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Solar Energy Farm Site Selection Using GIS Multi-Criteria Decision Analysis Surrounding Kirkuk City

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Abstract

Kirkuk province needs a comprehensive and specialized strategy to address these difficulties and identify the most suitable solar energy solutions to reduce its ecological impact and improve its energy security and economic sustainability in future years. This study aims to present a framework for solar energy farm site selection working with Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) techniques surrounding Kirkuk province, Iraq. Several spatial data sets were integrated in two steps to locate the best locations for solar energy farms. The first stage was to identify land availability with the elimination of constraints areas such as distance from major roads, distance from bodies of water, urban areas, distance from electric power transmission lines, and distance from industrial locations. The second stage was to choose the essential criteria, weigh them using an Analytical Hierarchy Process (AHP), and finally analyze the criteria using GIS to determine the best sites for solar energy farms. The available land results indicated their distribution in three regions with large areas, which are the north-east, north-west, and south-east, with a total area estimated at 40.182 km^2, in addition to separate small areas of about 1.698 km^2 in the rest regions of the study area. The highly suitable lands were dispersed throughout the northwest and north of the research region, covering a total area of 7.4304 km^2, while medium suitable lands, indicated by the yellow color, are spread out in the southeast, with a total area estimated at 2.9376 km^2. The low suitable lands cover some small areas south of the research area, shown in green, and cover an area of 1.8432 km^2.

Keywords: Solar Energy, Suitability Site Selection, GIS, Multi-Criteria Decision.

اختيار الموقع الأمثل لموارد الطاقة المتجددة بالاعتماد على تقنيات نظم المعلومات الجغرافية وتحليل القرار المتعدد (دراسة حالة لمحافظة كركوك)

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الخلاصة

أظهرت مصادر الطاقة المتجددة في الآونة الأخيرة، بالأخص الطاقة المستمدة من الشمس- فعاليتها كبديل للوقود الأحفوري. حيث ان استخدام الطاقة الشمسية كمصدر نظيف واقتصادي أحد السبل المتاحة للحد من ظاهرة الاحتباس الحراري. تهدف هذه الدراسة إلى تقديم إطار عمل لاختيارامثل موقع لمزرعة الطاقة الشمسية

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باستخدام نظام المعلومات الجغرافية (GIS) وتقنيات تحليل القرار المتعدد المعايير (MCDA) حول محافظة كركوك. أُجريت الدراسة على مرحلتين. المرحلة الأولى، حددت الأراضي المتاحة عن طريق استبعاد المناطق الغير مناسبة مثل محددات المسافة من الطرق الرئيسية، والمسطحات المائية، والمناطق الحضرية، وبعد المسافة للأراضي عن خطوط نقل الطاقة الكهربائية، إضافة الى بعد المواقع الصناعية. في المرحلة الثانية، تم اختيار المعايير الأساسية وتحديد أوزانها باستخدام عملية التسلسل الهرمي التحليلي (AHP). حللت المعايير باستخدام نظام المعلومات الجغرافية لتحديد أفضل مواقع مزارع الطاقة الشمسية. حيث أظهرت نتائج الدراسة توزيع الأراضي المتاحة في ثلاث مناطق واسعة: الشمال الشرقي والشمال الغربي والجنوب الشرقي، وتغطي مساحة إجمالية تقدر بـ 40.182 كيلومتر مربع. بالإضافة إلى ذلك، توجد مساحات صغيرة منفصلة بمساحة حوالي 1.698 كيلومتر مربع في باقي منطقة الدراسة. وزعت الأراضي المرتفعة المناسبة في جميع أنحاء الشمال الغربي والوسط الشمالي لمنطقة البحث، وتغطي مساحة إجمالية قدرها 7.4304 كيلومترات مربعة. بينما الأراضي المتوسطة المناسبة مشتملة في الجنوب الشرقي بمساحة إجمالية تقدر بحوالي 2.9376 كيلومتر مربع. وأخيراً، تُظهر الأراضي المنخفضة المناسبة، والتي تغطي بعض المساحات الصغيرة في جنوب منطقة البحث، باللون الأخضر وتغطي مساحة 1.8432 كيلومتر مربع.

1. Introduction

Energy is critical to attaining modern societies' attached objectives involving providing human demands for heating, cooling, lighting, transportation, running many different technologies, and supplying power and heat to manufacturing processes [1]. The growth of population combined with shortages of electric power requires an emergence of solutions for supplying electric power for urban areas and commercial, industrial, and government institutions. As a result, solar energy is regarded as one of the alternatives supporting the Kirkuk province power plants. Many countries are rapidly expanding their use of solar energy. In this sense, several research studies have been conducted worldwide, concentrating on academics, governments, and organizations [2]. In recent years, various levels of policy and regulation have been established in developed countries to promote renewable energy. As of 2013, at least 144 nations have set distinct renewable energy objectives and regulations and have received national support for renewable energy development [3]. The present energy planning framework includes various aims, definitions, and criteria, making it more challenging to achieve a system with a sustainable perception. Thus, an adequate planning system that considers necessary political, social, economic, and environmental aspects is required to meet increasing energy demands while maintaining a sustainable development vision [4]. The selection of ideal locations for solar power sites is a complex subject; it demands a proper combination of several parameters, such as solar potential, land availability, infrastructural presence, and so on [5]. Multi-Criteria Decision Analysis (MCDA) methodologies have discovered widespread use in both public and private sector decisions on agriculture resource management, immigration, education, transportation, investment, environment, argumentation, and health care, many other topics [4]. Since several factors may influence site selection, using multiple criteria decision-making (MCDM) approaches to guide the decision-making process can aid in selecting convenience-scale grid-connected solar energy systems [6]. The AHP technique quantifies relative priorities for a given set of alternatives based on pairwise judgments of decision-makers. This approach allows for constructing decision-making criteria as a hierarchy, calculating the weights of the criteria and alternatives, and emphasizing the consistency of alternative comparisons [7]. Remote sensing technologies and satellite data enable the identification of changes in time series data from particular land cover classes across multiple periods [8]. Utilizing remote sensing technology is a primary goal for metropolitan regions as locations for environmental and social development and economic urban planning [9]. The selection of criteria is based on three stages: previous studies, analysis of criteria, and opinions of experts [10].

GIS technologies identify factors influencing solar power plant installation and their acquisition in a geographic database, as well as practical assessments of relevant assessments [11]. The geographical database is necessary to accurately assess technical, environmental, economic, land use, and social factors when using energy from solar and wind resources [12]. The spatial analysis using GIS is the best way to produce spatial representation maps [13]. The study aims to propose a framework for selecting solar energy farm sites in the Kirkuk region of Iraq using Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) approaches.

