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AHP with GIS for a Preliminary Site Selection of Wind Turbines in the North West of Jordan

Abdel Rahman Al-Shabeeb, Rida Al-Adamat*, Atef Mashagbah

Department of Geographic Information Systems and Remote Sensing, Institute of Earth and Environmental Sciences, Al Al-Bayt University, Mafraq, Jordan
Email: *ridaali@aabu.edu.jo

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Abstract

The aim of this study was to identify potential sites for wind turbine in the North West of Jordan. The Analytic Hierarchy Process (AHP) was used in a novel approach to identify the potential sites for the wind turbine in the study area based on five physical criteria (Wind Speed, Rainfall, Slope, Altitude and Land use) that affect the wind turbine sites. The importance of each criterion was based on experts' opinions. The ratings for each criterion were based on the available literature review. The consistency ratio between the experts' opinions was evaluated using the pairwise comparison method and a final weight was computed for each criterion. A wind turbine suitability map was generated using the weighted linear combination (WLC) method within GIS environment. It was found that 45% of the study area has high and very high suitability for wind turbine. In conclusion, this research will contribute to the enhancement of the available renewable energy resources in Jordan if the selected sites will be utilized for wind turbine.

Keywords

GIS, AHP, Site Selection, Wind Turbine, Jordan

1. Introduction

Energy is vital for sustaining life on earth. It will remain the basic foundation for human and economic development and world peace. World energy demand has been increasing exponentially. It has been estimated that the world population will reach 8 billion by 2020. On the other hand, it is very clear that conventional energy resources are limited on earth. The rapid depletion of fossil-fuel resources, the limited reserves and their unstable prices on a worldwide basis have necessitated an urgent search for alternative energy and significantly increased the interest in renewable energy sources.

Therefore, it is essential that other sources are exploited in such a way that present and future generations are able to flourish without jeopardizing their life supporting systems [1].

Of the many alternatives, photovoltaic and wind energy has been considered as promising toward meeting the continually increasing demand for energy [2] [3]. In the 1990s, global environment concerns have been increasing, where world attention has been focused on global warming caused by greenhouse gases. Today, wind and photovoltaic generators are utilized in such applications as water pumping, lighting, electrification of remote areas and telecommunications [2] [4]-[6].

The wind energy is one of the most important ways for sustainable energy development projects. The feasibility of wind turbine project should be done before its construction, because the cost of wind turbine project is rather high.

In Jordan, the total energy consumption is exponentially increasing. In the last two decades, the rising cost of energy has put a heavy burden on the government budget and difficult challenge for Jordan economy due to country's meagre local resources of economic energy and its reliance on imports.

Jordan has no significant fossil fuel energy resources of its own and must rely on neighbouring Arab oil producing countries. It imports almost 95% - 97% of its energy needs in the form of oil and petroleum products [7]-[10].

According to [11] energy imports reached approximately 13% of Jordan Gross Domestic Product (GDP) in 2009. It is estimated that the levels of energy and electricity consumption in Jordan will be doubled in 15 years. Also, the electricity consumption is forecasted to grow at an annual rate of 6%. Jordan has set targets regarding its policy for renewable energy resources. These targets are established in the Strategy of Energy Sector. In this policy, 10% of the energy generation capacity should come from renewable energy resources until 2020. By 2020, the government should have investments of 300 - 600 MW of solar capacity and 530 - 660 MW of wind capacity for electricity generation to meet the expectation of renewable energy share in the overall electricity generation in the country [11].

The highly demanding energy era of the present necessitates the effective utilization of the non-conventional energy resources. Wind energy is one of the most promising alternatives.

Geographic Information System (GIS) could be utilized for renewable energy project siting. Site selection criteria can be developed to determine the optimum locations for wind farms and even positions of individual turbines to maximize resource potential. In this research, Analytical Hierarchy Process (AHP) in combination with GIS will be used for a preliminary site selection for wind turbines in the North West of Jordan.

