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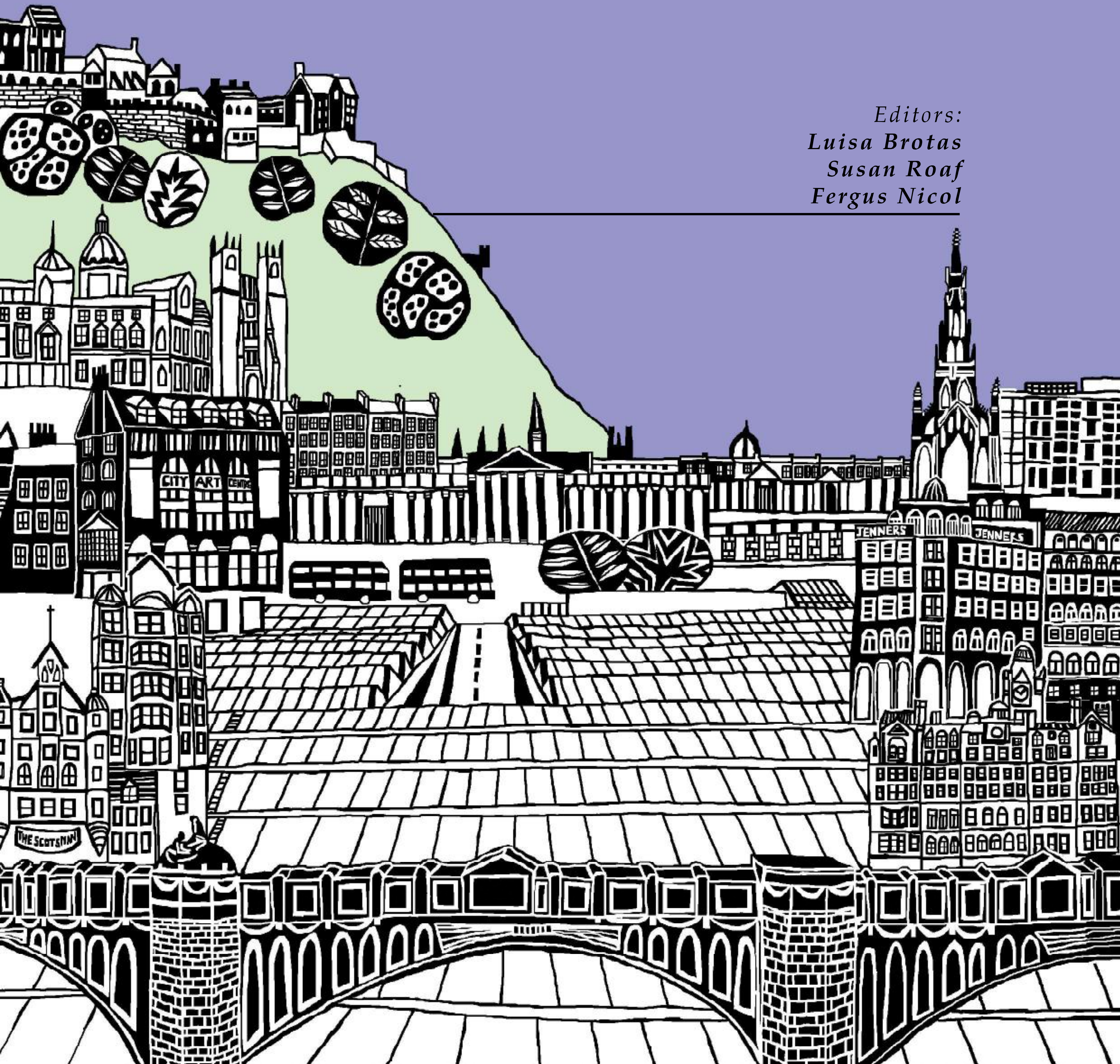

Volume 1

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Land Suitability for Wind Farms in Suez Governorate, Egypt

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Abstract: By the development of the industrial technology, the greenhouse gases (GHG) emissions increased, which contributed to the phenomena of climate change. This research is concerned with using the renewable energy source of wind farms as a tool to reaching zero carbon dioxide gases emissions. This is also part of the new Egyptian vision that aims to increase wind power capacity to 20% by 2020.In line with this vision, the aim of the research is to find the suitable lands in Egypt to accommodate wind farms in Egypt. With the variety of variables affecting wind farms' locations as well as the density of current land uses in Egypt; it is important to find the suitable tool that could conduct these types of analysis. The research used the land suitability analysis conducted by the geographical information systems (GIS), in which multi criteria could be used to identify the appropriate locations. Different variables affecting the presence of wind farms could be added and overlaid in GIS including wind speed maps, wind directions map, and topography maps. The findings of this research help identifying the suitable locations in Suez Governorate in Egypt that could accommodate wind farms.