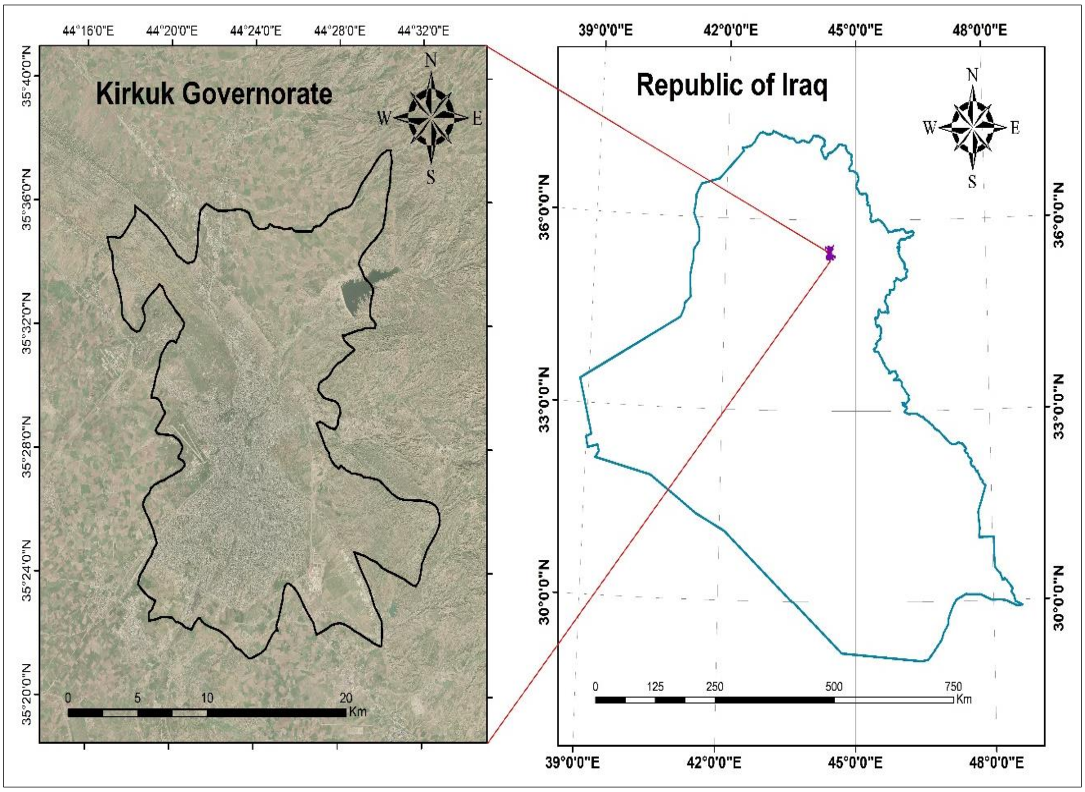

Figure 1: The study area is Kirkuk province

1. Study area

Kirkuk province is located 286 km north of Baghdad, the capital of Iraq, bordered by the governorates of Erbil to the north, Sulaimaniyah to the northeast, and Tikrit to the south and southwest [14]. Kirkuk is located between longitudes (44˚ 10′ E) - (44˚ 30′ E) and latitudes (35˚ 20′ N) – (35˚ 32′ N), and its area is about 9679 km^2 [15]. Kirkuk City is the center of Kirkuk Governorate, and according to The Central Statistical Organization of Iraq, the city's population is approximately 1,600,000 people. Kirkuk is a vital Iraqi province, and among the most critical factors that contributed to its success are underground resources such as oil and natural gas and the fertility of its agricultural lands. Also, its distinguished geographical and commercial location serves as a connection between central and northern Iraq. Furthermore, Kirkuk is an archaeological center because it contains archaeological sites, the most important of which is the Kirkuk Citadel, built in 850 B.C. Figure 1 states the study area (Kirkuk province) [16].

2. Methods and Materials

This section describes the methodologies and data used to identify a suitable site for establishing a solar energy station surrounding Kirkuk province. There are two crucial phases when selecting the ideal site for a solar power station: first, identify the available areas based on the essential factors, and then select the best place throughout these available areas based on the weighting of the main and sub-criteria. The overall methodologies are illustrated in Figure 2.

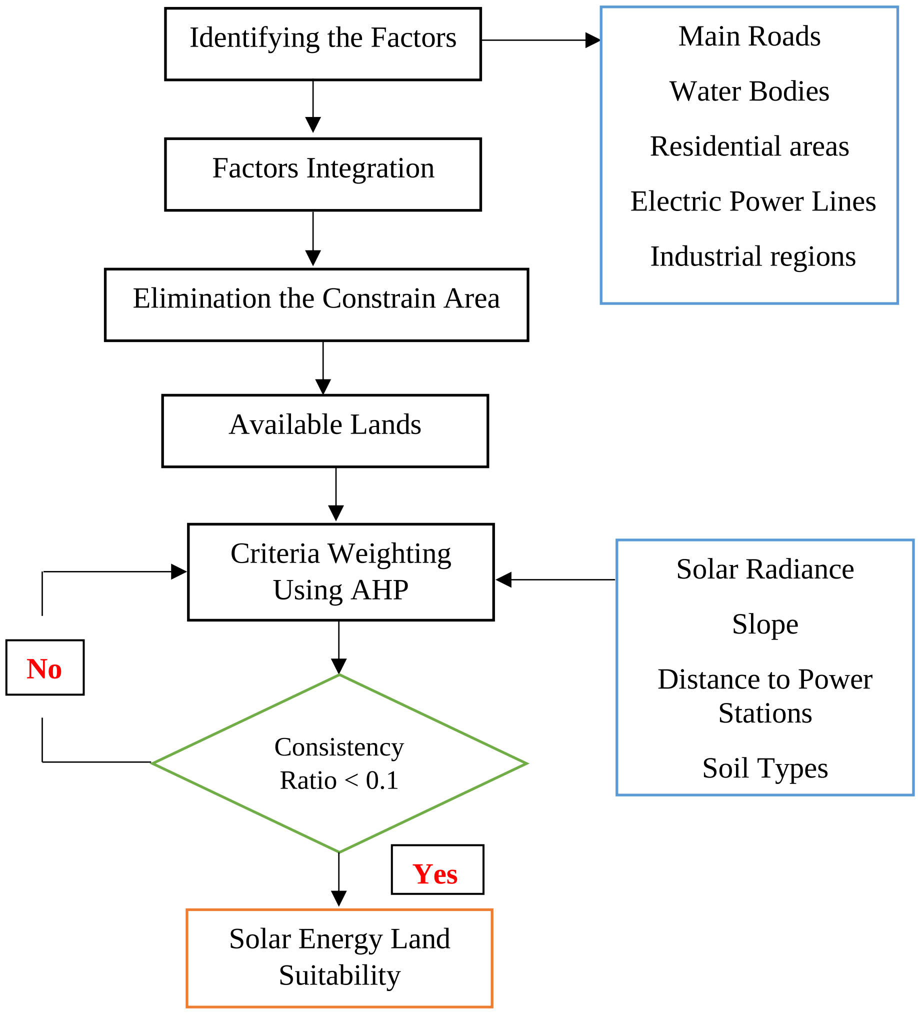

Figure 2 : Flowchart of Solar Energy Farm Site Selection

2.1 Data used

Several types of data were used in this study; the following is the list of data with sources:

- Digital Elevation Model (DEM) was downloaded from USGS Earth Explorer with a spatial resolution of 30 × 30 m and is derived to be 12.5×12.5 m.
- Landsat-8 OLI was downloaded from USGS Earth Explorer with a spatial resolution of 30×30 m. Five bands were used in this study: the visible bands, near-infrared, and short-wave infrared (SWIR). Landsat satellite images are helpful and open-source data for the classification process [17].
- Aerial Photograph of Kirkuk 2019.
- Vector data, including road networks, industrial areas, and electric power stations, were obtained from the Urban Planning Department in Kirkuk.

The details and specifications of all data are included in Table 1.

