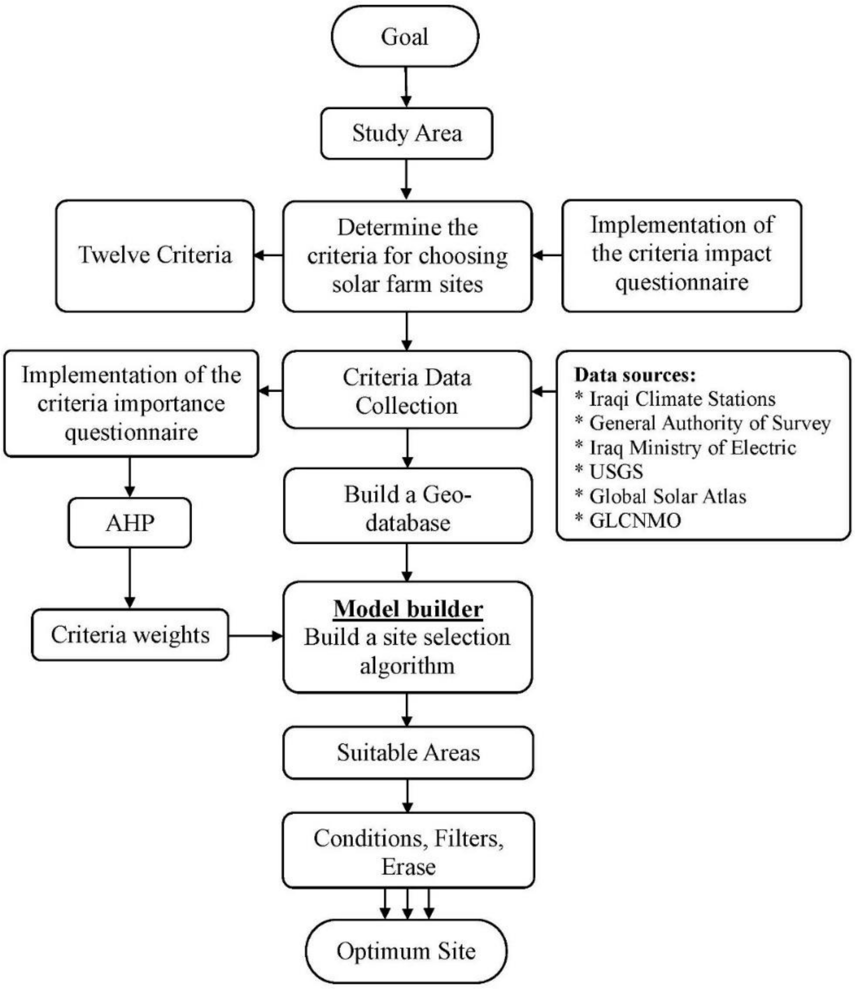



**Figure 2-** Flowchart of the adopted methodology

3.1 Definition of criteria and weights

Through the review of relevant studies, the categories of main and sub-criteria affecting planning for solar farms were identified. Since the selection criteria differs according to the location of study area, a questionnaire was prepared regarding the impact of these criteria in Iraq. The questionnaire has presented to the local energy experts. Only 12 criteria received high approval from the experts and were classified into four main groups, as shown in Figure 3.