Keywords: Global warming, Climate change, Wind farm, Geographical Information System (GIS), Land suitability analysis.

Introduction

Global warming and climate change are important phenomena that appeared in the last century. Their appearance depended on the significant increase of temperature that resulted from the presence and development of the industrial revolution (Organization, United Nations, 1992). The awareness of the earth's population increased and led to finding solutions that could help facing this problem. Most of environmental sector governments started to set certain regulations to reduce the phenomena of global warming and climate change by using renewable energy sources.

For Egypt, the highest percentage of greenhouse gas emissions is coming from indirect sources: i.e. burning fuel in transportation and producing goods for consumers. According to the climate investments fund, Egypt is the 11 speediest country producing greenhouse gas (GHG) emitting nations on the world. The climate investments funds warn and expect to exceed the percentage of the greenhouse gas (GHG) emissions to 300% by 2017. The increase in population (range up to 2.6% per year) in Egypt will also lead to increased use of energy, which by its turn will effect on the Egyptian economy (Funds, 2005). The energy industry and transportation sectors emit a lot of carbon intensive. The percentage of carbon footprint emitted from the transportation sector and power generation are calculated to be 42% and 21% respectively of Egypt's total GHG emissions (Funds, 2005). The government is now heading toward building stations for generating a renewable energy: i.e. Wind Farm, and

Solar panels aiming to reduce the greenhouse gas emissions that contribute to climate change. Wind farms are one of the sustainable projects encouraged nowadays. They consist of number of turbines located in certain place (sea or land) to generate electricity. This type of energy has been enlarged by governments especially after the oil crisis in 70's (Harborne et al, 2009).

This study sheds light to the concept of global warming and climate change in Egypt. It focuses on the wind farms as an important renewable source of energy. The main aim of this research is to locate through the Geographical information systems (GIS) the best suitable lands in Suez Governorate, Egypt that could be able to accommodate wind farms.

Literature Review

During the past few decades, the Geographic Information System (GIS) have been used to find the suitable location for wind farms' installation (Rodman, L.C et Meentemeyer, R.K, 2006). GIS collects large geospatial information as criteria and integrate them into decision-making to install wind farms. Baban and Parry (2001) set 14 criteria (including slope, land use, and historic site) based on data collection from literature review and questionnaires to identify the suitable location of wind farms in the United Kingdom by using weighted overlay analysis in GIS. In the same way, Janke (2010) applied multi-criteria GIS modelling to find the best location for wind farms in the State of Colorado, U.S. The criteria involved the wind potential; distance to cities and roads; and population density, all collected from the geospatial databases. The data were converted into raster data and overlaid to suitability map located in north-eastern Colorado. According to the previously mentioned factors, Van Hoesen and Letendre (2011) added new criteria such as new ecological and economic aspects to reduce the total cost and avoid bird migration. The visual impacts of wind turbines in State of Vermont were taking into consideration as another critical factor of view added by Van Hoesen and Letendre (2010). Rodman and Meentemeyer (2006) used certain rules in GIS modelling approach to determine the suitability map of wind farms in Northern California, U.S. The factors were classified into three categories, being physical, environmental and socio-economic. In south-western Taiwan, they used similar approach to locate wind turbines (Yue and Wang, 2006). In Egypt, Effat, H., (2014) had two types of factors. First factors contained wind speed, elevation of zones to get wind power density and the second factors included economic factors such as distance from roads, power lines, and urban areas.

Table 1. Study areas, modelling approaches and factors adopted by studies on land suitability for wind energy development (modified from Szurek et al., 2014).