Table 1: The data used in this study

Data	Source	Specifications
Digital Elevation Model (DEM)	USGS Earth Explorer	Spatial resolution is (30*30 m) and derived to (12.5*12.5 m)
Landsat-8 OLI	USGS Earth Explorer	Spatial resolution (30×30 m). (Path =169 and Row = 036). (Date Acquired = 31/5/2022). (Land Cloud Cover = 0%)
Aerial Photograph of Kirkuk 2019	Urban Planning Department in Kirkuk	Columns and Rows (283181, 230841) Number of Bands (3) Cell Size X. Y (5.36441*5.36441) Uncompressed Size (182.64) Pixel Depth (8 Bit) Spatial Reference (GCS_WGS_1984)
Road networks, industrial areas, and electric power stations	Urban Planning Department in Kirkuk	Vector data

Figure 3: Digital Elevation Model image of Kirkuk Province

2.2 Land availability

The availability of suitable land for solar energy production is the first and foremost necessity for developing such facilities [18]. Because it significantly impacts the most favored classes, removing the electrical requirements is the best strategy to increase the amount of available land for renewable energy farm developments [19]. This paper provides a method for utilizing GIS to identify possible solar farm locations within Kirkuk province and assesses whether various characteristics affect land availability.

2.2.1 Main factors

The main factors of this study are stated in Figure 5 and derived from several sources as follows below (classification method and Urban Planning Department):

2.2.1.1 Classification method

Support Vector Machine (SVM) is among the most effective resiliency regression and classification techniques used in various applications [20]. It is a relatively new supervised learning technique. Numerous studies have confirmed the validity of SVM in categorizing hyperspectral images. The features of the training data and the classification strategy significantly influence classification performance; the analyst should consider these aspects [21]. SVM was applied on Landsat image 2022 to extract the urban and water bodies class as an essential factor in determining the availability of land within solar energy site selection, as stated in Figure 4.

The equation of SVM can be written as [22]:

$$f(x) = \mathrm{sign}\left(\sum_{i}^{r} \propto_i y_i x_i + b\right) \quad (1)$$

$$f(x) = \mathrm{sign}\left(\sum_{i}^{r} \propto_i y_i k(x, x_i) + b\right) \quad (2)$$

A spectral response is represented as a vector (x_i) for each of the r training cases, together with a description of the class item (y_i). The Lagrange multipliers are $\propto_i$ (i =1,..., r), the kernel function is $k(x, x_i)$, and the hyperplane offset from the origin is denoted by b.

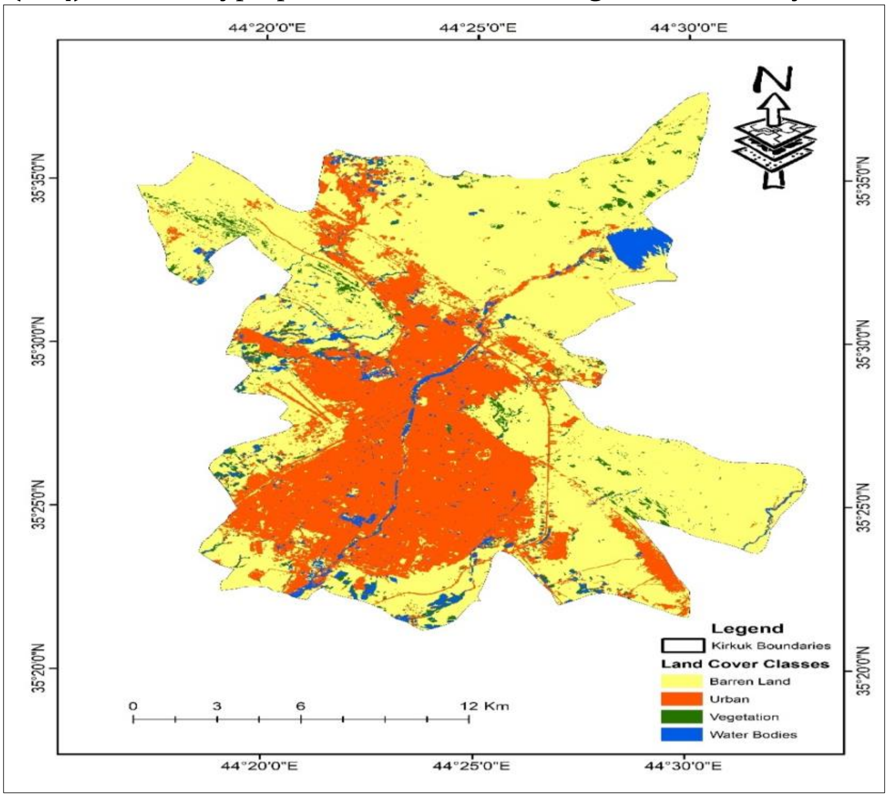

Figure 4: Land cover classes using the SVM classification method

The support vector machine (SVM) was applied on Landsat image 2022 to extract the urban and water bodies class as an essential factor in determining the availability of land within solar energy site selection.

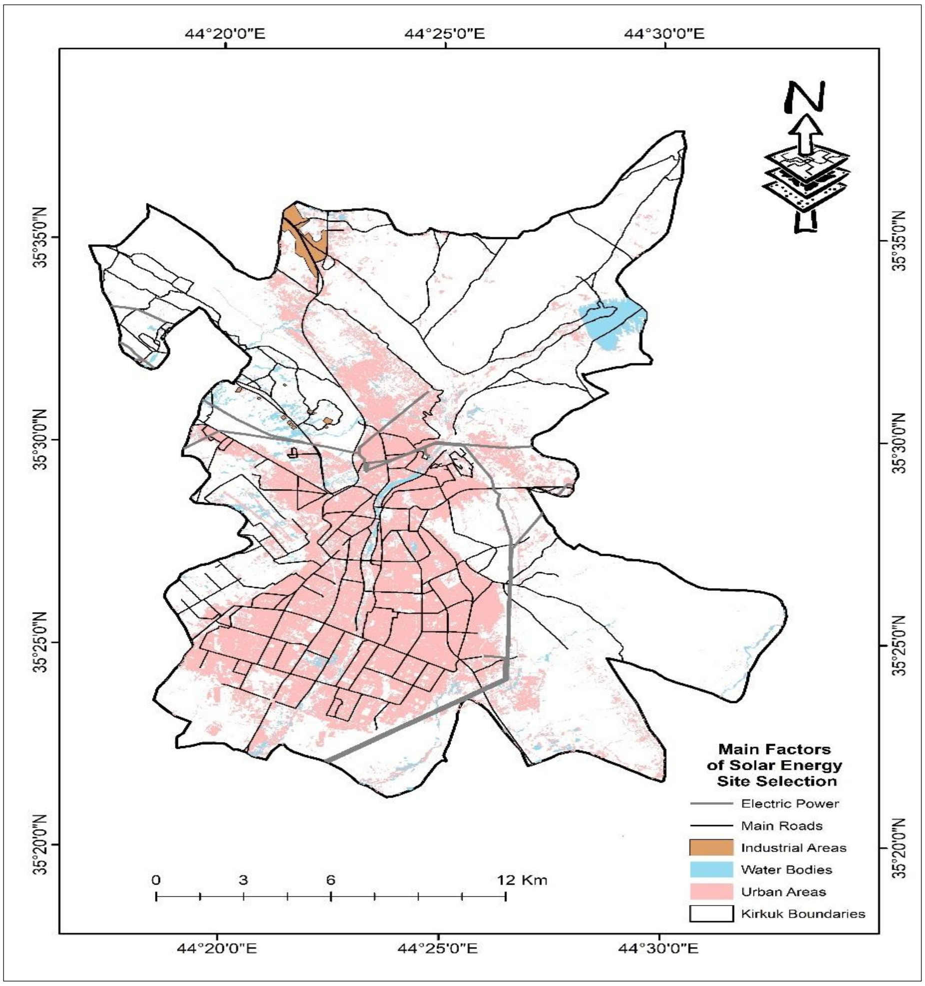

Figure 5: Main factors of solar energy site selection over Kirkuk Province

2.2.1.2 Urban Planning Department

Several feature layers were obtained from the Department of Urban Planning in Kirkuk province. These features are essential in determining the lands available for solar energy installations around Kirkuk, including industrial areas, the road network, and electric power distribution stations.