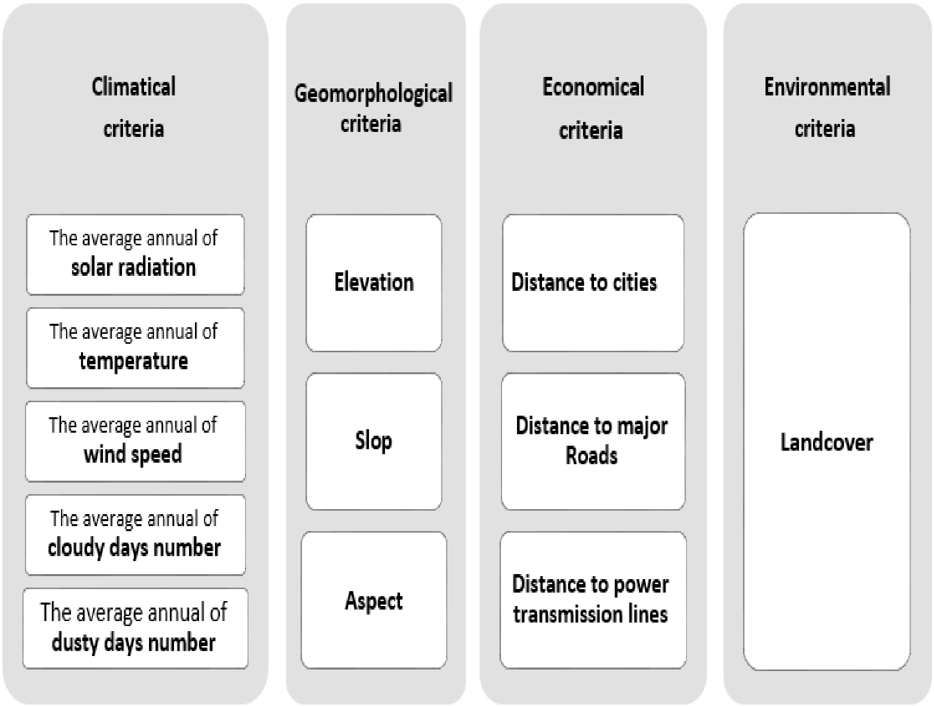



**Figure 3-** Criteria of the study

In addition, another questionnaire was presented to the experts in order to determine the importance level of the twelve criteria. The questionnaire was designed according to the AHP method which consists of making double comparisons of importance between the set of criteria under the same category. Therefore, one comparison was made for the main criteria and four comparisons for the sub-criteria. There are nine scales of importance according to the AHP method, as shown in Table 1. Experts had responded based on their experiences, so not all answers were equal. However, irregular answers were excluded to obtain a more consistent importance average.

**Table 1-**Importance scales according to the AHP method [24].

| Importance Scale | Definition of Importance Scale |
|---|---|
| 1 | Equally Important |
| 2 | Equally to Moderately Important |
| 3 | Moderately Important |
| 4 | Moderately to Strongly Important |
| 5 | Strongly Important |
| 6 | Strongly to Very Strongly Important |
| 7 | Very Strongly Important |
| 8 | Very Strongly to Extremely Important |
| 9 | Extremely Important |

The AHP method has been adopted to calculate the criteria's weights depending on the results of criteria importance questionnaire. A MATLAB code has been prepared to perform AHP calculations sequentially to the five pair comparisons used in this study. Initially, the code had built the Pairwise Comparison Matrix, which is a Square Matrix, with a diameter value equal to 1, and the values above the diameter are the opposite of the values below the diameter [15]. Next, the code has generated a Normalized Pairwise Comparison Matrix, which is also a

Square Matrix that had built according to the equation 1. Then, the vector of criteria weight had built by averaging the cells of each row of the Normalized matrix, as shown in equation 2. Finally, the MATLAB code had calculated the Consistency Index and Consistency Ratio.

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{s=1}^{m} a_{sk}} \quad (1)$$

$$w_j = \frac{\sum_{s=1}^{m} \bar{a}_{js}}{m} \quad (2)$$

Where:

a: Normalized Pairwise Comparison Matrix

$j^{th}$ represent the importance of the criterion according to the $k^{th}$ criterion

m: the number of criteria

w: the criteria weight vector

*3.2 Data collection and management*

The quality and reliability of data is crucial in building a robust geodatabase. In this research, a dataset for influencing criteria in the selection of solar farms had collected from various sources, as shown in Table 2. Among the most important collected data, were climate data. It includes locations and climate measurements of 34 meteorological stations spread over the study area for the past 30 years. The climate data were the averages of the monthly measurements for each of the past 30 years that were used to calculate the general average for the past three decades. The data had used to compute the main average of climate criteria over the past three decades, as well as, imported into the study geodatabase to produce climate raster models.

One of the most required data to implement the study is the digital elevation model (DEM). By using DEM, the three morphological criteria models can be generated (elevation, slope, and aspect). In this paper, the digital elevation model of Shuttle Radar Topography Mission (SRTM), 90m spatial resolution, was adopted because it demonstrated a higher accuracy than other models when tested on the terrain of Iraq. The standard deviation error for SRTM is 1.176m and the Mean error is 2.921m [37], [38]. On the other hand, GIS layers were obtained for economic criteria and protected area restrictions, which had merged with the adopted geodatabase after the topology was implemented.

**Table 2-** Data Sources

| Data Source | Data Type | Data Format |
|---|---|---|
| Iraqi meteorological organization and Seismology | Locations of meteorological stations | Coordinates sheet |
| | Solar radiation | Measurements sheet |
| | Temperature | Measurements sheet |
| | Wind speed | Measurements sheet |
| | Cloudy days | Measurements sheet |
| | Dusty days | Measurements sheet |
| General Authority of Survey, Iraqi Ministry of Water Resources | City borders | Shapefile / polyline |
| | Cities location | Shapefile / point |
| | The road network | Shapefile /polyline |
| | Water bodies | Shapefile /polygon |
| | Runway | Shapefile /polygon |
| Energy Institute, Iraqi Ministry of Electricity | Electric lines | Shapefile / polyline |
| | Electric station | Shapefile /point |
| Iraqi Ministry of oil | Oil pipelines | Shapefile /polyline |
| | Oil fields | Shapefile /polygon |
| Iraqi Ministry of cultural, Tourism and Antiquities. | Archeological sites | Raster map |

| | | |
|---|---|---|
| United States Geological Survey (USGS) | DEM / SRTM | Raster model |
| GLCNMO (Global Land Cover by National Mapping Organizations) | Landcover | Raster model |

*3.3 Site selection algorithm*

In this study, the great potential of Model Builder has been used to construct the optimal site selection algorithm for solar farms. Model Builder has bundled a series of geo processing tools to feed one tool's output into another tool (as input), so it can be considered as visual programming for the workflow (Figure 4). The building of the optimal site selection algorithm went through the following steps:

1. Create raster models: The data that is dealt with in Model Builder must be in a raster format. Therefore, many geo processing tools have been applied sequentially to convert criteria Feature Classes in the geodatabase to the raster models. First, the ordinary Kriging method of the Kriging tool has been used to create the climatic raster models. The climatic annual average was adopted as a Z value, while the output cell size determined to be 90 meters, in line with the resolution of DEM. On the other hand, slope and aspect raster models had been generated using 3D analyst tools (Slope tool and Aspect tool). These tools had been included in ModelBuilder, and the DEM had been adopted as input data. In addition, the Euclidean distance tool had been used to generating Raster data for the three economic criteria.
2. Reclassify: Raster data reclassification had been implemented in order to simplify the output data and getting rid of unnecessary information. The raster data had been reclassified using the reclassify tool / Spatial Analyst Tools. The new reclassify raster data contained five classes, which will be fed later by the values of the weights.
3. Weighted Overlay: The Weighted Overlay method refers to overlay- analysis to solve problems with multicriteria such as models of suitability of site selection. The weighted overlay approach allows multiple phases of the general, overlay- analysis process to be implemented within a single tool. In this paper, the input data of the Weighted Overlay tool was the raster data for the adopted criteria after the reclassification was performed. The Weighted Overlay tool had fed with the criteria weights and class weights that had calculated by the AHP method. The Landcover raster layer had been inserted into the overlay tool as a platform for optimal selection. The output of the Overlay tool was a raster map for the suitability area.
4. Condition and Filter tools: The Con tool had been adopted to excluding low suitability areas and generating a new raster layer for areas with high suitability only (suitability level 75 and more). After that, the Filtering tool had been applied to exclude small areas that are not useful for solar farms installation. Finally, areas that overlap with protected areas had been erased.