2. Methodology

2.1. Study Area

The study area is located in the North West of Jordan (**Figure 1**). It is located in the Northern west of the Yarmouk River basin and Jordan Valley. Most of the governorate

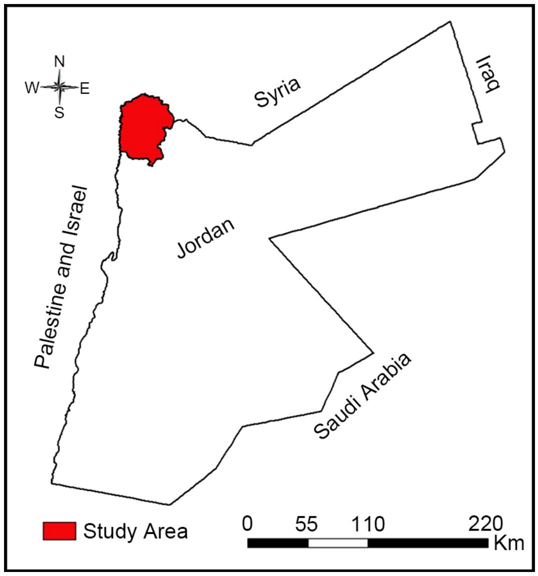

Figure 1. Study area.

in the study area are part of the Hawran plateau, which covers northern Jordan, and South West of Syria. The North West of Jordan has three governorates (Jeresh, Ajloun and Irbid). The total area of the study area is 2396.82 km^2 which represent approximately 2.68% of the total area of Jordan.

2.2. Site Selection Methods

Multiple-criteria decision-making analysis (MCDA) technique is important for renewable energy resources management, which involves choosing criteria and decision options [12]. In the literature, several methods of MCDA have been adopted within GIS environment (e.g. [13]-[20]).

Weighted linear combination (WLC) is a major technique used for site selection within GIS environment. The use of the WLC in a GIS environment for the selection of potential sites for wind turbine has been widely used over the past years (e.g. [21]-[25]).

The AHP method is based upon the construction of a series of Pairwise Comparison Matrices (PCMs), which compare all the criteria to one another. In the PCMs a comparison between all possible pairs of criteria is conducted to determine which one is of a higher priority. A scale from 1 to 9 for PCMs elements was by suggested [26] (**Table 1**). The value of 1 indicates that the criteria are equally important and a value of 9 indicates that the criterion under consideration is extremely important compared to the other criteria. PCMs include a consistency check to identify judgment errors and to calculate a consistency ratio.

Based on [27] and [28] there are three main stages to make decisions based on PCMs in the AHP method operations:

- The determination of the important criteria in the problem (Wind turbines sites),
- The assessment of the relative importance of each criterion to each other. This is usually done by experts using a scale from 1 to 9,

Table 1. Scales for the pairwise comparisons method (adapted from [26]).

Intensity of Importance	Definition	Explanation
1	Equal importance in a pair	Two criteria contribute equally to the objective
3	Moderate importance	Judgment and Experience slightly favor one criterion over another
5	Strong importance	Judgment and Experience strongly favor one criterion over another
7	Very strong importance	Judgment and Experience very strongly favor one criterion over another
9	Extreme importance	The evidence favoring one criterion over another is of highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed
Reciprocals	Values for inverse comparison	If criterion i had one of the above numbers assigned to it when compared with criterion j , then j has the reciprocal value when compared with i

- The assessment of the consistency through pairwise comparisons to assign the Consistency Ratio (CR). This stage involves the following operations:
  - Calculating the priority vector for a criterion.
  - Computing λmax (The Principal Eigenvalue).
  - Computing the Consistency index (CI).
  - Determining the appropriate value of the random consistency ratio (RI).
  - Calculating CR.

Based on [26], **Table 2** provides a summary for the average random consistency indices (RI) using N number of criteria (N = 1 up to N = 15).

2.3. Adopted Selection Criteria

As stated earlier in this article, there are many studies concerned with the wind turbine site selection using GIS. In this research, these studies were used to define the wind turbine site selection criteria in combination with the local experts' opinions. Based on [21] five physical criteria were used this research, which include; Wind Speed (W), Rainfall (R), Slope (S), Altitude (A) and Land use (L). **Table 3** provides a justification for the importance of each criterion.