2.2.2 Filtering and constraints

Analyzing constraints and filtering information is essential to site suitability evaluations [23]. Identifying the best place for an objective or development entails studying multiple factors and constraints. The unsuitable area was often first eliminated from MCDA studies using the AHP, implementing consideration of the constraints, and then the optimum size for each analysis unit was calculated considering the weights obtained by the AHP [24]. A GIS overlay approach was used to rule out unsuitable sites, considering various constraints and limitations under account [25]. In this study, the filtering process was conducted for some essential factors in the study area, including roads with a buffer of 100 m, water bodies with a buffer of 300 m, electric power transmission lines with a buffer of 500 m, industrial with their buffer of 500 m barrier, and the entire urban area. The constraint areas of the study region were extracted by merging all the factors with their settings and subtracting using the analysis tool in ArcMap GIS to produce the available lands for solar farm site selection.

2.3 Land suitability

Land suitability evaluations involve using criteria to identify where land is most and least appropriate for establishing structures and infrastructure [26]. GIS assists the user in determining which areas are most and least suitable for development in terms of land suitability; the outcomes of a GIS analysis may facilitate decision-making in this manner [27]. The analysis of land suitability evaluations involves (i) organizing objectives, (ii) identifying the criteria as well as sub-criteria for achieving the objectives, (iii) modifying data to generate choices and assigning weights, and (iv) estimating decision-making areas by integrating the weighted criteria.

2.3.1 Multi-criteria decision analysis

Multi-criteria decision analysis (MCDA) assists decision-making by weighing several alternatives' positive aspects and negatives for achieving a specific objective [28]. Previously, site selection was practically entirely based on commercial and technical considerations. A higher level of refinement was currently expected. Several social and environmental components must also be met by the selection criteria specified by legislation and government regulations [29]. (Khazael, S. M., & Al-Bakri, M. (2021) [30] combined a multi-criteria decision-making technique, Analytic Hierarchy Process (AHP), and Geographic Information System (GIS) to evaluate the land suitability for solar farms established in Iraq. (Shorabeh, S. N. et al. (2022). [31] integrated GIS-based Multi-criteria Evaluation models with an economic framework to predict the optimal purchasing price for electricity generated by wind turbines.

2.3.2 The Analytic Hierarchy Process

One of the most significant methods, the Analytical Hierarchy Process, described by Saaty et al. (1980), is crucial to selecting the best alternatives [33]. It is a technique for resolving complicated problems by organizing them into a hierarchical framework [34]. Each main criterion and sub-criteria have been considered by the AHP approach [35]. The three principles of AHP are Hierarchical Structuring, Weighting, and Logical consistency [36]. Four main criteria, including distance from electric power stations, solar radiance, slope, and soil types, were used in this study to evaluate the suitability of land sites for solar energy farms over Kirkuk Province. The weights of the main criteria and their sub-criteria were calculated using AHP. Tables 4, 5, 6, 7, and 8 show the pairwise and normalized main criteria and sub-criteria.

The following are essential procedures to calculate the weights of the main and sub-criteria [23]:

a- State the suitable main and sub-criteria.

b- Design a hierarchical framework for the problem with degrees for the purpose, criteria, sub-criteria, and alternatives while considering the outcomes of setting targets.

c- The results were assessed using a pairwise comparison scale to compare each criterion to a particular degree. Table 2 states the AHP preference pair-wise comparison scale.

Table 2: Pair-wise comparison scale for AHP preferences [37]

Intensity of Relative Importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance of one over the other
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or Demonstrated importance
8	Very, very strong
9	Extreme importance

d- For each criterion, determine the maximum eigenvalue, consistency index (CI), consistency ratio (CR), and normalized values.
The maximum Eigenvalue (**λ**max) and the consistency index (CI) for the full pair-wise comparison matrix; the value for max is just the average value of the consistency vector.

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

Where n is the matrix size
Table 3 and Equation 2 show the average random consistency index (RI.)

$$CR = CI/RI \quad (2)$$

Table 3: Average consistency index (RI) [37]

Size of matrix	1	2	3	4	5	6	7	8	9	10
Random consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

e- The consistency of judgments may be examined using the consistency ratio CR=CI/RI.
f- Decide on the matrix repeatedly if the CR value or composite weight is more than 0.10. Table 9 illustrates the CR according to each criteria and sub-criteria matrix.

Table 4: The pairwise and normalized main criteria for solar farm site selection

Pairwise				
Criteria	**Distance from Power**	**Solar radiance**	**Slope**	**Soil type**
Distance from Power	1	2	4	6
Solar radiance	0.5	1	2	4
Slope	0.25	0.5	1	3
Soil type	0.166666667	0.25	0.333333333	1
Sum	1.916666667	3.75	7.333333333	14

Normalize					
Criteria	**Distance from Power**	**Solar radiance**	**Slope**	**Soil type**	**Weights**
Distance from Power	0.52173913	0.533333333	0.545454545	0.428571429	0.507274609
Solar radiance	0.260869565	0.266666667	0.272727273	0.285714286	0.271494448
Slope	0.130434783	0.133333333	0.136363636	0.214285714	0.153604367
Soil type	0.086956522	0.066666667	0.045454545	0.071428571	0.067626576
Sum	1	1	1	1	1

Table 5: The pairwise and normalized distances from electric power stations sub-criteria for solar farms site selection.

Pairwise			
Criteria	**2000 m from power stations**	**4000 m from power stations**	**6000 m from power stations**
2000 m from power stations	1	2	3
4000 m from power stations	0.5	1	2
6000 m from power stations	0.333333333	0.5	1
Sum	1.833333333	3.5	6

Normalize				
Criteria	**2000 m from power stations**	**4000 m from power stations**	**6000 m from power stations**	**Weights**
2000 m from power stations	0.545454545	0.571428571	0.5	0.538961039
4000 m from power stations	0.272727273	0.285714286	0.333333333	0.297258297
6000 m from power stations	0.181818182	0.142857143	0.166666667	0.163780664
Sum	1	1	1	1

Table 6: The pairwise and normalized solar radiance sub-criteria for solar farm site selection

Pairwise			
Criteria	**2.63 - 2.66**	**2.66 - 2.69**	**2.69 - 2.72**
2.63 - 2.66	1	2	3
2.66 - 2.69	0.5	1	2
2.69 - 2.72	0.333333333	0.5	1
Sum	1.833333333	3.5	6

