Integrating AHP and GIS as a decision-making tool for the optimal allocation of wind farm: A case study of Syria

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Abstract: Nowadays, renewable energy is commonly applied to ensure a sustainable development and minimize the reliance on fossil fuels. Wind is considered as one of the most significant inexhaustible sources of energy for power generation through turbines. However, choosing an appropriate site of wind farm and designing a turbine array to fit it are a key issue to success as expected. Geographic Information Systems (GIS) technology has been widely accepted in a number of areas as a decision support system based on analyzing geospatial data to facilitate reaching desired results in shorter time and less cost. The process of establishing the best-suited location of wind parks require analysis of spatial multi-criteria within a GIS environment using the Analytic Hierarchy Process (AHP). This research focuses on defining the main factors that influence wind energy development and presents GIS-based land suitability analysis model to determine the optimal allocation of wind farm in Syria. As a part of this study, the procedure of designing geodatabase for wind power plants is illustrated that includes conceptual, logical, and physical design phases. The results show efficiency of the integrated technique in site suitability evaluation of the presented case.

1. Introduction
Global warming as an essential form of climate change is a major factor leading to a higher incidence of natural disasters. It has also an impact on population health status of affected communities that gives rise to humanitarian crises [1]. This phenomenon is resulted from the carbon dioxide releases due to many human activities such as burning of fossil fuels [2]. Nowadays, renewable energy is considered as a suitable option to produce clean energy that seek to minimize greenhouse gas emissions and to solve the problem of its increasing demand around the world [3]. The green energy is environmentally friendly and its resources are available free of charge all over the world [4]. The use of wind power is quickly growing as the one of those commonly applied renewables that relies on mean value of wind speed and variation of this speed [5]. Determination of the ideal site of wind farms plays a vital role in wind power development to achieve a satisfying turbines performance [6].

Geographic Information Systems (GIS) is a type of decision-making support system, which is used for collecting, processing, analyzing and visualizing geospatial data and information [7, 8]. It is a powerful tool for spatial siting of wind parks based on multi-criteria decision analysis (MCDA) by comparing the alternatives within the framework of the determined criteria [9]. The most popular and practical approach to deploy MCDA is the AHP that is defined as an organised process to build weighted factors to split the decision-making method into a simple steps [10]. The AHP provides a ranking of options with regard to decision-makers to fulfil the objective that can be hierarchically performed for
the case study [11]. The extensive use of AHP for providing solutions to a multi-criteria issue is attributed to the fact that it takes into account both tangible and intangible criteria [12].

Accordingly, identifying an appropriate site of wind farm is complex and difficult process, where the evaluation is based on selecting the most suitable location among the other alternatives [13]. It contains different factors such as economic, environmental and physical restrictions, which should be described correctly during the decision-making stages with reference to the characteristics of the project. Furthermore, the estimation of weights to these various parameters is very critical and should be performed using AHP [14]. The main objective of this paper is to design and implement a geodatabase for wind farms of a pilot study, which addresses the application of a GIS in analyzing data related to land suitability selection for determining the optimal allocation of wind power stations. Several GIS functions are utilized including spatial multi-criteria assessment model using ArcGIS 10.2. Figure 1 indicates a schematic diagram for the general methodology of the framework in this research.

![Figure 1. Schematic flowchart methodology of wind farm site selection](image)

2. Materials and Methods
As previously mentioned, wind power is the most common environmentally friendly and alternative resource of renewable energy to generate electricity through turbines, which should be erected especially in windy sites to reach the maximum performance and efficiency. The increasing wind energy investment is related to land-use planning, which has two different goals, economic benefit and nature preservation, both linked to the concept of sustainable development [15]. Therefore, choosing a suitable location of wind farm requires taking into account a set of factors and balancing several purposes. This section focuses on the description of the study area, data collection and identification of decision criteria.

2.1 Study area
The case study is situated in the Middle East in the region of Syria that stretches northward from the western end of Asia and consists of the capital (Damascus) and thirteen governorates, as shown in Figure 2. The land has four distinct seasons and a climate that is well suited for variety of activities. Syria is bordered on the north by Turkey, the south by Jordan, the east by Iraq and the west by the Mediterranean Sea and Lebanon. Its area is 184,479 Km², located at 32° 30’ N - 37° 30’ N and 35° 30’ E - 42° 30’ E. The terrain surface throughout Syria consists of various landforms such as mountain ranges, deserts,
plains, water bodies and coastal features. Land-use within the country contains rural and agricultural land, power generation and distribution, built-up areas and so on.

The uprising and conflict that had begun in March 2011 affected migration patterns in the country, where much of the population was expelled to other parts to be internally displaced or outside to become refugees. This war has transformed Syrian cities into scenes of apocalyptic devastation where buildings and infrastructure had bombed or entirely destroyed. In the positive view, it is the best time to start using clean and sustainable energy in a right way to serve the country well into the future by decreasing greenhouse gas emissions and reducing fuel consumption.

2.2 Data collection and preparation

Data collection remains the most expensive and time-consuming aspect of setting up a major GIS facility. The creation of accurate geodatabases is a very important part of GIS and vital to decision making, since good decisions require good information derived from data. The key aspect of GIS functionality helps the users integrating and analyzing data from many sources with difference in scale, accuracy, resolution but does not provide information about the effects of combining these various levels of data uncertainty on the input maps and the output maps resulting from spatial querying and analysis [16]. As the high level of the positional accuracy will be the popular means of all spatial data, they should be defined in a proper coordinate reference system [17]. A rectangular coordinate system is one of the most popular in representing points on a map. Georeferenced data is captured from various sources (GPS, remote sensing, surveying, scanned topographic map, etc) that usually reveals the data having different coordinate systems. Therefore changing the coordinates must be applied to unify data references. The conformal mapping system used for Syria in the study is UTM zone 37 N that is based on WGS 84 datum. The main sites of Syria that have the potential for wind farm are represented using ESRI’s ArcGIS 10.2, where the GIS layers illustrated in Figure 3.
2.3 Identification of decision criteria

Choosing an appropriate site of wind power plants does not rely only on a wind speed, but indeed it is a multi-criteria decision issue and the relative significance of each parameter must be performed correctly. By taking into consideration each of the defined criteria, it must also be verified that final determined wind farm locations are not on restricted areas. The criteria should meet the national legislation according to wind farm development and integrate local conditions such as infrastructure and place characteristics [19]. Figure 4 presents the hierarchy structure of the site suitability criteria for wind parks.