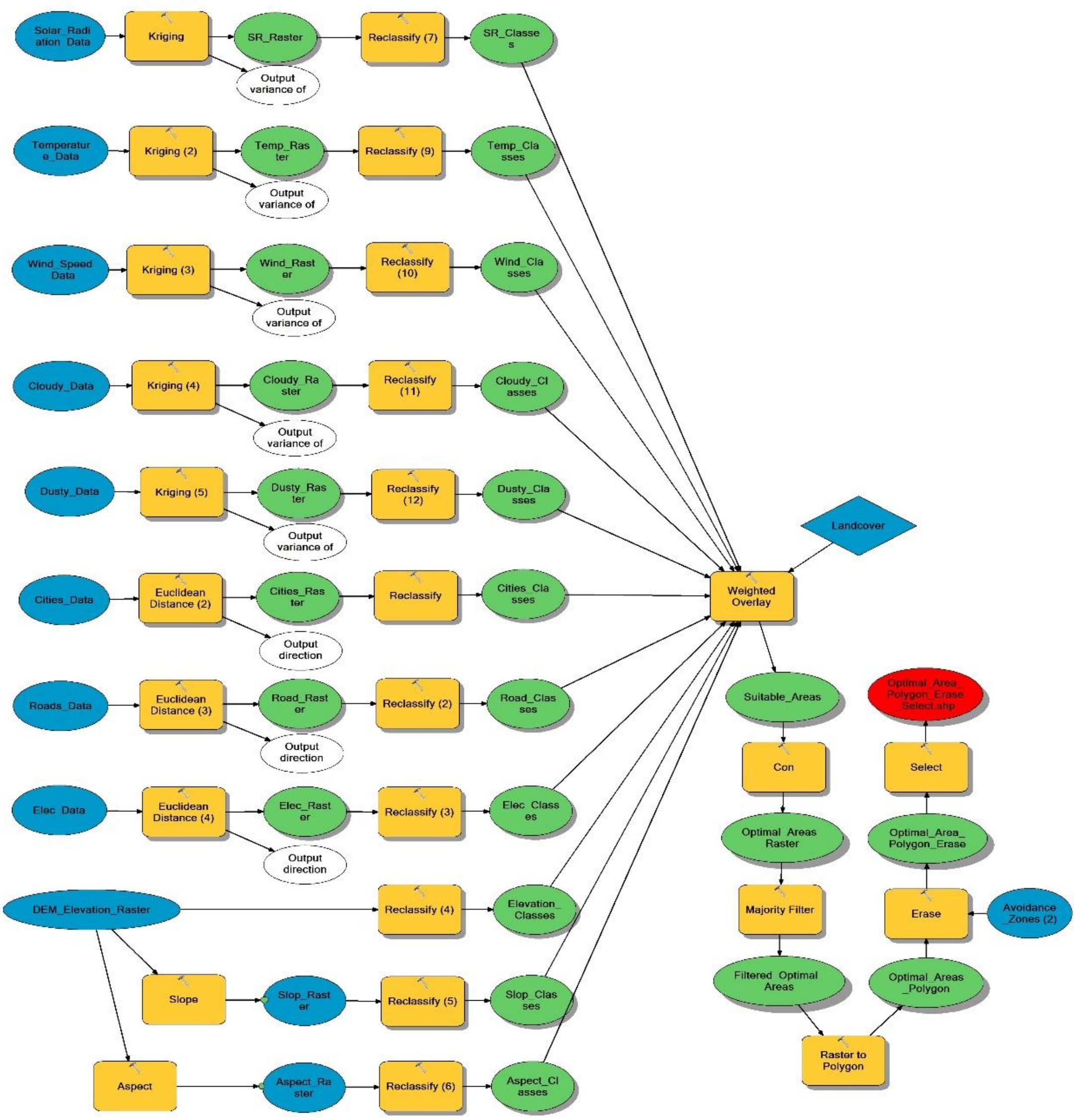



**Figure 4-**Shows the optimum site selection algorithm using the model builder.

## 4. Results and Discussions

4.*1 Weights of criteria*

The results of the first questionnaire identified a set of twelve criteria influencing the selection of solar farms in the study area. This set of criteria was adopted in the second questionnaire (Criteria Importuncy Questionnaire). The AHP method had employed with the results of the second questionnaire to calculate the weights of main and sub-criteria.

The results of the main criteria had revealed that the climate criterion had achieved the highest weight with a value of 0.56, while the environmental criterion had scored the lowest weight with a value of 0.06 at a consistency ratio of 0.08. On the other hand, the solar radiation criterion had achieved the highest weight among the climate sub-criteria (0.54 at a consistency ratio of 0.036), while the aspect criterion had ranked first in the weights of the geomorphological sub-criteria (0.70 at a consistency ratio of 0.035). Furthermore, Distance to Power lines had appeared at the top of the economic sub-criteria weights (0.67 at a consistency ratio of 0.022). The results of the weights of the main, sub-criteria, and weights of the classes are summarized in Table 3.

**Table 3**-Weights of the main, sub-criteria, and weights of classes.

| Main Criteria | Main Weight | Sub-Criteria | Sub Weight | Partial Weight = Sub Weight * Main Weight | GIS Class | | Class Weight | Final Weight = Class Weight * Partial Weight |
|---|---|---|---|---|---|---|---|---|
| Climatical | 0.563 | The average annual of solar radiation (Mw/cm$^2$/day) | 0.536 | 0.302 | less | 442 | 0.10 | **0.030** |
| | | | | | 442 | 452 | 0.15 | **0.045** |
| | | | | | 452 | 462 | 0.20 | **0.060** |
| | | | | | 462 | 472 | 0.25 | **0.075** |
| | | | | | 472 | more | 0.30 | **0.091** |
| | | The average annual of temperature (Celsius degree) | 0.094 | 0.053 | less | 20 | 0.10 | **0.005** |
| | | | | | 20 | 22 | 0.15 | **0.008** |
| | | | | | 22 | 24 | 0.25 | **0.013** |
| | | | | | 24 | 26 | 0.30 | **0.016** |
| | | | | | 26 | more | 0.20 | **0.011** |
| | | The average annual of wind speed (m/sec) | 0.061 | 0.034 | less | 2.3 | 0.10 | **0.003** |
| | | | | | 2.3 | 2.7 | 0.15 | **0.005** |
| | | | | | 2.7 | 3.1 | 0.25 | **0.009** |
| | | | | | 3.1 | 3.5 | 0.30 | **0.010** |
| | | | | | 3.5 | more | 0.20 | **0.007** |
| | | The average annual of cloudy days number (day/year) | 0.156 | 0.088 | less | 20 | 0.30 | **0.026** |
| | | | | | 20 | 26 | 0.25 | **0.022** |
| | | | | | 26 | 32 | 0.20 | **0.018** |
| | | | | | 32 | 38 | 0.15 | **0.013** |
| | | | | | 38 | more | 0.10 | **0.009** |
| | | The average annual of dusty days number (day/year) | 0.153 | 0.086 | less | 8 | 0.30 | **0.026** |
| | | | | | 8 | 12 | 0.25 | **0.022** |
| | | | | | 12 | 16 | 0.20 | **0.017** |
| | | | | | 16 | 20 | 0.15 | **0.013** |
| | | | | | 20 | more | 0.10 | **0.009** |
| Geomorphological | 0.223 | Elevation (m) | 0.195 | 0.044 | less | 200 | 0.10 | **0.004** |
| | | | | | 200 | 500 | 0.15 | **0.007** |
| | | | | | 500 | 900 | 0.20 | **0.009** |
| | | | | | 900 | 1400 | 0.25 | **0.011** |
| | | | | | 1400 | more | 0.30 | **0.013** |
| | | Slop (%) | 0.102 | 0.023 | less | 1 | 0.30 | **0.007** |
| | | | | | 1 | 2 | 0.25 | **0.006** |
| | | | | | 2 | 3 | 0.20 | **0.005** |
| | | | | | 3 | 4 | 0.15 | **0.003** |
| | | | | | 5 | more | 0.10 | **0.002** |
| | | Aspect (Azimuth) | 0.703 | 0.156 | Flat | | 0.20 | **0.031** |
| | | | | | N | | 0.01 | **0.002** |
| | | | | | NE | | 0.03 | **0.005** |
| | | | | | E | | 0.08 | **0.013** |
| | | | | | SE | | 0.15 | **0.023** |
| | | | | | S | | 0.26 | **0.041** |
| | | | | | SW | | 0.15 | **0.023** |
| | | | | | W | | 0.08 | **0.013** |
| | | | | | NW | | 0.03 | **0.005** |
| | | | | | N | | 0.01 | **0.002** |
| Economical | 0.153 | Distance to cities (Km) | 0.078 | 0.012 | less | 10 | 0.30 | **0.004** |
| | | | | | 10 | 30 | 0.25 | **0.003** |
| | | | | | 30 | 60 | 0.20 | **0.002** |
| | | | | | 60 | 100 | 0.15 | **0.002** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | 100 | more | 0.10 | **0.001** |
| | | Distance to major Roads (Km) | 0.256 | 0.039 | less | 5 | 0.10 | **0.004** |
| | | | | | 5 | 15 | 0.30 | **0.012** |
| | | | | | 15 | 30 | 0.25 | **0.010** |
| | | | | | 30 | 60 | 0.20 | **0.008** |
| | | | | | 60 | more | 0.15 | **0.006** |
| | | Distance to power transmission lines (Km) | 0.666 | 0.102 | less | 10 | 0.30 | **0.030** |
| | | | | | 10 | 30 | 0.25 | **0.025** |
| | | | | | 30 | 60 | 0.20 | **0.020** |
| | | | | | 60 | 100 | 0.15 | **0.015** |
| | | | | | 100 | more | 0.10 | **0.010** |
| **Environmental** | 0.062 | Land cover | 1 | 0.062 | Barren area (gravel, rock) | | 0.56 | **0.034** |
| | | | | | Barren area (sand) | | 0.28 | **0.017** |
| | | | | | Crop field | | 0.09 | **0.005** |
| | | | | | Forests + Sparse vegetation | | 0.07 | **0.004** |
| | ∑= 1 | | | ∑= 1 | | | | ∑= 1 |