Normalize

Normalize				
Criteria	**2.63 - 2.66**	**2.66 - 2.69**	**2.69 - 2.72**	**Weights**
2.63 - 2.66	0.545454545	0.571428571	0.5	0.538961039
2.66 - 2.69	0.272727273	0.285714286	0.333333333	0.297258297
2.69 - 2.72	0.181818182	0.142857143	0.166666667	0.163780664
Sum	1	1	1	1

Table 7: The pairwise and normalized slopes sub-criteria for solar farm site selection

Pairwi					
Criteria	**0 - 3 %**	**3 - 6 %**	**6 - 9 %**	**9 - 68 %**	
0 - 3 %	1	3	5	9	
3 - 6 %	0.333333333	1	3	7	
6 - 9 %	0.2	0.333333333	1	4	
9 - 68 %	0.111111111	0.142857143	0.25	1	
Sum	1.644444444	4.476190476	9.25	21	
Normalize					
Criteria	**0 - 3 %**	**3 - 6 %**	**6 - 9 %**	**9 - 68 %**	**Weights**
0 - 3 %	0.608108108	0.670212766	0.540540541	0.428571429	0.561858211
3 - 6 %	0.202702703	0.223404255	0.324324324	0.333333333	0.270941154
6 - 9 %	0.121621622	0.074468085	0.108108108	0.19047619	0.123668501
9 - 68 %	0.067567568	0.031914894	0.027027027	0.047619048	0.043532134
Sum	1	1	1	1	1

Table 8: The pairwise and normalized soil types sub-criteria for solar farm site selection

Pairwise				
Criteria	**Brown Soil deep phase**	**Brown soil medium and shallow**	**Lithosolic soil**	
Brown Soil deep phase	1	3	6	
Brown soil medium and shallow	0.333333333	1	2	
Lithosolic soil	0.166666667	0.5	1	
Sum	1.5	4.5	9	
Normalize				
Criteria	**Brown Soil deep phase**	**Brown soil medium and shallow**	**Lithosolic soil**	**Weights**
Brown Soil deep phase	0.666666667	0.666666667	0.666666667	0.666666667
Brown soil medium and shallow	0.222222222	0.222222222	0.222222222	0.222222222
Lithosolic soil	0.111111111	0.111111111	0.111111111	0.111111111
Sum	1	1	1	1

Table 9: Consistency ratio of AHP matrixes

Matrix	CR
Main criteria	0.017106
Distance from Power	0.007939
Solar radiance	0.007939
Slope	0.042514
Soil type	0

2.3.3 Suability spatial analyst

Four main criteria, solar radiance, slope, distance from power stations, and soil types and their sub-criteria, were weighted using the calculation of AHP. The final step of determining the suitability of lands for solar energy farms is a raster calculator within Map Algebra in ArcMap GIS. A raster calculator is a professional tool that deals with multiple tasks of activities such as selection, mathematical calculations, and weighing and merging rasters for acceptance analysis [38]. Finally, the weight rasters of the main criteria are merged to produce a solar energy site suitability map.

3. Results and discussions

3.1 Land availability result

Figure 6 depicts the available land area for constructing a solar energy station surrounding Kirkuk Province. These lands are dispersed throughout the study area's northeastern and northwestern zones, with areas of 20.205 km^2 and 8.843 km^2, respectively. Furthermore, these lands were distributed in the southwestern areas with a measurement of 15.134 km^2, and there are additional separated available lands in the southern part of the study area with a total area of 1.698 km^2. This distribution is based on the factors successfully integrated and employed in this study, which include buffering of main roads, urban areas, distance from water bodies, and distance from industrial regions in Kirkuk Province.

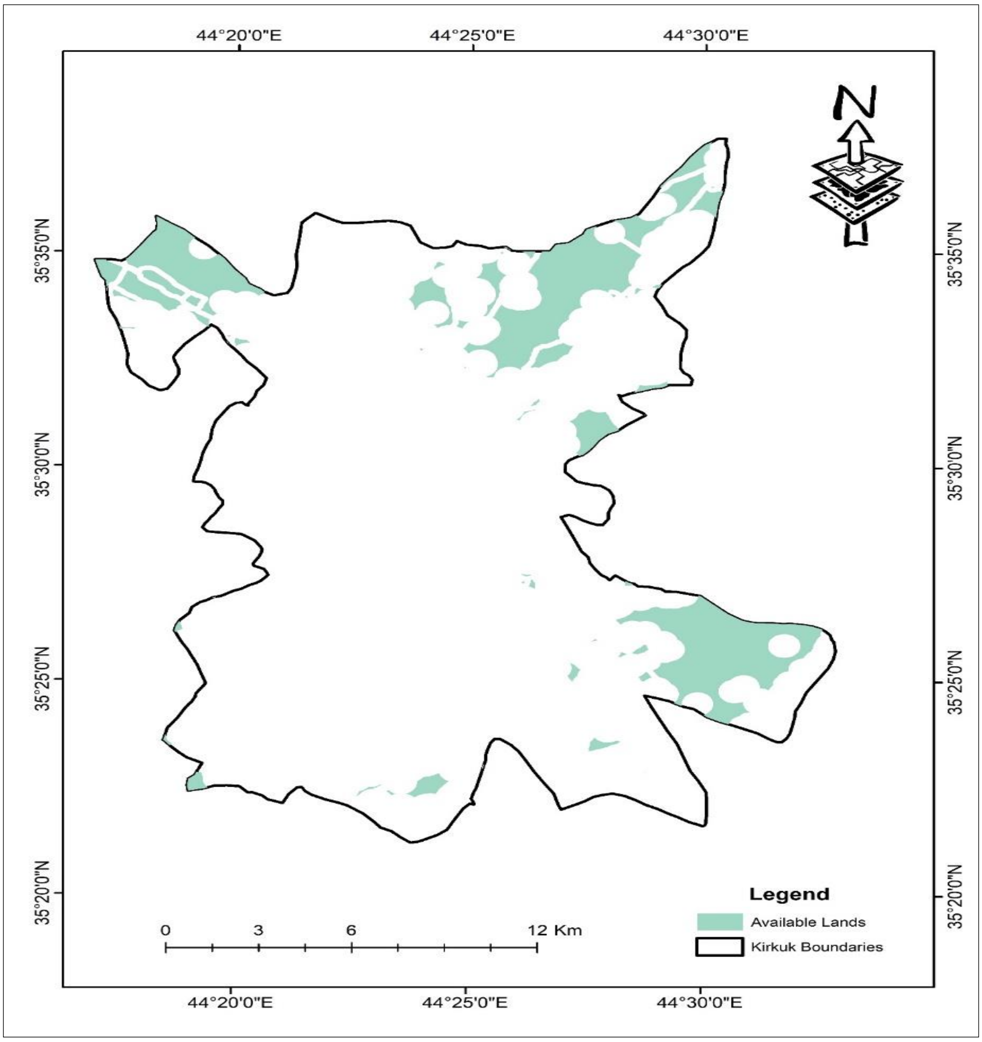

Figure 6: Available lands for solar energy farms surrounding Kirkuk Province

3.2 Main criteria results

3.2.1 Solar radiance map

Figure 7 depicts the spatial distribution of solar radiation over Kirkuk. The research area was divided into three separate classes of solar radiation. The high solar radiance, valued between 2.69 to 2.72 kWh/m^2/d, was dispersed south of the study region. The solar radiance values between 2.66 and 2.69 kWh/m2/d were spread in the middle of the research region. The lowest solar radiance values were found towards the north of the research region, with values ranging from 2.63 to 2.66 kWh/m^2/d. Due to the small scale of the research region, the difference between the kinds of solar radiation for Kirkuk is very quiet. This distribution seems logical since olfactory radiation reduces toward the north of the equator.