City	Source	Approach	Factors
Western Turkey	Aydin et al., 2010	Multi-criteria decision-making with fuzzy set theory	Distance to: natural reserves, large cities, from towns, distance from airports, noise, from lakes and wetlands, wind power.
United Kingdom	Baban and Parry, 2001	Multi-criteria analysis & questionnaire	Slope, distance to water bodies, historical sites, urban areas, roads and railways, land use and the presence of important ecological areas
Colorado, U.S.	Janke, 2010	Multi-criteria analysis	Wind potential, distance to transmission lines, distance to cities, population density, distance to roads, land cover, federal land
Northern California, U.S.	Rodman and Meentemeyer, 2006	Rule-based spatial analysis	Physical criteria: wind speed, forest density, valley slope and distance to ridge; Environmental criteria: vegetation, endangered plant species and wetlands; Human impact criteria: urban areas and recreation areas

New York, U.S.	Van Haaren et Fthenakis, 2011	Multi-stage multi-criteria analysis	Economic evaluation: distance to transmission grid, distance to roads, land clearing costs, wind resources; Bird impact evaluation; Excluded locations: urban areas, federal lands, reservations, roads, lakes, steep slopes, karst areas; Planning criteria: noise Van
Prusice, Poland	Szurek, Blachowski and Nowacka, 2014	Gis-based multicriteria analysis	Location of nature protection areas and their buffer zones, built-up areas and their buffer zones, location and distance from power lines, location and distance from rivers and surface waters, location and buffer zones from forests, - location, technical standards and distance from roads, location, technical standards and distance from railways, slope, aspect, location and distance from telecommunication lines
Red Sea Governorate, Egypt	Effat, 2014	The Analytical Hierarchy Process	First factors are wind speed, elevation zones used to derive the wind power density. Second factor is economic factors involved distances from urban areas, roads and power-lines. Third, land constraints were derived from the evaluation.
Poultney Valley, Vermont, U.S.	Van Hoesen and Letendre, 2010	GIS-based overlay analysis	Wind potential, view shed for visual impact including heights of canopy, slopes and elevation

In this paper Land Suitability Analysis, based on Geographic information system (GIS), will be applied in Egypt to identify the suitable place for wind farm. By using Geographic information system, the identifying suitable land based on current land use maps, water network system maps, climate maps within maximum temperature and minimum temperature, rain fall time, wind speed maps, wind direction maps, humidity and bird migration. Every map of this information has different raster layers with another scale. The urban planner could not combine with two different units of raster layer such as: raster of ground water in (m3/year) within raster of climate (m3/year). The selection of the suitable land for Wind Farm is based on: Wind Resources, Roughness of the terrain and obstacles, Road Access, Orography of the region, Accessibility to transmission and/or distribution networks, Soil Conditions, and Environmental Impacts Obviously (Baban& Parry, 2001).

Methods

Description of the Suez Governorate, Egypt

Suez governorate coastline is located on the northern part of the Gulf of Suez between latitude 29° 58' 25.36"N and Longitude 32° 31' 34.57" E. The Suez Governorate is bordered from the north by Governorate of Ismailia, north Sinai Governorate, from the south by Red Sea Governorate, from East bounded by South Sinai governorate, and from West bounded by Cairo Governorate and Giza Governorate. The area of the governorate is 10,056.43 miles. The weather condition in Suez is known by a desert climate. In Suez, there is almost no rainfall during the year. The Suez governorate is identified by a dominantly hot and windy climate. In Suez city, the average temperature is 22.7°C. The annual relative humidity is 53.5%. The annual evaporation is 9.6 mm per day. The wind speed in some zones reach 7.9 m/sec, and in other zones may reach 11.7 m/sec which is high potentials for Wind Energy. The average of rainfall is 20 mm. May is the driest month and has 0 mm of precipitation. Rainfall starts in

November. The warmest month is August. The minimum temperature is 14.8°C in January, and average temperature is 29.8°C.

Figure 1. Suez Governorate of Egypt Map

Selection of Model Factors

There are 5 criteria selected for doing suitability analysis to find the suitable location for wind farms. The criteria are Wind Energy potentials, Powerline, Roads, Slopes, Shoreline, and Exclusionary areas (i.e. Cities and Towns). The selection of the criteria is based on the comprehensive literature Review. These crucial criteria are to identify suitable location for Wind farms installation in Suez Governorate. The layers were projected co-ordinate system into UTM 1984 Zone 36N, and then turn these layers into raster data structure. Table 2 shows the criteria, data source, Reasons for Selection, Original Data Structure, and Original Data Structure.

Table 2. Criteria and source of Data used in model and Criteria and Excluded zones (Constraints) threshold.

