

Mapping Potential Wind Energy Zones in Suez Canal Region, Using Satellite Data and Spatial Multicriteria Decision Models

Hala A. Effat

National Authority for Remote Sensing and Space Science, Cairo, Egypt

Email: haeffat@yahoo.com, heffat@narss.sci.eg

How to cite this paper: Effat, H.A. (2017) Mapping Potential Wind Energy Zones in Suez Canal Region, Using Satellite Data and Spatial Multicriteria Decision Models. *Journal of Geoscience and Environment Protection*, 5, 46-61.
<https://doi.org/10.4236/gep.2017.510005>

Received: July 31, 2017

Accepted: October 16, 2017

Published: October 19, 2017

Copyright © 2017 by author and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Spatial mapping of potential zones for wind energy is crucial for sustainable regional planning. The Suez Canal Region, Egypt, is currently a focus for national government and international investments for developing the logistic area. The Suez Governorate region is known of its high wind speed along the Gulf of Suez coast. This paper aims at estimating and mapping the potential zones for harnessing wind energy in such region. The method utilizes satellite data and spatial multi-criteria evaluation. Landsat 8 OLI satellite image was used to derive the land-use/land-cover map. Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) was used in modeling the wind power density map using the region's annual average wind speed data. Decision criteria including the climatic conditions, topography, infrastructure and land-cover maps were standardized, weighted and aggregated using weighted linear combination to identify the potential wind energy zones. The results reveal that the highest potential zones for wind energy reach a maximum value of 650 Watt/m² and a mean of 310 watt/m² and are located in the south-eastern part of the Suez Governorate Region along the Gulf of Suez. Findings indicate a high potential for harnessing wind energy in the region. The resultant maps can be used as guidelines for regional planning and zoning of renewable energy resources.

Keywords

Wind Energy, Remote Sensing, Multi-Criteria, Evaluation, Suez, Egypt

1. Introduction

1.1. Spatial Planning for Renewable Energy Resources

The twenty first century experienced attempts to improve urban planning

process by taking into consideration energy efficiency. Egypt's attempt to develop wind and solar energy was initiated in 1986 when the New and Renewable Energy Authority (NREA) was set up with the objective of assessing the country's renewable energy resource and investigating the technology options through studies and demonstration projects. According to [1] (*Mortensen et al.*, 2006) the wind resources of Egypt have been assessed by the New and Renewable Energy Authority, the Egyptian Meteorological Authority and Risø National Laboratory; (NREA). Their results are reported in a Wind Atlas for Egypt. Numerical wind atlas data helped in solving the issue of insufficient wind measurements from meteorological stations. A predicted map for wind climate of Egypt was determined by meso-scale modeling showing the mean wind speed in [m/s] at height of 50 m over the actual land surface [1]. Wind power density is a most important factor, it provides information on the most feasible and profitable areas in the region for sitting a wind power project [2] (*Vanek and Albright*, 2008). Studies were carried out on wind power and its applications in Egypt [3] (*Shata & Hanitsch* 2008, [4] *Shata & Hanitsch* 2006, [5] *Mayhoub & Azzam* 1997). [6] *Ahmed & Abouzeid* (2001) have presented a study about utilizing wind energy in some remote areas to feed part of the need of some isolated communities. The studied areas covered the north coast, the red sea coast and the east of Owainat. The Red Sea coast was again the scope of the work presented by [4] *Shata & Hanitsch* 2006, where an assessment of several regions on the red sea coast was conducted. Based on a technical and an economical assessment the cost of generating wind electricity in the studied regions were found it to be very competitive when compared to other sources of electricity generation. The most recent study conducted over an Egyptian site was the assessment of the city of Ras Benas situated on Red Sea coast and was presented by [7] *Shata* (2010).

Estimation of wind power in a region has been a subject for several researchers all over the globe as well as energy planners, regional planners and urban development engineers. Intensive researches have been conducted. Methods include new technologies such as satellite data and remote sensing, Spatial Decision Support Systems (SDSS) and spatial cartographic models. Spatial Multicriteria Evaluation (MCE) concepts are decision-making models frequently used to obtain continuous suitability maps [8] [9]. It is used to provide an optimal framework for the integration of the environmental, economic, and social factors that affect land suitability for a certain use and site selection [10] [11] [12] [13] [14]. Use of Artificial Neural Network has been used for estimation of wind power, wind speed [15] [16] and [17], wind energy [18]. [19] *Voivontas et al.* (1998) established a methodology depended on a Decision Support System (DSS) for the assessment of wind energy potential for Crete Island, Greece. [20] *Aydin et al.* (2010) established a decision support system for selection of suitable sites for wind turbines using Geographic Information System (GIS) tools. [21] *Nygaard et al.* (2010) conducted a study of the wind of Mali on the national

scale. Their approach utilized satellite data and output from meteorological models to provide a first estimate of the wind resource. [22] *Pandian and Iyappan* (2015) identified the most favorable locations for wind farm in Tirumangalam Taluk, India using GIS tools. The Analytic Hierarchy Process (AHP) is commonly used in spatial decision support models [23] [24] [25] [26]. The phases of the elaboration of a typical decision-making model include: (i Definition of the problem and objectives (ii Specification of evaluation criteria (iii Establishment of the decision rule (iv Calculation of criteria relative weights and consistency (v Determination of the suitability of the land area for a specific use. The current study uses remote sensing data and applies the Analytic Hierarchy Process and spatial multicriteria evaluation (SMC) in delimitation of potential wind energy zones and estimation of the wind power density in the Suez Canal Region.