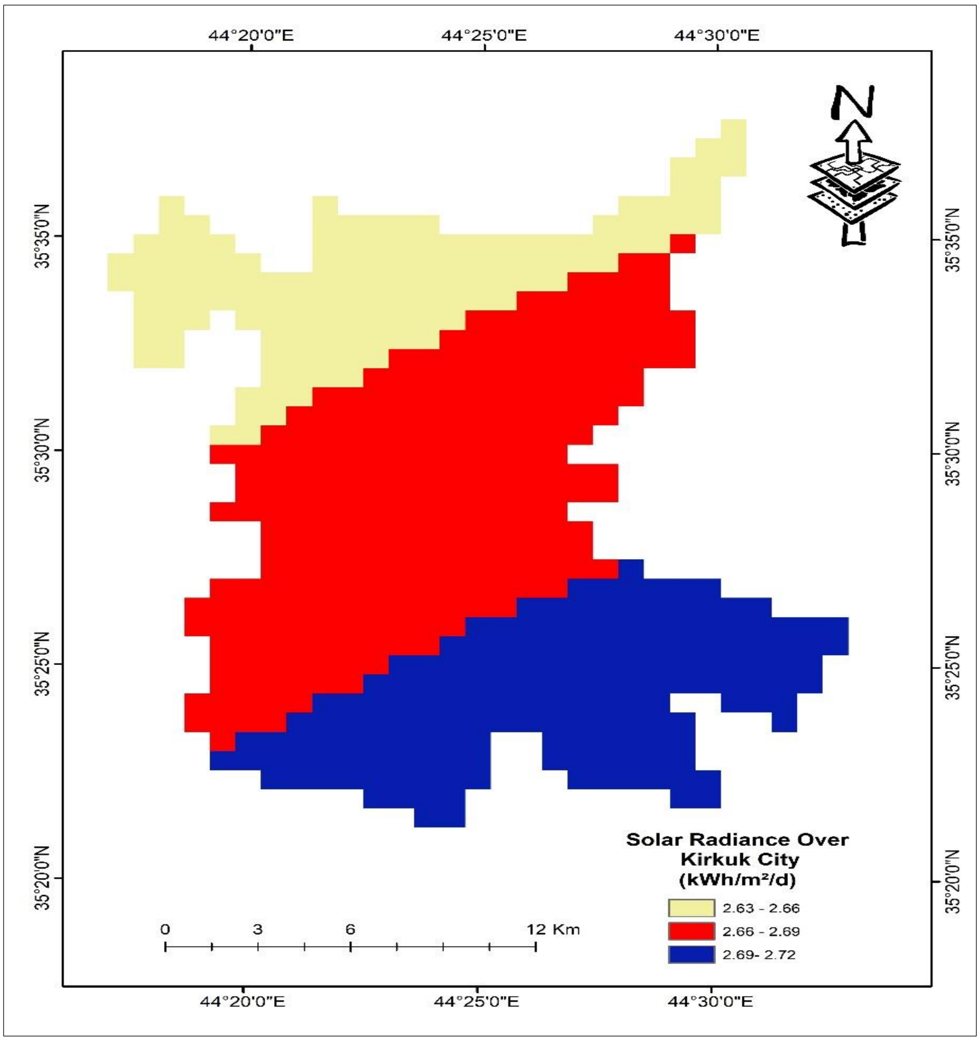

Figure 7: Spatial distribution of solar radiance criteria over Kirkuk Province

3.2.2 Slope map

Figure 8 shows a map of the spatial distribution of slopes in Kirkuk. Kirkuk Province is known to be located within undulating areas, and the elevations differ from one place to another. The slope in the study area was classified into four categories, represented in blue, which represent slope values from 0 to 3%, and it was considered the most suitable slope for the construction of projects. The second slope class has values ranging from 3 to 6%, represented by the light green color. As for the third class in orange, its value ranges between 6 and 9%. The fourth class, which is not desirable for the construction of projects on it, ranges between 9 and 68% and is represented by the red color, and it is widely spread in the northern and northeastern regions of the study area. The categories of slope somewhat overlap and are not separate.

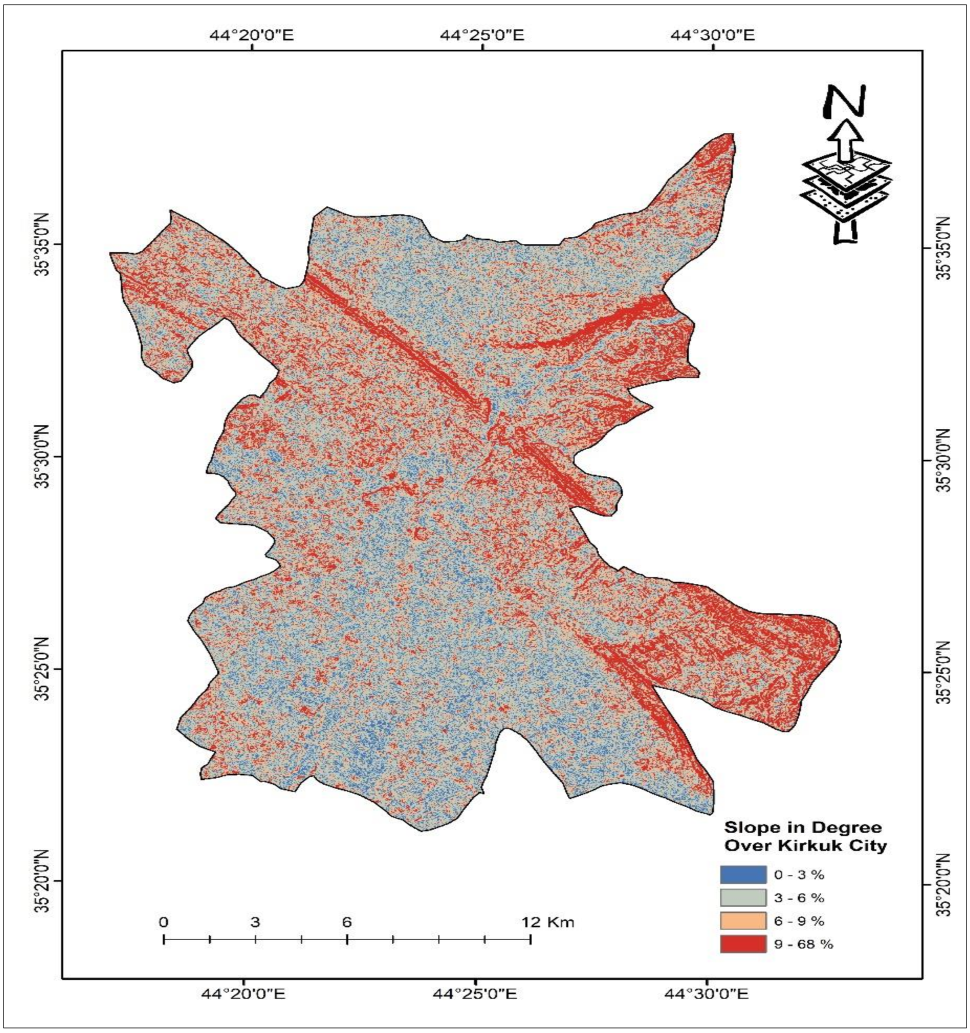

Figure 8: Spatial distribution of slopes criteria in % over Kirkuk Province

3.2.3 Distance from power stations

Figure 9 depicts the distances from the Kirkuk Province electric power stations at 2000, 4000, and 6000 m, represented by yellow, light violet, and pink, respectively. These distances encompass the whole research area except for the north-east and sections of the northern and southern areas. For the installation of solar energy farms, distances of 2,000 m from the stations are preferable to distances of 4,000 and 6,000 m. The area was predicted to be 116.74 km^2 for lengths of 2000 m and 119.17 km^2 for distances of 4000 m; the smallest area is 60.97 km^2 for a distance of 6000 m from the electric power stations.