4.*2 Criteria raster models*

The initial results of the site selection algorithm had revealed the reclassified raster models for the criteria adopted in this research, as shown in Figure 5. Part A in Figure 5, shows that high values of solar radiation are in the south and southwest of the study area, while the northern regions recorded low values of solar radiation. These results are in line with the Global Horizontal Irradiation, so areas with higher radiation will be more eligible to install solar farms. On the other hand, Figure 5.B shows the results of temperature raster model. As usual, the average temperature is high in the south and middle of Iraq and somewhat low in the northern regions. Areas with temperatures between 22 to 26 degrees Celsius will be the most efficient for installing solar farms. In Figure 5.C, the highest wind speed is shown in the south and southeast of the study area, while it is low in the north and northwest. Wind speed is taken into consideration as a factor that helps cooling the solar cells, so regions with wind speed between 3-4 m/s are the best choice for installing solar farms. In addition, clouds are blocking a large amount of solar radiation from reaching the solar cell. Likewise, dust storms prevent sunlight and cause dust to settle on cell surfaces. However, Figures 5.D and 5. E are revealing an inverse spatial relationship between clouds and dust models. The northern regions have more cloudy days than the southern regions, while the number of dusty days is more frequent in the south compared to the north. The obvious explanation is lack of rain in southern Iraq, which is causing an increase in desertification. However, the highest average number of dusty days is 22 days/year in the south of the study area, while the highest average number of cloudy days is 43 days/year in the north. As a result, it can be said that southern Iraq will be more preferred to install solar farms.

On the other hand, Figure 5.F, 5.G, and 5.K show the raster models of the Geomorphological criteria (Elevation, Slope, and Aspect) respectively. The results have revealed that most lands of the study area are between flat to slightly sloping (less than 5%) while the northern regions and parts of the western region have steep slopes. As a result, the northern and western regions are unlikely to be eligible to install solar farms. In addition, Figures 5.H, 5.I, and 5.J have illustrated the raster models of the economic criteria. The figures show areas close to cities, roads, or power transmission lines in a light color. Those areas are encouraging establishment of solar farms. In contrast, regions with darker colors are not economically suitable for building solar farms. Finally, the raster model of the landcover is shown in Figure 5.L.