1.2. Modeling Optimum Zones for Renewable Energy in Suez Canal Region

Description of the Study Area

The study area is bounded by the Mediterranean Sea on the north, by the Gulf of Suez to the south and encompasses the Suez Canal (Figure 1). The administrative area encompasses four provinces which are El Suez, Port Said, Ismailia and AL Sharkia. The study area includes geomorphologic units ranging in elevations to more than 1223 meters from sea level at the summit of El Galala Mountain to the North of Eastern Desert. In the northern part, topography of Port Said is

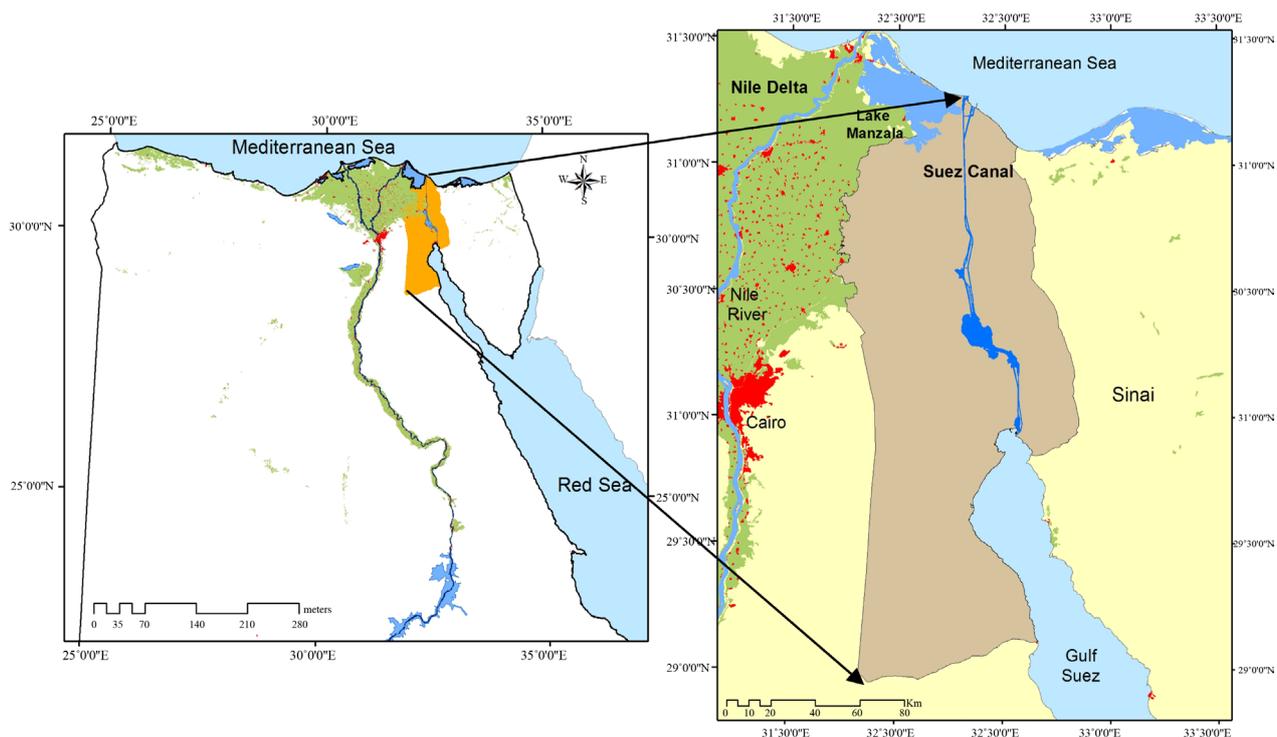


Figure 1. Location of the Suez Canal Region.

characterized by flat lands with contours ranging from half a meter to one meter above sea level as it is part of sandy coastline. It covers parts of the southern region of the Manzala Lake. Port Said sector is mainly a strip of sand bordered by the Mediterranean Sea from North and by the boundaries of Ismailia sector from South [27]. Suez province, located in the south, is characterized by rugged soil and mountains, Ataka and El Galala Mountains on the western side and the heights of Sinai from east which are separated by large wide valleys. Koppen-Geiger climate classification system classifies the Suez Region climate as a hot desert (BWh) zone.

2. Materials

Shuttle Radar Topography Mission (SRTM) data acquired by space shuttle Endeavour mission in 2001 by C-band SAR interferometry instrument were used in this study. The data is processed by NASA and the USGS. **Landsat 8 OLI** data created by the U.S. Geological Survey and was obtained in geographic Tagged Image-File format (GeoTIFF) for August 2015. The topographic map published by the Egyptian General Survey Authority (1989) scale 1:50,000 was scanned, geometrically corrected, all data were projected to WGS-84 of the Universal Transverse Mercator System (UTM) of geographic coordinates.

3. Methods

A cloud-free Landsat OLI image acquired in August 2015 was used. **Landsat 8 OLI** satellite data level 1 consist of quantized and calibrated scaled Digital Numbers (DN) representing multispectral image data acquired by both the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). Atmospheric correction was conducted in ENVI 5.0 software. A supervised classification was conducted using the Maximum Likelihood Classification (MLC) algorithm to produce the land-use/land-cover maps. Seven classes were identified as urban, cultivated land, canal and water bodies, fish farms, sabkha, bare-land and desert zones. Field validation was carried out and an overall accuracy assessment of 84.79% was achieved.

Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) was processed using ESRI ArcGIS spatial to derive the slope and aspect angles. The DEM was used to estimate the air density as described in Section 3.1.1.

Spatial Multi-criteria evaluation and Analytic Hierarchy Process were used to determine the wind energy potential zones maps. The method involved specification of criteria, assignment of criteria weights, exclusion of constraint and aggregation by conducting a map overlay. A conceptual flow chart is depicted in **Figure 2**.