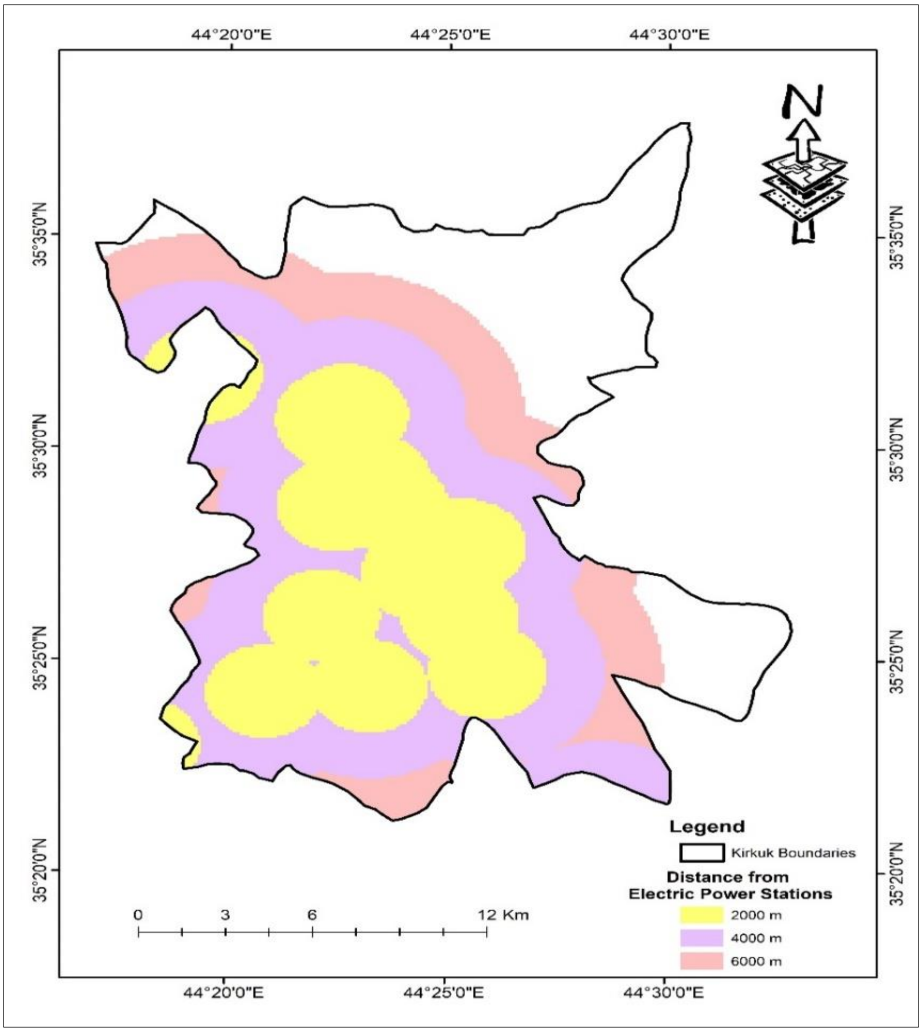

Figure 9: The distance from electric power stations criteria over Kirkuk Province.

3.2.4 Soil types

Figure 10 shows the spatial distribution of the three soil types in the study area, Kirkuk Province: Brown Soil deep phase, Brown soil medium and shallow, and Lithosolic soil. The first type, the dominant type, is the Brown Soil deep phase. It covers the north and north of the province center and extends to the southwest, represented by the light purple color, and its area is about 235.531 km^2. The second type is Brown soil, medium and shallow, and is distributed in the east and southeast of the study area and is indicated in light green with an area estimated at 97.899 km^2. The third type, which has a smaller area, is Lithosolic soil, distributed in small specific areas in the south and west of the study area with a total area of 54.428 km^2.

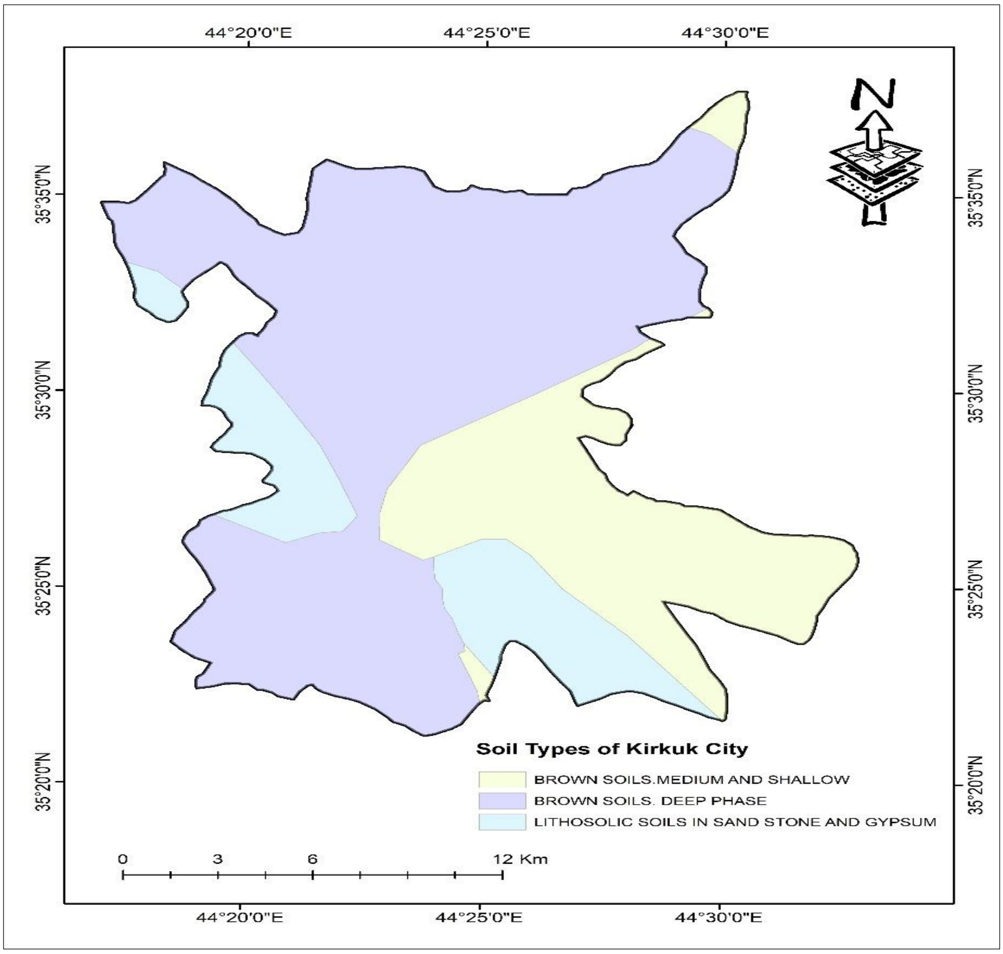

Figure 10: Spatial distribution of soil types criteria over Kirkuk Province

3.3 Criteria weights

Table 10 indicates the final weights of the sub-criteria selected to evaluate the suitable sites for constructing solar energy farms. These weights of sub-criteria were obtained from the AHP process. Rasters of all sub-criteria were over-less in map algebra raster calculation, which led to classifying the suitable lands according to appropriateness for setting up the solar energy farms.