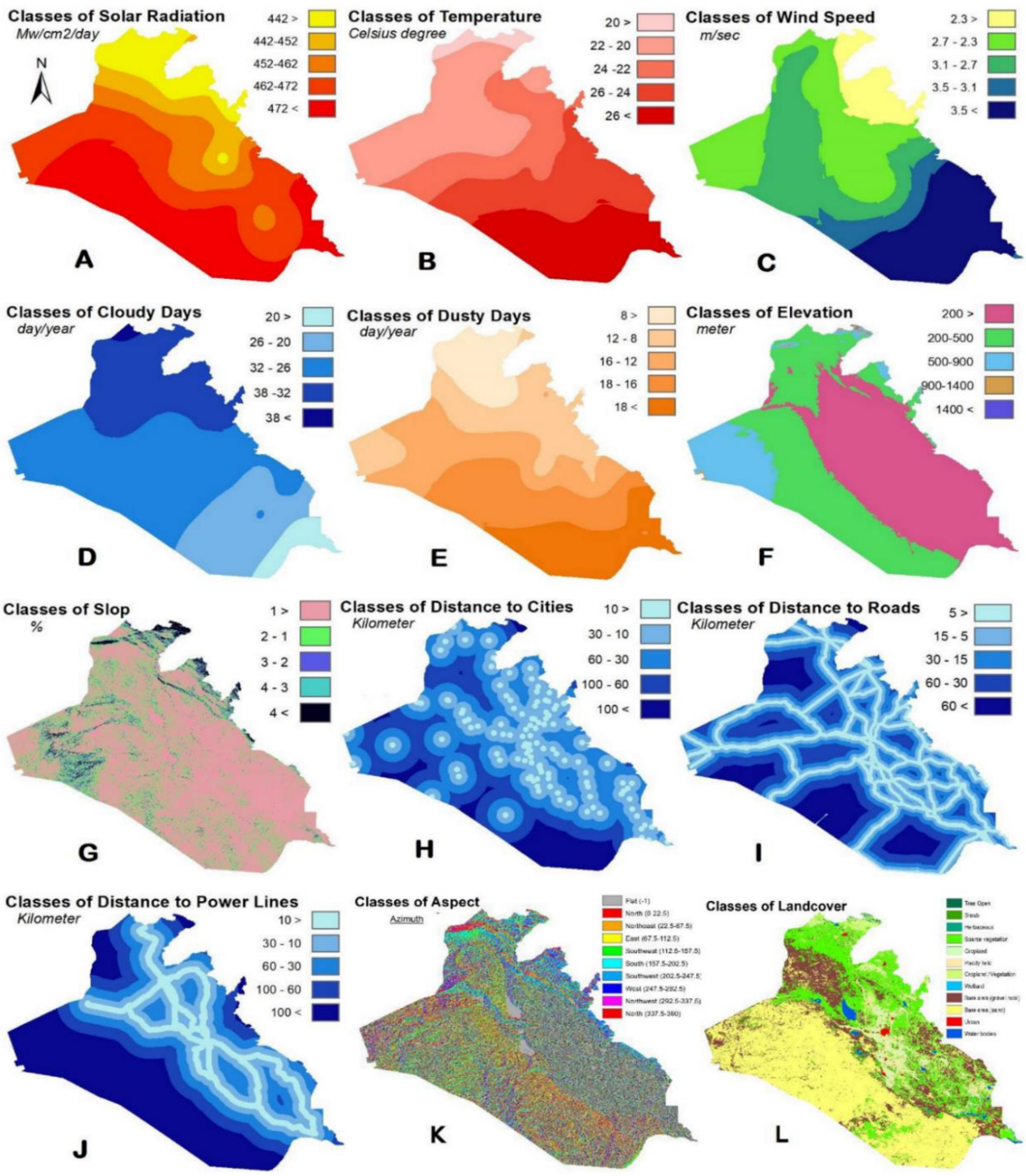



**Figure 5-** Reclassified raster models for the criteria adopted in the study.

### 4.*3 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 6. The first category is the white color class with a zero suitability level, while the last category is the dark brown color class with a high level of suitability (76-100%). Although the western regions of the study area have high solar radiation values, the results showed that areas with high suitability for establishing solar farms were concentrated in the southern and southeastern regions with few parts of the western region. The reason for this contradiction is that, the site selection algorithm did not adopt the solar radiation criterion only, but other climatic, economic, and geomorphology criteria had a clear influence on the decision-making. For example, the western regions of the study area are almost devoid of cities, roads, and power transmission lines, so installing solar farms in there will increase production costs, in addition to, energy loss due to its transportation over large distances towards 400Kva line network. On the other hand, the Iraqi electricity network deals with the entire country (except for the Kurdistan region) as one electrical unit; thus, all Iraqi cities will benefit from the energy supplies of solar farms when installed in their suitable areas.