3.1. Specifications of the Decision Criteria and Rules

3.1.1. Climate Criteria and Estimation of Wind Power Density

Wind energy resources can be mainly exploited in areas where wind speed

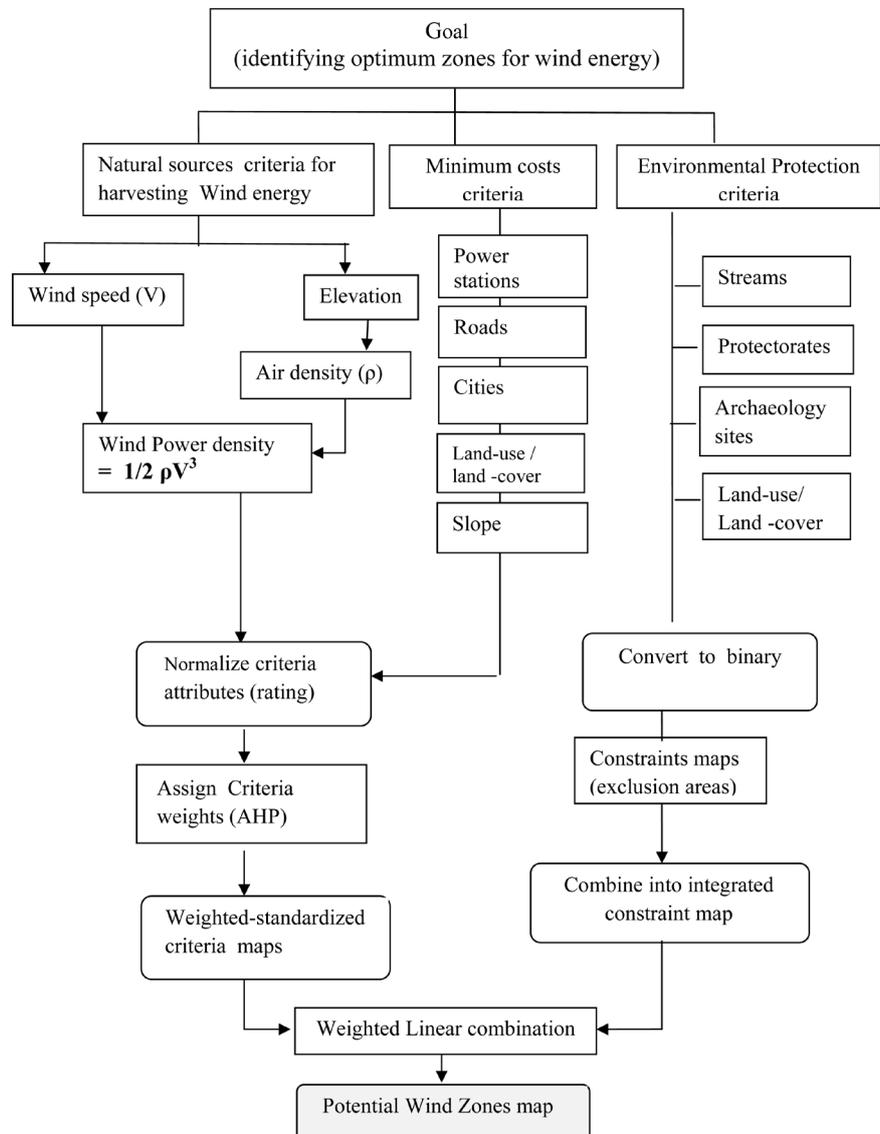


Figure 2. Conceptual design for the applied methodology.

equals or exceeds 5.5 m/s [28]. The climate factor is the most important parameter as it defines the resource potential energy based on wind speed. Wind power density is a useful way to evaluate the wind resources available at a potential site. The wind power density, measured in watts per square meter, indicates how much energy is available at the site for conversion by a wind turbine [29]. [12] Bartniki and Williamson, 2012 explain that wind power density is a function of the area's average wind velocities and the air densities, which involves land elevations. [30] Shata and Hanitsch 2000 explain that the specific power available in a cross-sectional area perpendicular to the wind stream moving at speed V (m/s) is calculated and expressed per unit area.

According to [31] Hughes (2000), the amount of wind energy depends on the density of the air, area and the cube of the wind velocity. He explains that if the area of study is close to sea level, and is in a region with moderate climate, using

the value of 1.225 kg/m^3 will not introduce a huge error into the estimate of wind power density. This is especially so if we are looking at annual average values, so that changes in air density due to seasonal changes in air temperature are averaged over time and a variety of conditions. However, if the area is much above sea level, or if more precision is required, one can use this approximation to account for elevation change. The average wind speed map developed by [1] *Mortensen et al.* (2006) average wind speed map (or velocity) for Egypt was downloaded in a JPEG format, geometrically corrected, digitized, projected, converted to raster format and a resample function was applied. Shuttle Radar Topography Mission SRTM digital elevation model was used for the current study to give more precision to the air density by using Equations (1) [12]. Applying Equation (2) [31] (*Hughes*, 2000) in which the average wind speed map was a variable; the wind power density map was produced.

$$\text{Windpower} = 1/2 \rho V^3 \quad (1) [12]$$

$$\rho = 1.225 - \left[(1.194 * 10^{-4}) * \text{elevation} \right] \quad (2) [31]$$

where :

V = average wind speed (m/s)

ρ = air density (kg/m^3)

wpd = wind power density (watt/m^2).

3.1.2. Cost Criteria

Distance from road network: To minimize construction costs, wind turbines should be located as closely as possible to the existing road network. [32] *Tegou et al.* (2010) set the maximum distance to a main road to 2500 meters. The study area was classified into nine classes of equal distances, where minimum distances to a main road are assigned a higher suitability value and vice versa. Buffer of 200 meters was masked out based on legislative constraints.

Distance from electricity grid: In order to reduce costs associated with cabling and electricity losses over long transmission distances, wind farms should be located in the proximity of the electricity grid. [32] *Tegou et al.* (2010) set the threshold to 2000 m. The study area was classified into nine equal distances classes, the less distance to an electricity grid, the better. 500 meters set back from the power grid was used.

Slope of terrain: [12] *Bartnicki and Williamson*, 2012 explain that at the summit of steep slopes wind may not hit the turbine rotor at a perpendicular angle and may result in an increased level of turbine fatigue. Slope angles greater than 5 degrees may yield more turbulent wind patterns causing disruptions in turbine stability in addition, building on higher slopes increases project costs. Accordingly, the slope was reclassified into three categories with most suitable for flat to less than 5 degrees, suitable for 5 - 15 degrees and unsuitable for slopes greater than 15 degrees.

Distance from Urban Areas: Similarly, the study area was classified into nine

classes of equal distances, a setback buffer of 1,500 m. from urban areas to allow for future city expansion and green belt.

3.1.3. Environmental Protection Criteria (Constraints or Exclusion Areas)

The suitability of an area for locating wind turbines depends on the prevalent land cover type. In Egypt, the cultivated land is protected by law. Fish farms, sabkha, water bodies, urban areas are unsuitable for locating wind turbines. A constraint map was created for the developed, protected and vulnerable lands including the lakes, cultural values and nature protected sites, urban areas, cultivated lands and faults. The buffer zone of 500 meters was created around lakes to protect the gulls and the shoreline ecology. A buffer zone of 200 meters was created around the faults. Constraints maps were converted into binary maps giving a value of “zero” to the constraint zones and “one” to the developable lands.