![Hierarchical diagram of site suitability criteria for wind parks](image)

**Figure 3.** GIS layers for wind park sites [18].

**Figure 4.** Wind farm selection criteria.

Annual average wind speeds in the region is considered as the most significant criteria to convert the wind energy into electrical power. Figure 5 represents the map of annual average wind speed in Syria that was produced using kriging interpolation method within GIS environment. Digital Elevation Model (DEM) is useful to avoid highlands when assigning locations of wind power plants as a high altitude will increase the investment cost [20]. The DEM surface and streams for the test area are demonstrated in Figure 6. The restriction criteria, data structures and feature types are listed in Table 1, where this data is reclassified to produce the raster dataset as shown in Figure 7. The exclusionary zones are deemed as unsuitable to place wind parks due to realistic considerations and regulations.
Table 1. Constraints on wind farm siting

| Criterion             | Data structure | Buffer (m) | Feature type |
|-----------------------|----------------|------------|--------------|
| Urban area/town       | Vector         | 1000/750   | Polygon      |
| Waterways             | Vector         | 400        | Polyline     |
| Protected regions     | Vector         | 1000       | Polygon      |
| Airports              | Vector         | 12000      | point        |
| Railways              | Vector         | 250        | Polyline     |
| Highways              | Vector         | 500        | Polyline     |

Figure 5. Distribution of annual average wind speed (m/s) in Syria.

Figure 6. (a) DEM and (b) waterways for the study area.
3. Results and discussions
As stated previously, the suitability analysis is applied to rank and score sites relied on defined criteria. After the restricted areas were excluded from the country (Figure 7), it is possible to determine wind farm sites by evaluating variety of decision factors according to the specific requirements of planners. Table 2 describes criteria that are used in the current study with their justifications of choice, data structure and feature type. Each criterion is represented in GIS as a feature class (layer) for the whole area. It is important that different formats of data are standardized and changed into forms, which can be compared with each other. All of these criteria are converted into raster format by reclassifying to alternative values for creating suitability model as shown in Figure 8.

| Criterion                  | Reason of selection                                      | Data structure | Feature type |
|----------------------------|----------------------------------------------------------|----------------|--------------|
| Wind energy potential      | Decisive for wind energy success                         | Vector         | Polygon      |
| Slope                      | Affect construction costs and maintenance                | Vector         | Polygon      |
| Land use                   | Decreasing the environmental influence of development on socio-ecological systems | Vector         | Polygon      |
| Proximity to power lines   | Reducing the cost of energy transmission to the grid      | Vector         | Polyline     |
| Proximity to main roads    | Facilitating access for logistics and construction        | Vector         | Polyline     |

Figure 7. Map of buffer zones around the restricted features in Syria.
Land suitability assessment of wind power is extremely related to the opinions of different stakeholders. Therefore, this research focuses on some criteria are deemed out of the scope of this study. Furthermore, in order to build accurate suitability map for wind energy development, it should be associated with a weight to each criterion or GIS layer in a systematic and comprehensive procedure. AHP uses a pairwise comparison method to evaluate criteria relative significant and compute their
weights. The wind energy potential is given high weight since it is essential in location selection of wind turbines as listed in Table 3. Weighted overlay analysis is a useful tool for handling multi-criteria issues such as wind power plants suitability model. However, the resulted map of appropriate sites of wind parks in Syria. Figure 9 is distributed into four classes where the most convenient areas are placed in the southwestern and in the middle part of the country.

Table 3. Assigned weights of criteria

| Criterion                   | Weight % |
|-----------------------------|----------|
| Wind energy potential       | 37.5     |
| Slope                       | 22.5     |
| Land use                    | 20       |
| Proximity to power lines    | 10       |
| Proximity to main roads     | 10       |

Figure 9. Suitability map for development of wind power stations in Syria.

4. Conclusions
Wind energy is commonly utilized in recent years for increasing the usage of renewable energy resources as an alternative of fossil fuels. Choosing a proper site of wind parks is an essential problem to get a high performance of wind power turbines from technical and economic point of view without harming the environment and the society. A proposed methodology is introduced to define appropriate places of wind power stations, which are related to some assumptions, requirements, and constraints. Climate, natural, geological, socio-economic, and environmental are the main factors contribute to develop site selection issue. Although GIS has effective tools for analysing geospatial data to identify the best locations, but this application not capable to overcoming the problem of inconsistency in expert opinions when attempt to rate each of criteria that are included in a suitability analysis. The AHP approach is widely used in multi-criteria decision making to estimate the weights to the various factors. Applying this technique with GIS in the study have proved to be a powerful technique for wind farm site selection. The resulted map of wind farm in Syria shows that the majority of the areas with high appropriate are
situated the southwestern and in the middle part of the country. Finally, efforts should be made to promote using clean and sustainable energy as a post-conflict plan in Syria that contributes to reduce greenhouse gas emissions and decrease fuel consumption. In addition, commitment with environmental standards and principles of spatial planning to develop wind energy will help in avoiding their future negative impacts on land use.

5. References

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