After defining the physical criteria for selecting Wind turbines sites, a structured face to face interview was conducted with 5 local experts (Renewable Energy and GIS) from Al-al-Bayt University/Jordan in March 2016. The questionnaire (**Table 4**) was used to identify the relative importance of the selection criteria. This questionnaire was based on the scale of 1 - 9 to assess the relative importance of each criterion.

The analytic questionnaire was used to check the consistency ratio (CR) and identify the weights for the selected criteria.

Table 2. Average random consistency indices (RI) for different number of criteria (adapted from [26]).

Number of criteria (N)	1	2	3	4	5	6	7	8
Random consistency indices (RI)	0	0.0	0.58	0.90	1.12	1.24	1.32	1.41
Number of criteria (N)	9	10	11	12	13	14	15	
Random consistency indices (RI)	1.45	1.49	1.51	1.54	1.56	1.57	1.59	

Table 3. Selection criteria justification.

Criteria	Justifications
Wind Speed (W)	Wind turbines depend on having enough wind speed to rotate the wind turbine blades to generate electricity
Rainfall (R)	Areas with more rainfall will generate more runoff which will have an effect on the wind turbines sites
Altitude (A)	Areas with higher altitude have the potential of getting more winds than their surrounding
Slope (S)	Areas with high slope will generate more runoff. Also, high slopes cause technical difficulties when installing wind turbines
Land use (L)	Land uses are important for environmental and socio-economic reasons. It is imperative not to degrade the economical value of the land that has a fundamental use. Also, it is significant not to damage the environment; mainly the wild life (Flora and Fauna)

Table 4. A sample from the questionnaire used to determine the relative importance of criteria.

Criteria	More importance								Equal importance	Less importance								Criteria
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
W																		W
R																		R
A																		A
S																		S
L																		L

3. Data Collection

The selection of Wind turbines sites requires the availability of suitable data; both primary and secondary data. The primary data collected in this research was based on the interviews with experts to calculate the weight for each criterion. The secondary data were collected from various national Jordanian and international organizations. Table 5 shows the major GIS data used in this research.

Table 5. Secondary data used in this research and their sources.

GIS Data	Scale/Resolution	Source
Wind Speed	1:250,000	HCST, (2007)
Climate	1:250,000	
Slope	1:250,000	RJGC, (1995)
Land use/Land cover based on Landsat TM Data	30 m	USGS, (2013)
Slope based on ASTER DEM	30 m	USGS, (2011)

HCST: Higher Council for Science and Technology; RJGC: Royal Jordanian Geographic Centre and USGS: United States Geological Survey.

4. Data Analysis and Results

4.1. AHP Analysis

Pairwise Comparison (PWC) was applied to check the consistency of weights given by the experts for the selection criteria. The traditional implementation of AHP used in this study was based on [27] [29] [30].

The consistency ratio (CR) was calculated for the experts opinions to check if it is less than or equal to 0.1, thereby to check the suitability of each pairwise comparison matrix for the AHP analysis.

The pairwise comparison matrix produced for the local experts is listed in Table 6. Table 7 lists the computed Principal Eigenvalue (λmax), the Consistency index (CI), Random consistency ratio (RI), and the Consistency Ratio (CR) of the evaluations of all the experts. It can be seen that the computed CR is less than or equal to 0.1 for all experts. This indicates that experts' weightings are consistent and suitable of the implementation of the AHP approach. The results of the conducted questionnaire are summarized in Table 6.

4.2. Site Selection Criteria (Weights and Ratings)

To identify the potential sites for the wind turbines, site selection depends on the ratings and the weights of each thematic layer. As listed in Table 7, the weights of each site selection criterion for the wind turbines has been calculated based on experts' opinions. While, the ratings for the five physical criteria were based on the literature review. Using the WLC technique, the rate was assigned to each criterion in the scale of 1 to 4. This is the scale adopted by most of the related literature to date. Table 8 summarizes the ratings of the selection criteria for wind turbines within the study area.

4.3. Criteria Analysis

All related thematic layers were integrated using ArcGIS® in order to derive a map depicting the suitable areas for the wind turbines within the study area. The total weight of each map of the final integrated layer was computed using Equation (1):

$$\mathrm{Si} = (\mathrm{Ww} \times \mathrm{Wr}) + (\mathrm{Rw} \times \mathrm{Rr}) + (\mathrm{Sw} \times \mathrm{Sr}) + (\mathrm{Aw} \times \mathrm{Ar}) + (\mathrm{Lw} \times \mathrm{Lr}) \quad (1)$$

Table 6. The pairwise comparison matrix of the experts' opinions.