3.2. Criteria Standardization and Weighting

Analytical Hierarchy Process [9] was used to assign weights to each criterion, and thus determine their relative importance in the final decision adopted within the model. The method is based on pair-wise comparison within a reciprocal matrix, in which the number of rows and columns is defined by the number of criteria. Accordingly, it is necessary to establish a comparison matrix between pairs of criteria, contrasting the relative importance of each pair with all the others. Subsequently, a priority vector is computed to establish weights (w_j). These weights are a quantitative measure of the consistency of the value judgments between pairs of factors [33] (Saaty, 1992). The ratings of factors were discussed by the authors and planning experts. Each member was asked to evaluate the factors according to Saaty's nine points weighting scale [23] (Table 1). The average weight for each factor was calculated from the values estimated by the experts. The matrix was built as follows: If we call a weight a_{ij} , and use that scale of comparison, and if the relative weighting is $a_{23} = 3/1$, then the relative importance of attribute 3 with regard to 2 is its reciprocal $a_{32} = 1/3$. This process generated an auxiliary matrix in which the value in each cell is the result of the division of each value judgment (a_{ij}) by the sum of the corresponding column. Finally, the average of the normalized values of rows was obtained, which corresponds to the priority vector (w_j). This was normalized by dividing each vector value by n (the number of vectors), thus obtaining the normalized overall priority vector, representing all factor weights (w_j).

Estimation of the consistency, involves the following operations: a) Determination of the weighted sum vector by multiplying matrix of comparisons on the right by the vector of priorities to get a new column vector. Then divide first component of new column vector by the first component of priorities vector, the second component of new column vector by the second component of priorities vector, and so on. Finally, sum these values over the rows. b) Determination of

Table 1. Saaty's Nine-Point relative importance weighting scale.

Extremely importance	9	Extremely less importance	1/9
Very to extremely strongly importance	8	Very to extremely strongly less importance	1/8
Very strongly importance	7	Very strongly less importance	1/7
Strongly to very strongly importance	6	Strongly to very strongly less importance	1/6
Strongly importance	5	Strongly less importance	1/5
Moderately to strongly importance	4	Moderately to strongly less importance	1/4
Moderately importance	3	Moderately less importance	1/3
Equally to moderately importance	2	Equally to moderately less importance	1/2
Equally importance	1		1

consistency vector by dividing the weighted sum vector by the criterion weights. Once the consistency vector is calculated, it is required to compute value for the consistency index (CI). The value for lambda is simply the average value of the consistency vector. This measure can be normalized as follows:

$$CI = (\lambda - n) / (n - 1) \quad (3)$$

The term CI, referred to as consistency index, provides a measure of departure from consistency. To determine the goodness of CI, AHP compares it by Random Index (RI), and the result is CR, which can be defined as:

Table 1: Saaty's Nine-Point relative importance weighting scale

$$CR = CI / RI \quad (4)$$

Random Index is the CI of a randomly generated pairwise comparison matrix of order 1 to 10 obtained by approximating random indices using a sample size of 500 [23] (Saaty, 1980) (Table 2) shows the value of RI sorted by the order of matrix.

The consistency ratio (CR) is designed in such a way that if $CR < 0.10$, the ratio indicates a reasonable level of consistency in the pairwise comparisons; if, however, $CR > 0.10$, then the values of the ratio are indicative of inconsistent judgments. In such cases one should reconsider and revise the original values in the pairwise comparison matrix.

3.3. Aggregation of Criteria

Aggregation of criteria was conducted according to [9] Eastman *et al.* 1995 equation:

$$\text{Suitability} = \sum wiXi * \prod Cj \quad (5)$$

where wi = weight assigned to factor i

Xi = criterion score of factor i

Cj = constraint j

Table 2. Random consistency index.

Order matrix	1	2	3	4	5	6	7	8	9	10
R.I.	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

4. Results and Discussions

The land slope map reveals flat lands in the northern parts while high slopes exist along the Red Sea coasts where most of the mountainous zones exist (**Figure 3(a)**). The aspect map shows the spatial distribution of the land slope direction in azimuth (**Figure 3(b)**). Location factors and distance to roads reveal a lack of road network facility in the southern zones (**Figure 3(c)**). Distance to power grid and distance to cities show extension of urban areas along the Gulf of Suez and Suez Canal and towards the middle and eastern zones while almost absent in the south western zone (**Figure 3(d)** and **Figure 3(e)**). The results of classification of the **Landsat OLI** satellite image revealed an inventory of land cover areas. The study area covers an area of 18,104 sq-km, most of which consists of desert zones (11,956 sq-m) constituting 65%, whereas, the cultivated lands occupy 3568 sq-m. which is 20% of the total area. Bare land occupies 176 sq-m spreading between the cultivated lands while the urban areas occupy 371 sq-m. amounting to 2% of the total area. Water bodies and sabkha occupy 639 and 476 sq-m. representing 4% and 3% of total area respectively. Large areas of flat and gentle slopes extend in the northern part along the Mediterranean coast (**Figure 3(f)**).

Results of standardization of factors attributes into a suitability scale and the buffer zones are presented in **Table 3** and **Table 4**. Criteria weight assignment using AHP pairwise matrix is presented in **Table 5**.

4.1. Wind Power Density Map

The study area shows a land relief of wide range varying from flat lands to high mountains (**Figure 4(a)**). Wind velocity range between 5 - 11.9 m/sec (**Figure 4(b)**). Wind power density range between 75 and 650 watt/m². High potential zones are found in the Suez Governorate, south west of the Suez Canal. In such zones the wind speed, the main contributor factor to wind energy, reaches its maximum (between 7 and 11.9 m/sec). The air density being affected by the altitude range between 1.07 - 1.23 kg/m³ on the elevated zones.