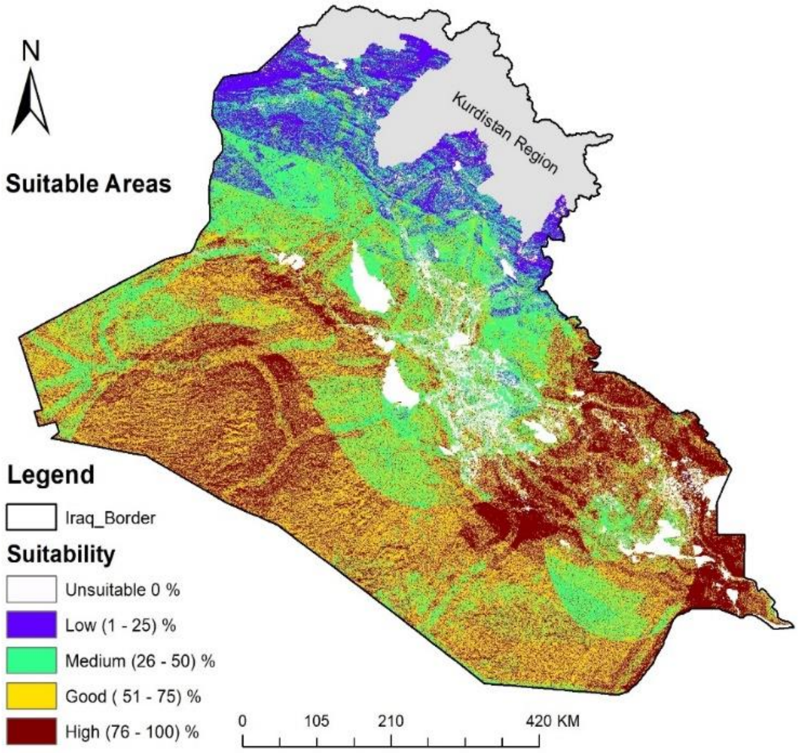



**Figure 6-** Results of suitable areas for installing solar farms.

The results of suitable areas had verified to determine whether the degree of suitability is really the most appropriate. The visual analysis had applied to samples of the results by comparing them with recent satellite images of the Landsat-8, as shown in Figure 7. From satellite images, it can be seen that most lands with a suitability level of 0% are either urban areas or water bodies. As a result, they are not suitable at all for establishing solar farms. Furthermore, satellite images revealed that the areas with a high level of suitability are barren lands and thus are candidates for containing solar farms as well as other preference factors.

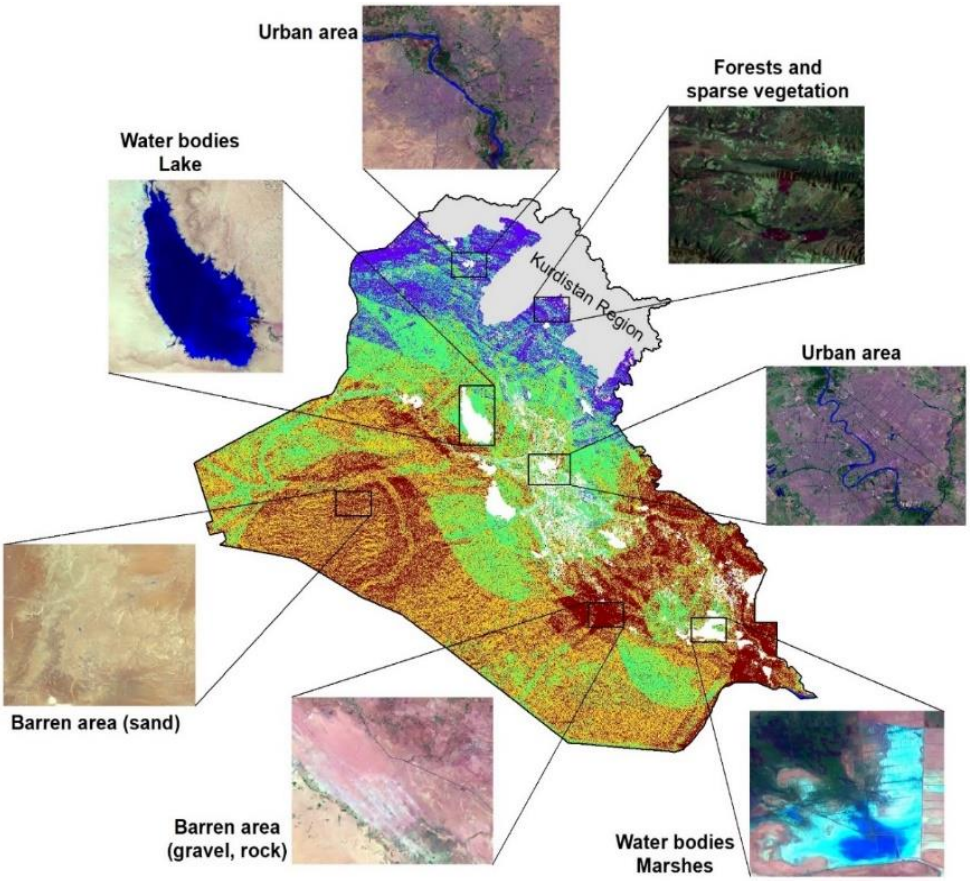
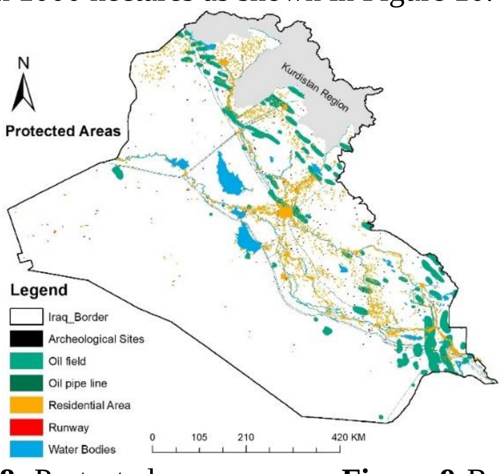