Criteria	W	R	A	S	L
W	1	1	2	2	2
R	1	1	2	2	1
A	0.5	0.5	1	1	1
S	0.5	0.5	0.5	1	0.5
L	0.5	1	1	2	1
Sum	3.5	4	6.5	8	5.5

Table 7. The computed values of weights (priority vector), CI, RI and CR for experts opinions.

Criteria	Weights (priority vector)	λmax	CI	RI	CR
W	0.291				
R	0.255				
A	0.146	5.5	0.125	1.12	0.1
S	0.112				
L	0.196				

where, "w" represents the weight of each criterion (Table 6), and "r" represents the rating of each criterion (Table 8): Wind Speed (W), Rainfall (R), Slope (S), Altitude (A) and Land use (L). "Si" is the wind turbine index, which is a dimensionless number that identifies the suitable sites for the wind turbine in the area.

The five GIS layers representing the physical criteria were subjected to a GIS analysis in order to select the optimum sites for wind turbines in the study area based on these criteria. In order to calculate the wind turbine index, the following spatial analysis techniques were used within ArcGIS®:

- Updating attribute tables of each thematic layer,
- Converting to a raster format,
- Deriving Slope from ASTER DEM,
- Extracting Land use from Landsat TM imagery using unsupervised classification,
- Raster reclassification,
- Raster calculation (integrated to produce the optimum sites for the wind turbine within the study area).

The following Figures 2-6 show each criterion after multiplying its ratings with its weight.

The WLC method was then used to integrate the generated suitability maps of the individual physical criterion into a one suitability map for wind turbine in the study area (Figure 7). The study area was classified into five classes based on the minimum and maximum of the criteria maps as listed in Table 9.

Table 8. The rating of the five selection criteria.

Criteria	Range	Rating
W (m/s)	<5.35	1
	5.35 - 6.2	2
	6.2 - 8	3
	>8	4
R (mm)	>700	1
	500 - 700	2
	300 - 500	3
	<300	4
A (m)	<1000	1
	1000 - 1500	2
	1500 - 2000	3
	>2000	4
S (%)	>45	1
	30 - 45	2
	15 - 30	3
	<15	4
L (Class)	Forest, surface water	1
	Industrial	2
	Agriculture	3
	Pasture and dry land, mixed pasture	4

Table 9. Areas and percentages of suitability classes.

Suitability	Area (km^2)	% of Study Area
Very Low	311.59	13
Low	359.52	15
Moderate	407.46	17
High	790.95	33
Very high	527.3	22
Total	2396.82	100