4.2. Model Output for Potential Zones for Wind Energy

Results reveal that the potential wind energy zones are found south-east of the Suez Region (**Figure 5(a)** and **Figure 5(b)**). An inventory was conducted on the potential zones (**Table 6**). There are 39 zones of total area equivalent to 240.8 sq-km having potential wind power energy equivalent to or exceeds 300 watt/m². Two zones of area 132 sq-km. having potential wind energy that exceeds or are equivalent to 400 watt /m². Two zones have potential energy greater or equal to 500 watt/m². Two zones of total area equivalent to 132 sq-km. having potential wind energy greater or equal to 600 watt/m². The inventory reveals a highly suitable

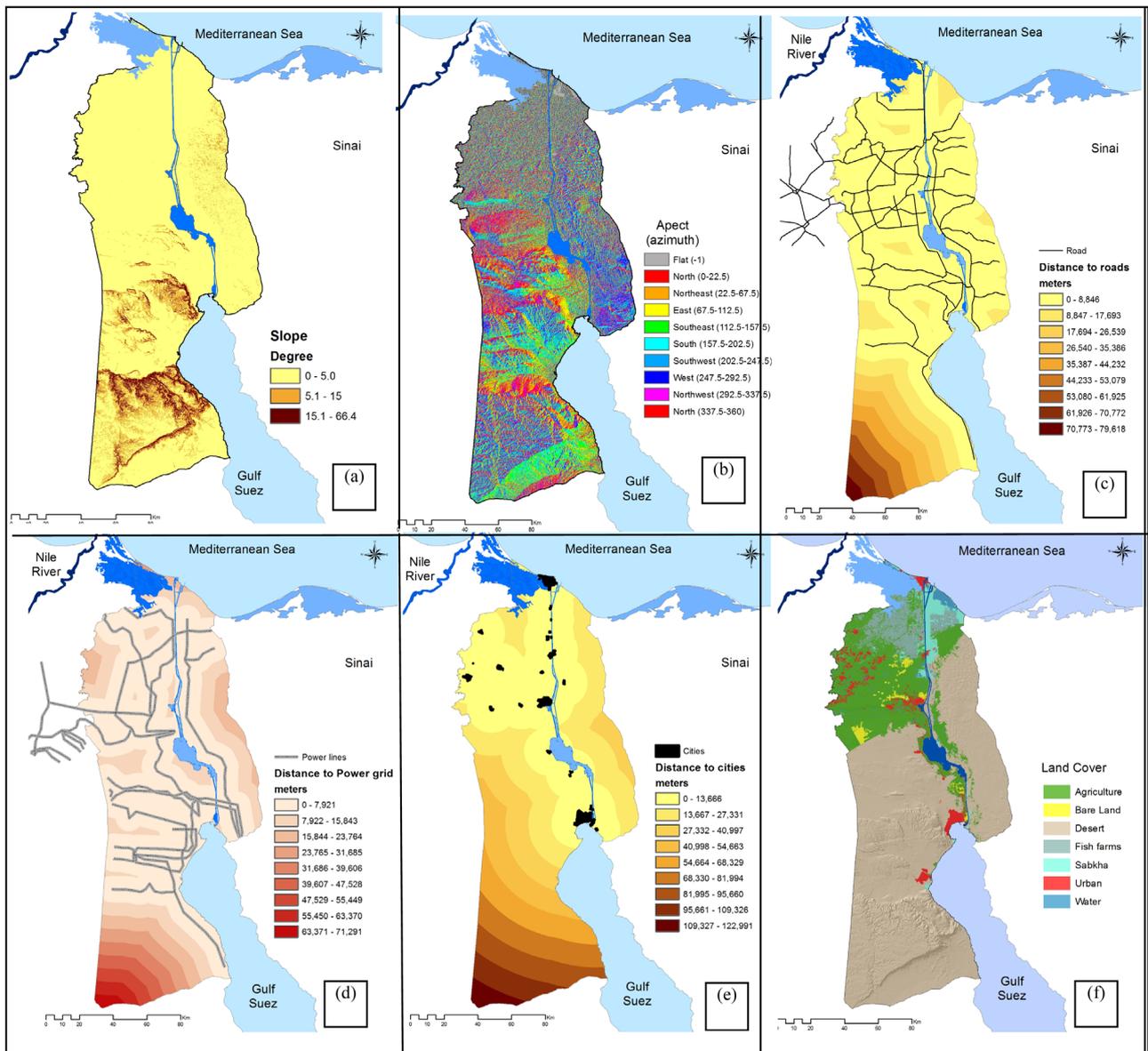


Figure 3. Criteria for infra-structure and natural environment: (a) Land slope angle; (b) aspect angle (azimuth); (c) distance to roads; (d) distance to power grid; (e) distance to cities; (f) land-cover.

potentiality for harvesting wind energy in such zone. A database was created for such zones. The zonal statistics as table tool in ESRI ArcGIS for the high potential zones and relevant wind power density. The mean, minimum and maximum values were calculated for each zone. This step gives the potential energy expected from each site knowing its land area and choosing a wind turbine system, the wind geographic and technical potentials can be calculated.

4.3. Model Validation

Model validation was conducted by a random selection and examination of 100 sites from the highest values of the suitability index to check their compliance with the decision rules. ESRI *zonal statistics as table tool* summarizes the values

Table 3. Criteria of topography factors, attributes and rating for criteria, climate and environment.

Criteria	Factors	Attribute values (indicators)	Suitability rating ratint	
Climate	Wind speed (m/sec)	5.0 - 55.6		
		5.0 - 5.6	5	
		5.6 - 6.4	6	
		6.4 - 7.5	7	
		7.5 - 8.6	8	
		>8.6	9	
		0 - 5	9	
			9	
			7	
			7	
Topography	Slope	5- 10	7	
		10 - 15	5	
		>15	5	
		-1 (flat)	0	
			0	
			9	
			0 - 45 (Northeast)	5
			45 - 90 (Northeast-East)	5
			90 - 135 (East-Southeast)	5
			Aspect	135 - 180 (Southeast-South)
	180 - 225 (South-Southwest) Soutwes	5		
	225 - 270 (Southwest-West)	5		
	270 - 315 (West-Northwest)	9		
	315 - 360 (Northwest-North)	9		