**Figure 7-**Verification of suitable areas results.

*4.4 Optimal areas*

The results of the optimal areas for installing solar farms have obtained after applying Con and Filtered tools on the results of high suitability areas in Figure 6. Then exclude parts of optimal areas that overlap with protected area, as shown in Figure 8. The final results for optimal areas are illustrated in Figure 9, which represents 19% of the study area. However, the size of optimum areas varies between few hectares to thousand hectares.

On the other hand, establishment of solar energy projects with high capacity would accelerate the solution of the energy shortage that has plagued Iraq for decades. Therefore, the optimum area for establishing solar farms that are capable of producing 500 megawatts should not be less than 1000 hectares as shown in Figure 10.



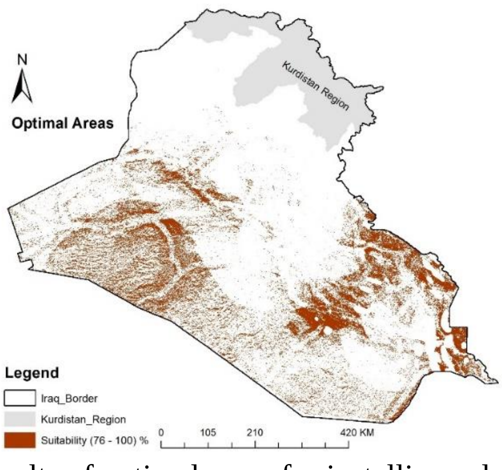




**Figure 8-** Protected areas **Figure 9-**Results of optimal areas for installing solar farms.

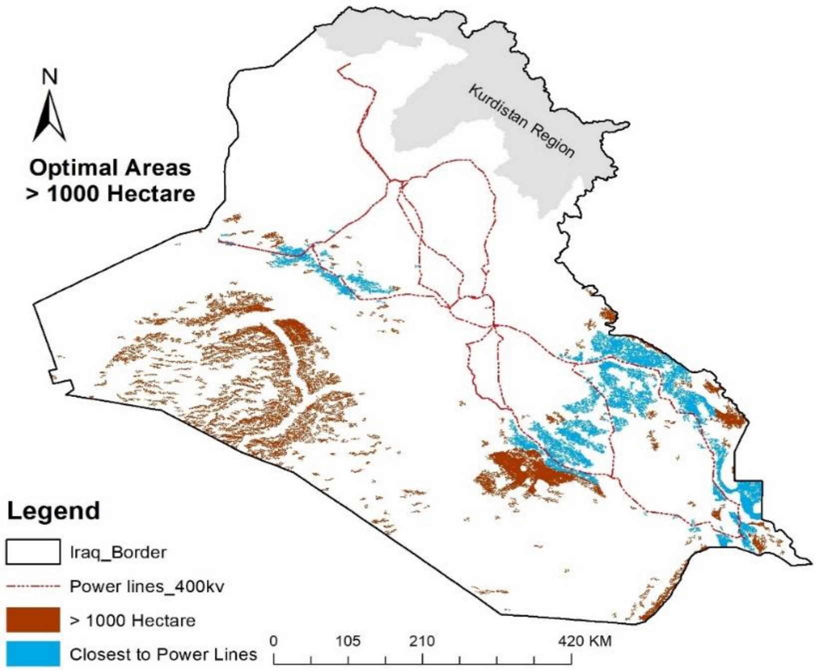



**Figure 10-** Optimum lands with an area of more than 1000 hectares

## 5. Conclusions

The following conclusions were drawn from the experimental results obtained in this study:

1. The adoption of solar energy can effectively contribute to solve the problem of scarce energy supplies in Iraq due to Iraq's unique location, which allows receiving large amounts of annual solar radiation. Furthermore, moving towards solar energy will diversify the country's energy mix, invest local energy resources, reduce environmental impacts, and ultimately support sustainable development.
2. The results of criteria importunacy questionnaire and AHP method showed that the criterion of solar radiation, aspect, and distance to power lines had a clear influence on decision-making regarding locations of solar farms.
3. The results indicated that 28% of the total lands of the study area have a high level of suitability, 36% of a good level, 23% of a medium level, 8% of a low level, and 5% of the lands are unsuitable for establishing solar farms. Areas with a high level of suitability were concentrated in the southern, southeastern regions, and few parts of the western region of Iraq.
4. It can be concluded that suitable lands of more than 1000 hectares are optimal lands for constructing high capacity solar power stations in the study area. The total area of optimum land is 3,900,000 hectares (about 10% of the study area) while only 1,500,000 hectares (about 4% of the study area) are located near the power transmission lines. Therefore, planners can prioritize those lands for developing solar energy in Iraq.

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