Table 10: The final weights of the main criteria for solar farm site selection

Main criteria	Weights	Sub - criteria	Weight	Final weights
Distance from Power	0.507274609	2000 m	0.538961039	0.273401251
	0.507274609	4000 m	0.297258297	0.150791587
	0.507274609	6000 m	0.163780664	0.083081772
Solar radiance	0.271494448	2.63 - 2.66	0.538961039	0.14632493
	0.271494448	2.66 - 2.69	0.297258297	0.080703977
	0.271494448	2.69 - 2.72	0.163780664	0.044465541
Slope	0.153604367	0 - 3 %	0.561858211	0.086303875
	0.153604367	3 - 6 %	0.270941154	0.041617744
	0.153604367	6 - 9 %	0.123668501	0.018996022
	0.153604367	9 - 68 %	0.043532134	0.006686726
Soil type	0.067626576	Brown Soil deep phase	0.666666667	0.045084384
	0.067626576	Brown soil medium and shallow	0.222222222	0.015028128
	0.067626576	Lithosolic soil	0.111111111	0.007514064
Sum				1

3.4 Land suitability

Figure 11 states the spatial of suitable land for solar energy farms over Kirkuk; the highly suitable lands with red color were distributed in the northwest and middle north of the study area with a total area equal to 7.4304 km^2. The medium suitable lands were spread in the southeast, represented by yellow, with a total area estimated at 2.9376 km^2. The last alternative distribution was the low suitable lands, which cover some small parts in the south part of the study area, referred to by green color, with an area of 1.8432 km^2.

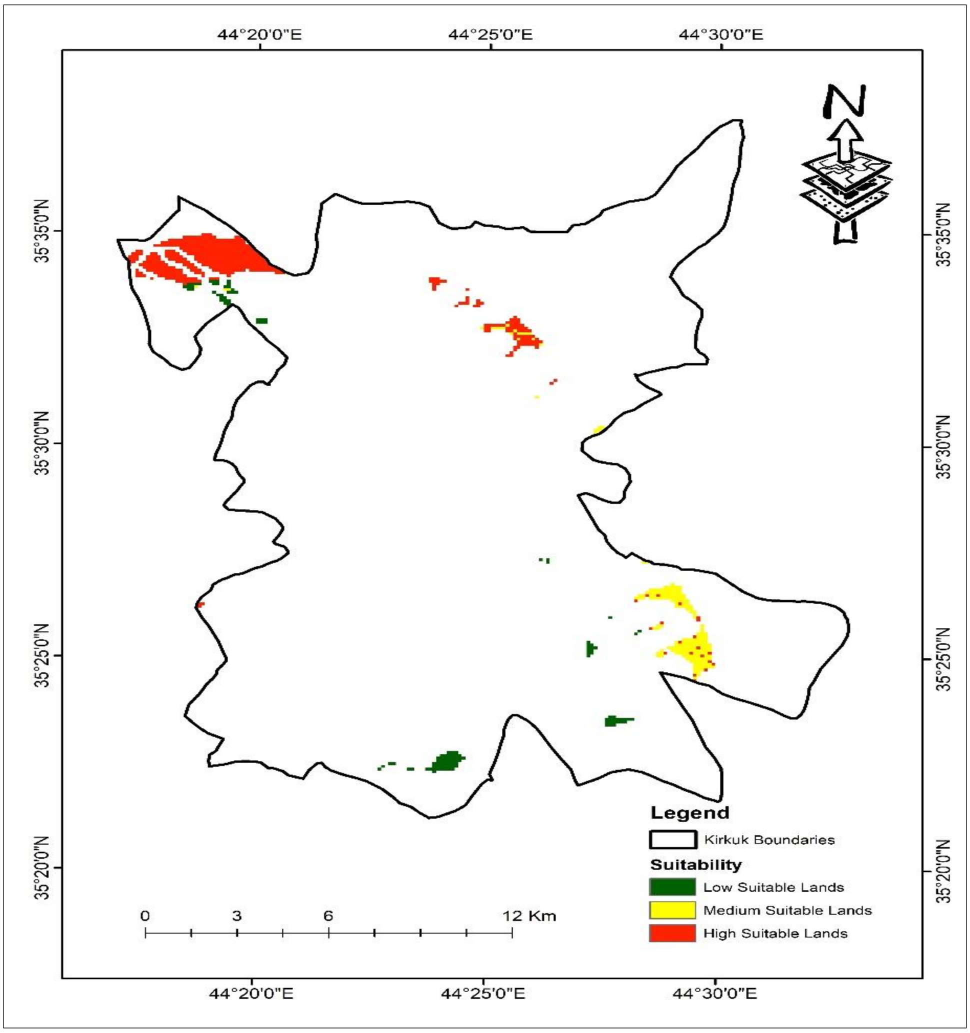

Figure 11: Suitability of lands for solar energy farms surrounding Kirkuk Province

4. Conclusion

Land availability concentrates on the constitutional and physical accessibility of land, whereas land suitability evaluates the natural and physical attributes of the property to decide if it is suitable for a given purpose. Both principles are critical in the site selection process to guarantee that the chosen location satisfies legal criteria and is suitable for the desired development. As a developing country with a power shortage, Kirkuk Province needs to find alternatives to electric energy through renewable energy. It must, ultimately, consider an exclusive advantage for selecting the best locations for solar energy farms. Planning and decision-making must incorporate more precise and improved tools such as GIS. The AHP algorithm has the potential to be employed in multi-criteria decision-making. Suitable areas were identified for solar energy farms in Kirkuk Province using the AHP approach. The oversight and study of several factors, such as major roads, bodies of water, residential areas, electric power lines, and industrial zones, affect the availability of land. Distance from electric power stations, solar radiance, slope, soil types, and their sub-criteria were utilized and weighted to evaluate land suitability areas for solar energy farms.

The findings of the available lands reveal their distribution in three regions with significant dimensions, including the northeast, northwest, and southeast, with an estimated total area of 40.182 km^2. Separate small areas, amounting to 1.698 km^2, were also found in the remaining parts of the research area. The highly suitable lands covered a total area of 7.4304 km^2 and were dispersed throughout the northwest and center north of the research region. Medium-suitable areas were dispersed in the southeast with an estimated total area of 2.9376 km^2. Low-suitability regions that are appropriate for development cover an area of 1.8432 km^2 south of the research area. In order to increase the suitable lands for solar energy farms, future research ought to contain surrounding areas and districts most comprehensively, considering this study was limited to areas within the administrative boundaries of Kirkuk Province.

Using multi-methods and additional factors will improve the site selection process in future work.

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