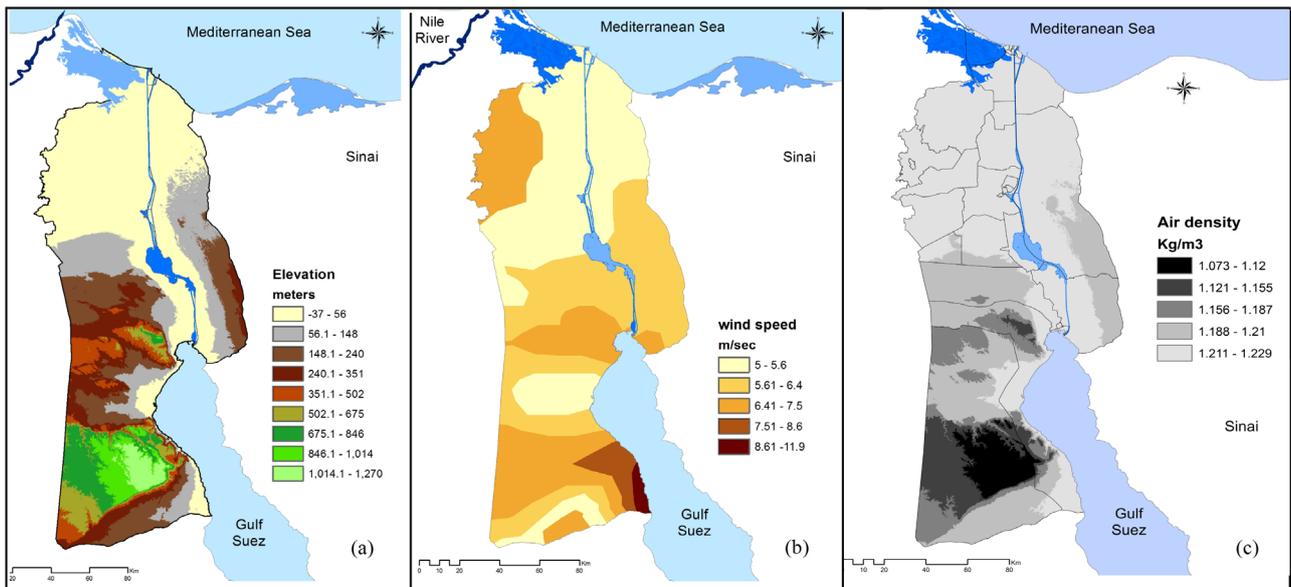


Figure 4. Meteorological criteria: (a) Elevation; b) wind speed; (c) Air density maps.

Table 4. Criteria, factors, attributes and rating for costs and environmental themes.

Criteria	Factors	Attribute values (indicators)	Suitability rating	Set back (meters)							
Costs criteria (Location)	Distance to main roads (meters)	0 - 8,846	9	2000 m							
		8,847 - 17,693	8								
		8,847 - 17,693			7						
		17,694 - 26,539				6					
		26,540 - 35,386					5				
		35,387 - 44,232						4			
		44,233 - 53,079							3		
		53,080 - 61,925								2	
		61,926 - 70,772									1
		70,773 - 79,618									
	Distance to power grid (meters)	0 - 7,921	9	2000 m							
		7,922 - 15,843	8								
		15			7						
		15,844 - 23,764				6					
		23,764 - 31,685					5				
		31,686 - 39,606						4			
		39,607 - 47,528							3		
		47								2	
		47,528 - 55,449									1
		55,450 - 63,370									
	Distance to cities (meters)	63,371 - 71,291	9	1500 m							
		0 - 13,666			8						
		13,667 - 27,331				7					
		27,332 - 40,997					6				
		40,997 - 54,663						5			
		54,664 - 68,329							4		
		68,330 - 81,994								3	
		81,995 - 95,660									2
81,995 - 95,660		1									
95,661 - 109,326											
Land use/land cover	109,326 - 122,991	0	500 m								
	Water bodies (lakes)			9							
	Bare land				0						
	Cultivated land					5					
	Desert, loose and shifting sand						0				
	Fish farms							1			
	Sabkha								0		
	Urban areas									0	
	Faults										0
	Streams										
Geology	Hi-order streams (100 m)	0	100 m								

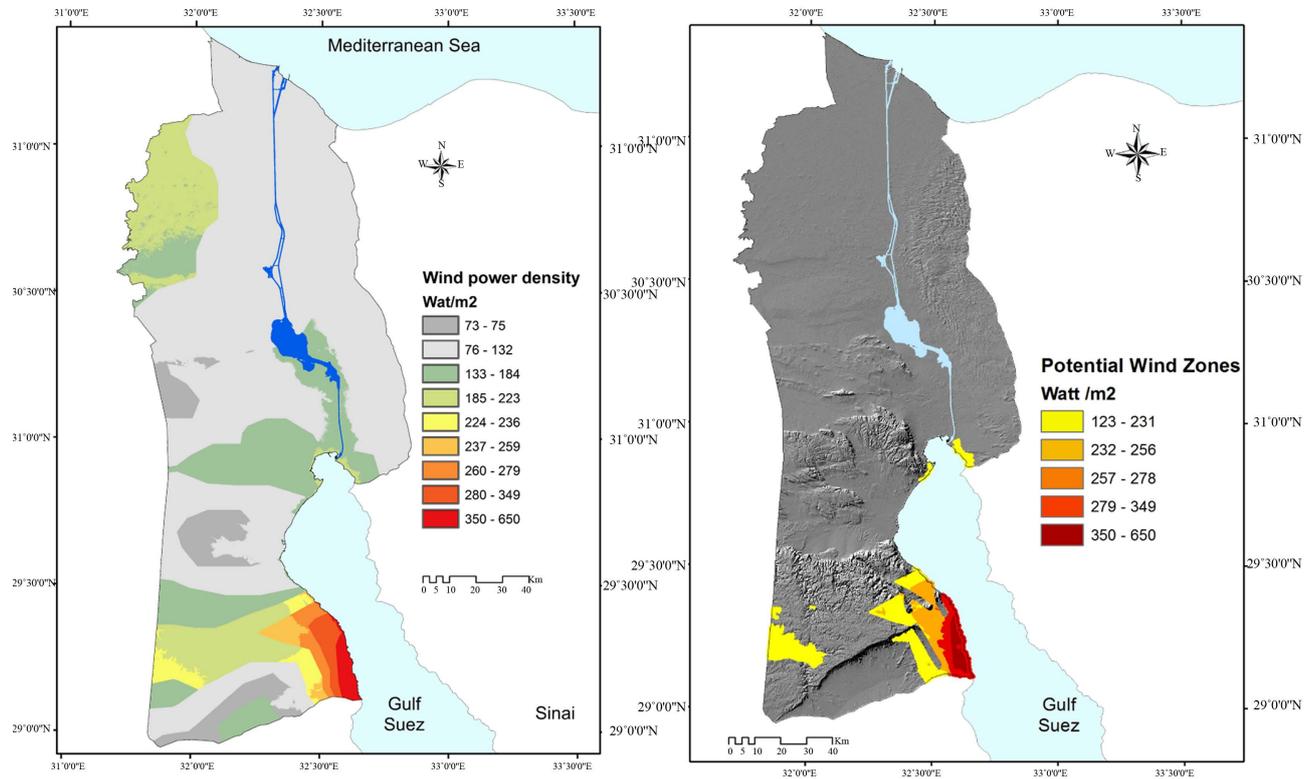


Figure 5. (a) Wind power density; (b) potential wind power zones.