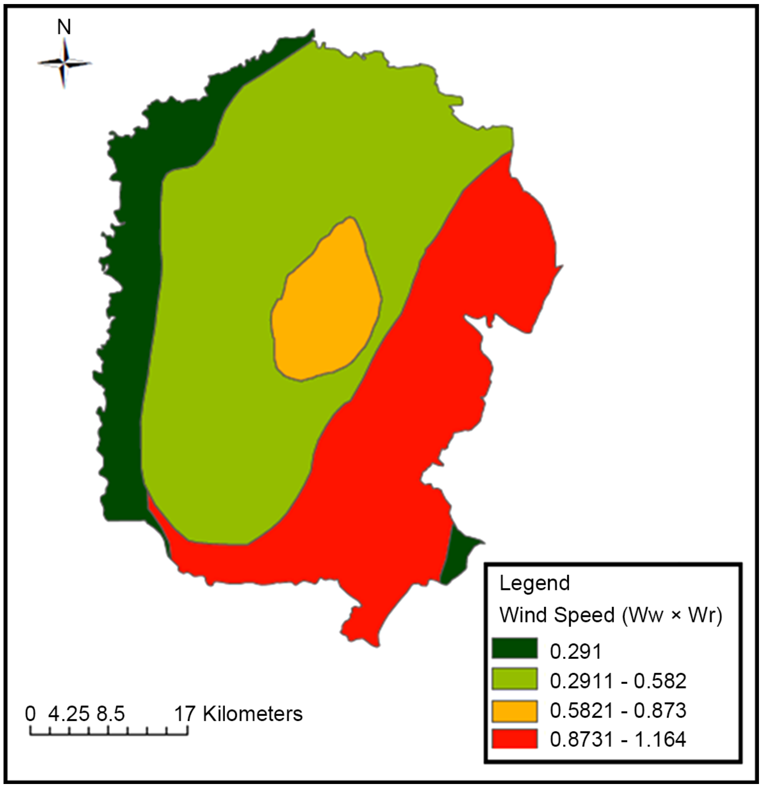

Figure 2. Wind speed (Ww × Wr).

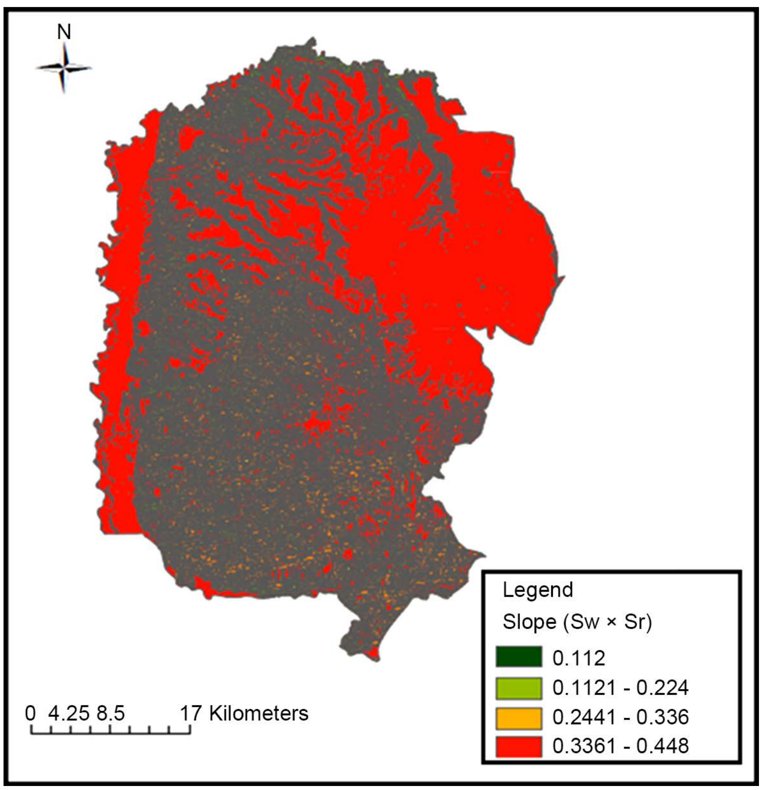

Figure 3. Slope (Sw × Sr).