Table 5. Pairwise Comparison Matrix.

	Climate	Topography	Location	Environment	Calculated weight
Climate	1	7	3	9	0.6436
Topography	1/7	1	3/7	9/7	0.0693
Location (cost)	1/3	7/3	1	9/3	0.2204
Environment	1/9	7/9	3/9	1	0.0665

CI = 1.1442, RI = 0.90, Cr = 0.053.

Table 6. Inventory for potential zones classes and areas in Suez Region (wind speed measured at height of 50 m based on Mortensen *et al.* 2005).

Class	Class Area (sq-km)	Percentage of total potential zones (%)	Wind Speed (m/sec)	Wind Power density (W/m ²)
9 (most suitable)	132.5	19.59	8.28 - 10.1	358 - 560
8	109.9	16.25	8.28 - 10.1	279 - 348
7	90.1	13.32	7.69 - 8.2	257 - 278
6	101.2	14.96	7.69 - 8.2	232 - 256
5 (suitable)	242.6	35.87	7.2 - 7.6	174 - 236

of a raster within the zones of another datasets (in this case the zones are the 100 selected sites and the raster datasets are the slope, aspect and wind power density). It was used to examine the sampled pixels of wind power density values.

First, sites were examined to verify their compliance with the topographic factors rules *i.e.* slopes less than 10 degrees and aspect zones are in prevailing wind directions (N-NW). Second, the selected sites are displayed with the constraints map to ensure they do not fall on a constraints zone.

5. Conclusion

The present study is an application that utilizes remote sensing data and a spatial decision support model for mapping potential wind energy zones in the Suez Canal Region, Egypt. Potential wind energy zones exist in the study area's south-eastern zone along the Gulf of Suez coastal line. High potential energy zones fall in range of 279 to 650 Watt/m² along the shoreline and on the elevated lands. Results reveal that maximum potential wind energy zones are found south-east of the Suez Region. High potential zones reached 538 sites. There are 39 zones of total area equivalent to 240.8 sq-km having potential wind power energy greater or equal to 300 Watt/m². Two zones of area 132 sq-km have potential wind energy that is greater or equal to 400 Watt/m². Two zones have potential energy greater or equal to 500 Watt/m². Two zones of total area equivalent to 132 sq-km having potential wind energy greater or equal to 600 Watt/m². The inventory reveals a high to excellent potentiality for harvesting wind energy. Results of this work can be useful for energy planning, zoning and site selection of wind energy farms.

Acknowledgements

This paper is part of a Research Project funded by the National Authority for Remote Sensing and Space Sciences, NARSS, Egypt and conducted during the year 2015-2016.

References

- [1] Mortensen, N.G., Hansen, J.C., Badger, J., Jørgensen, B.H., Hasager, C.B., Georgy Youssef, L., Said Said, U., Abd El-Salam Moussa, A., Akmal Mahmoud, M., El Sayed Youssef, A., Mahmoud Awad, A., Abd-El Raheem Ahmed, M., Sayed, A.M., Hussein Korany, M. and Abd-El Baky Tarad, M. (2005) Wind Atlas for Egypt, Measurements and Modelling 1991-2005. New and Renewable Energy Authority, Egyptian Meteorological Authority and Risø National Laboratory. ISBN 87-550-3493-4, 258. http://www.wasp.dk/dataandtools#wind-atlas_wind-atlas-for-egypt
- [2] Vanek, F.M. and Albright L.D. (2008) Energy Systems Engineering Evaluation and Implementation. McGraw-Hill Companies, New York. <http://197.14.51.10:81/pmb/ENERGETIQUE/0071495932.pdf>
- [3] Shata, A.S.A. and Hanitsch, R. (2008) Electricity Generation and Wind Potential Assessment at Hurghada, Egypt. *Renewable Energy*, **33**, 141-148. <https://doi.org/10.1016/j.renene.2007.06.001>
- [4] Shata, A.S.A. and Hanitsch, R. (2006) The Potential of Electricity Generation on the East Coast of Red Sea in Egypt. *Renewable Energy*, **31**, 1597-1615. <https://doi.org/10.1016/j.renene.2005.09.026>
- [5] Mayhoub, A.B. and Azzam, A. (1997) A Survey on the Assessment of Wind Energy