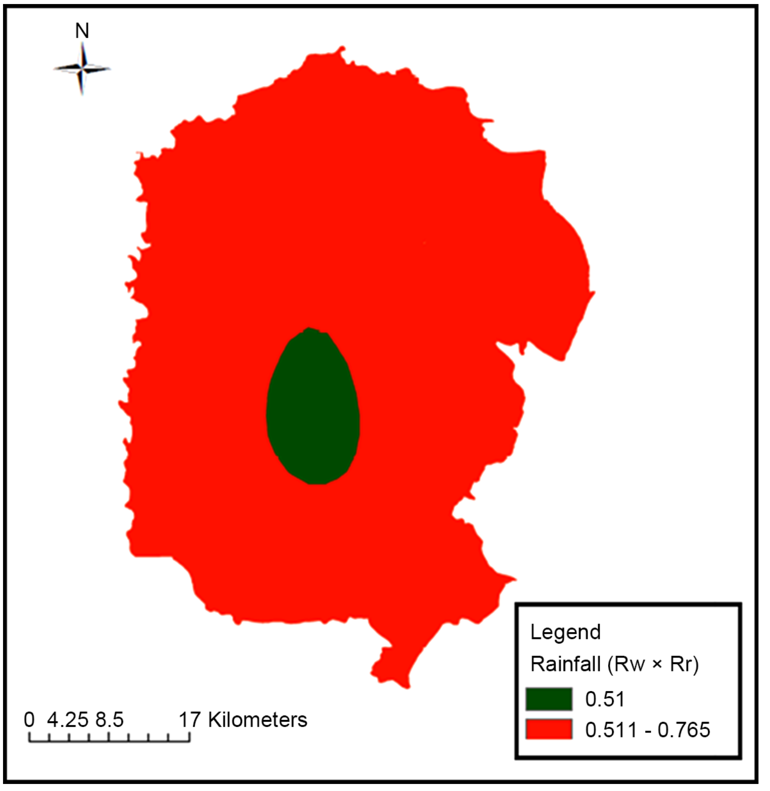

Figure 4. Rainfall (Rw × Rr).

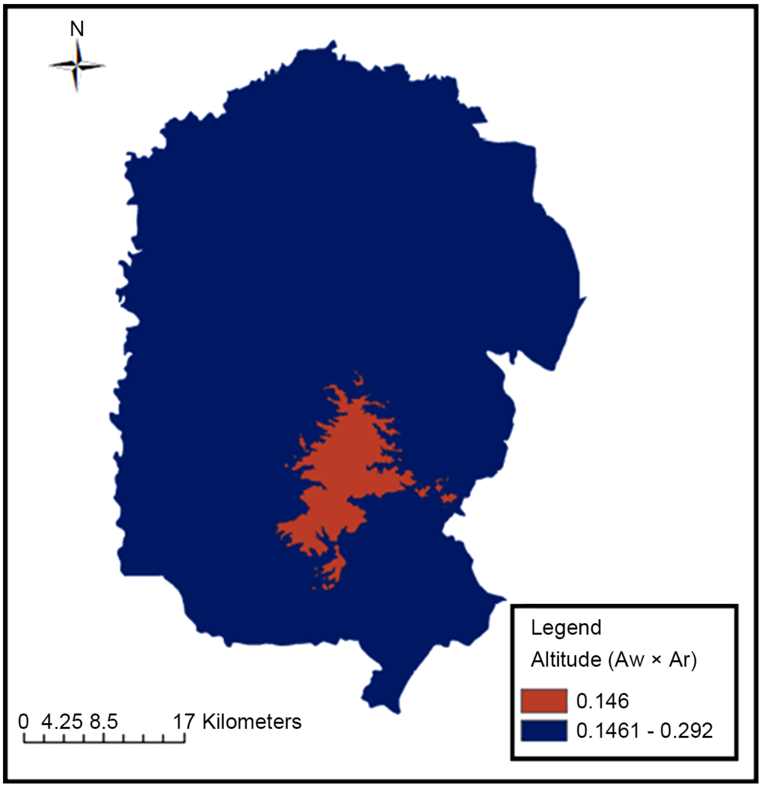

Figure 5. Altitude (Aw × Ar).