- Potential in Egypt. *Renewable Energy*, **11**, 235-247.
[https://doi.org/10.1016/S0960-1481\(96\)00113-9](https://doi.org/10.1016/S0960-1481(96)00113-9)
- [6] Ahmed, H.K. and Abouzeid, M. (2001) Utilization of Wind Energy in Egypt at Remote Areas. *Renewable Energy*, **23**, 595-604.
[https://doi.org/10.1016/S0960-1481\(00\)00132-4](https://doi.org/10.1016/S0960-1481(00)00132-4)
- [7] Shata, A.S. (2010) Wind Energy as Potential Generation Source at Ras Benas, Egypt. *Renewable and Sustainable Energy Reviews*, **14**, 2167-2173.
<https://doi.org/10.1016/j.rser.2010.03.006>
- [8] Saaty, T. (1997) A Scaling Method for Priorities in Hierarchical Structures. *Journal of Math Psychology*, **15**, 234-281. [https://doi.org/10.1016/0022-2496\(77\)90033-5](https://doi.org/10.1016/0022-2496(77)90033-5)
- [9] Eastman, J.R., Jin, W., Kyem, P.A.K. and Toledano, J. (1995) Raster Procedures for Multi-Criteria/Multi-Objective Decisions. *Photogrammetric Engineering and Remote Sensing*, **61**, 539-547.
- [10] Patel, B. and Rosier, A. (2013) Basic Criteria for Wind Project Site Selection and Optimization. ECOWAS Regional Workshop on Wind Energy, Praia.
- [11] Mann, D., Lant, C. and Schoof, J. (2012) Using Map Algebra to Explain and Project Spatial Patterns of Wind Energy Development in Iowa. *Applied Geography*, **34**, 219-229. <https://doi.org/10.1016/j.apgeog.2011.11.008>
- [12] Bartnicki, N. and Williamson, M. (2012) An Integrated GIS Approach to Wind Power Site Selection in Huron County, Ontario. Department of Geography, University of Guelph, Guelph.
- [13] Nguyen K.Q. (2007) Wind Energy in Vietnam: Resource Assessment, Development Status and Future Implications. *Energy Policy*, **35**, 1405-1413.
<https://doi.org/10.1016/j.enpol.2006.04.011>
- [14] Yue, C.D. and Wang, S.S. (2006) GIS-Based Evaluation of Multifarious Local Renewable Energy Sources: A Case Study of the Chigu Area of Southwestern Taiwan. *Energy Policy*, **34**, 730-742. <https://doi.org/10.1016/j.enpol.2004.07.003>
- [15] Candenas, E. and Riera, W. (2009) Short Term Wind Speed Forecasting in La Venta, Oaxaca, Mexico, Using Artificial Neural Networks. *Renew Energy*, **34**, 274-278.
<https://doi.org/10.1016/j.renene.2008.03.014>
- [16] Fadare, D.A. (2010) The Application of Artificial Neural Networks to Mapping of Wind Speed Profile for Energy Application in Nigeria. *Applied Energy*, **87**, 934-942.
<https://doi.org/10.1016/j.apenergy.2009.09.005>
- [17] Jung, S. and Kwon, S.D. (2013) Weighted Error Functions in Artificial Neural Networks for Improved Wind Energy Wind Potential Estimation. *Applied Energy*, **111**, 778-790. <https://doi.org/10.1016/j.apenergy.2013.05.060>
- [18] Mabel, M.C. and Fernandez, E. (2008) Analysis of Wind Power Generation and Prediction Using ANN: A Case Study. *Renewable Energy*, **33**, 986-992.
<https://doi.org/10.1016/j.renene.2007.06.013>
- [19] Voivontas, D., Assimacopoulos, D., Mourelatos, A. and Corominas, J. (1998) Evaluation of Renewable Energy Potential Using a GIS Decision Support System. *Renewable Energy*, **13**, 333-344. [https://doi.org/10.1016/S0960-1481\(98\)00006-8](https://doi.org/10.1016/S0960-1481(98)00006-8)
- [20] Aydin, N.Y., Kentel, E. and Duzgun, S. (2010) GIS-Based Environmental Assessment of Wind Energy Systems for Spatial Planning: A Case Study from Western Turkey. *Renewable and Sustainable Energy Reviews*, **14**, 364-373.
<https://doi.org/10.1016/j.rser.2009.07.023>
- [21] Nygaard, I., Rasmussen, K., Badger, J., Nielsen, T.T., Hansen, L.B., Stisen, S., Larsen, S., Mariko, A. and Ibrahim Togola, I. (2010) Using Modeling, Satellite Images and

- Existing Global Datasets for Rapid Preliminary Assessments of Renewable Energy Resources: The Case of Mali. *Renewable and Sustainable Energy Reviews*, **14**, 2359-2371. <https://doi.org/10.1016/j.rser.2010.04.001>
- [22] Pandian, P.K. and Iyappan, L. (2015) Developing a Geospatial Based Approach to locate Wind Farms in Taluk, Tamil Nadu, India. *International Journal of Technical Research and Applications*, **12**, 30-34.
- [23] Saaty, T.L. (1980) *The Analytic Hierarchy Process*. McGraw Hill, New York.
- [24] Jun, Ch. (2000) Design of an Intelligent Geographic Information System for Multi-criteria Site Analysis. *URISA Journal*, **12**, 5-17.
- [25] Pavlikakis, G.E. and Tsihrintzis, V.A. (2003) Integrating Humans in Ecosystem Management Using Multi-Criteria Decision Making. *Journal of the American Water Resources Association*, **39**, 277-288. <https://doi.org/10.1111/j.1752-1688.2003.tb04383.x>
- [26] Effat, H.A. (2014) Spatial Modeling of Optimum Zones for Wind Farms Using Remote Sensing and Geographic Information System, Application in the Red Sea, Egypt. *Journal of Geographic Information System*, **6**, 358-374. <https://doi.org/10.4236/jgis.2014.64032>
- [27] General Authority for Physical Planning (2015) *The Environmental Vision for Development Strategy in the Suez Region*. Published Report.
- [28] Cace, J., Horst, E., Syngellakis, K., *et al.* (2007) Urban Wind Turbines: Guidelines for Small Wind Turbines in the Built Environment. <http://www.urban-wind.org>
- [29] Islam, M.S., Islam, A., Hasan, M.M. and Khan, A.H. (2013) Feasibility Study of Wind Power Generation in Bangladesh: A Statistical Study in the Perspective of Wind Power Density and Plant Capacity Factor. *International Journal of Renewable Energy Research*, **3**, 476-487.
- [30] Shata, A.S.A. and Hanitsch, R. (2006) Evaluation of Wind Energy Potential and Electricity Generation on the Coast of Mediterranean Sea in Egypt. *Renewable Energy*, **31**, 1183-1202. <https://doi.org/10.1016/j.renene.2005.06.015>
- [31] Hughes, T. (2000) Calculation of Wind Energy and Power. Lesson Number 1 in an Oklahoma Wind Power Tutorial Series. <https://www.scribd.com/document/166379094/Lesson1-windenergycalc>
- [32] Tegou L., Polatidis H. and Haralambopoulos, D.A. (2010) Environmental Management Framework for Wind Farm Siting: Methodology and Case Study. *Journal of Environmental Management*, **91**, 2134-2147. <https://doi.org/10.1016/j.jenvman.2010.05.010>
- [33] T.A., (1992) *Decision-Making for Leaders*. 2nd Edition, RWS Publication, Pittsburgh, USA United States Geological Survey (USGS), Shuttle Radar Topography Mission. <http://seamless.usgs.gov>