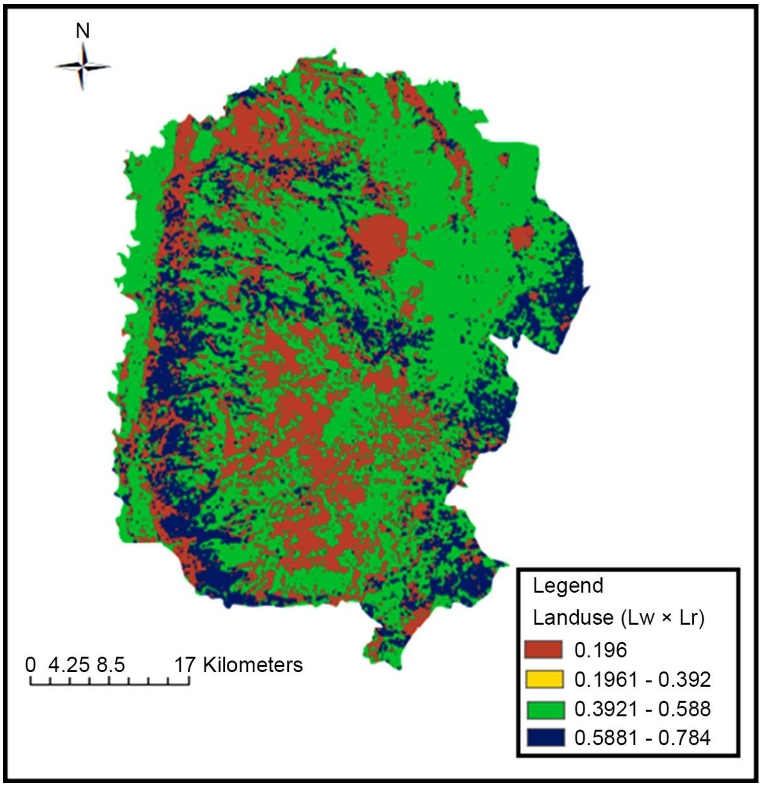

Figure 6. Land use (Lw × Lr).

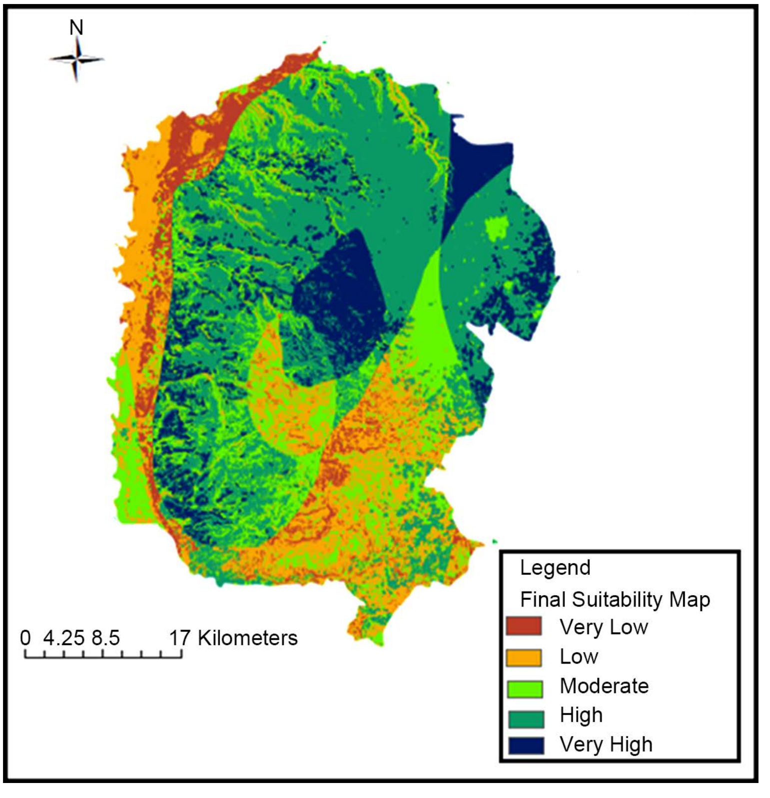

Figure 7. The final suitability map.

5. Discussion and Conclusion

The sites selected for the wind turbine necessitate the simultaneous use of several decision support tools such as Geographical Information System (GIS), remotely sensed data and Multi-Criteria Decision Analysis (MCDA). In this research, an attempt was made to have a preliminary site selection for wind turbine in the North West of Jordan based on the available physical data for the study area using the analytic hierarchy process (AHP) within GIS environment.

The results of this research showed that based on the physical criteria only, the areas that have high and very high suitability represent 45% of the total study area. The findings of this research could be used to assist in the efficient planning of the renewable energy (Wind Turbine) management to ensure a sustainable development of the renewable energy (Wind Turbine) in Jordan and in other areas suffering from energy shortages. In conclusion, this research will contribute to the enhancement of the available renewable energy resources in Jordan if the selected sites will be utilized for wind turbine. This will contribute to the sustainable socio-economic development of Jordan. Based on that, it is recommended to utilize the outcomes of this research and the adopted methodology by other researchers to refine the site suitability map after adding more site selection criteria.

Selecting suitable sites for wind turbine projects is a complex process involving not only physical criteria; it also involves other economical, social, physical, political, environmental criteria that might lead to different results. Based on that, it is recommended to conduct further investigation within the selected sites to test their suitability for renewable energy purposes (wind turbine).

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