Criteria	Data Sources	Reasons for Selection	Source	Buffer zone (m) around excluded zones
Wind Speed	Effat, H., (NARSS)	Important for wind energy production	Vector (Polygon)	
Slope	Effat, H., (NARSS)	Slope affects the ease of construction & maintenance	Raster	More than 9 degrees
Power Lines	Effat, H. (NARSS)	Ease in connection of electricity	Vector (Line)	250 m around Power lines
Cities & Urban settlements	Effat, H. (NARSS)	To reduce visual and noise impacts	Vector (Point)	2000 m around Cities
Land Use/ Land Cover	Effat, H. (NARSS)	Show environmental impacts	Raster	
Shoreline	Effat, H. (NARSS)		Vector	4000 m around Shoreline
Roads	Effat, H. (NARSS)	Ease of access for maintenance.	Vector (Line)	500 m around Roads

Criteria and Thresholds

These criteria can be used by environmentalist to identify the best location. For example, distance of wind farms installation and bird migration to reduce bird collisions, and to avoid visual impacts and noise for population zones. The most important criteria for installing wind turbine are the wind energy potentials and environmental fitness. While selecting the site, the criteria of wind energy potential and environmental acceptability must be taken into consideration. Moreover, any location that don’t have enough or adequate wind energy will be unsuitable for selecting wind turbines. Figure (2) represents a flow chart for the criteria and methodology being used.

Power-Lines Proximity and Setback Buffer

According to Nextra Energy Canada (2011) and, Bartnicki and Williamson (2012), the production cost is minimized by choosing a suitable location to be near to hydro lines and roads. Furthermore, the transmission line distance has to be short for transporting the wind turbine energy and minimizing cost. To maintain a suitable site, the land is linked to electrical grid. According to Moiloa (2009) and the DEADP (2006) a minimum distance were suggested by them, that about 250 meter must be apart from any high voltage.

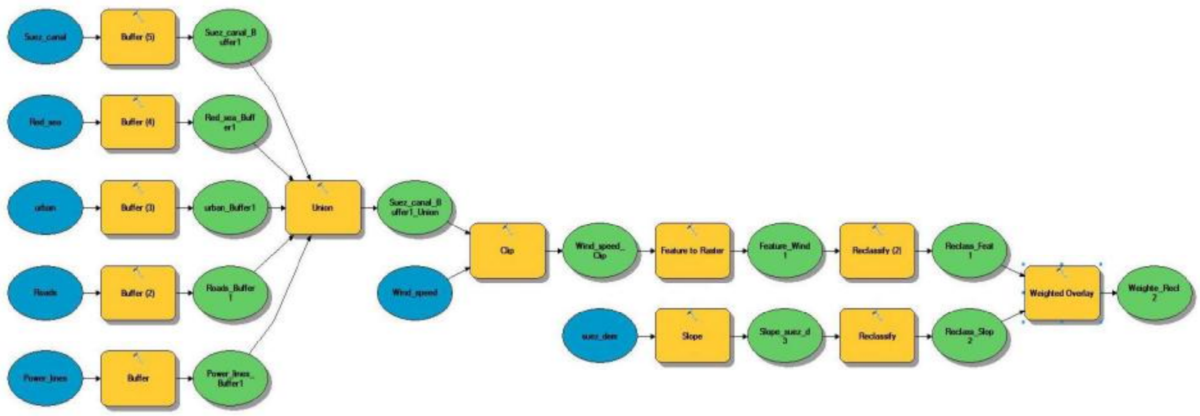

Figure 2. A conceptual chart for the applied methodology

Urban Areas and Cultural Sites Proximity and Setback: According to the CNdV Africa report (2006), the legacy sites as civilized and historical value with provincial or national name are clarified. These types of sites are categorized as educational amenities that must be protected carefully. Willamson and Bartnicki (2012) granted a 550-m setback for historic areas, recreational and urban. For the present study, historic sites used a setback of 1000 m however for the cities growth expansion a setback of 2000 m where used.

Slopes: Bartnickiet Williamson (2012) and Luo et al. (2007) reported that the probability of the turbine failure is increasing when the slope is higher than 9 dgrees as it is difficult for the wind to hit the rotor of the turbine perpendicularly at the summit of steep. Therefore, if the slope of exceeded 5 degrees this will harvest a high turbulent wind pattern causing instability in the wind turbine. In addition, the project cost highly increases if the buildings are on high slopes. Baban and Parry (2001) suggested that the terrain or zone must be flat or rounded to be able to tolerate high wind speeds. The classification of the slope was most suitable for 5 degrees; marginally suitable less than 10 degrees and slopes more than 10 degrees are totally unsuitable.

Ecological and Social Factors (Exclusion Zones/Constraints): Social and ecological evaluation criteria could be factors or constraints. A constraint is restrictedly inappropriate zone for installing wind turbines. According to Bennui et al. (2007), for protecting effect, it is excluded on communities, environment, eco-conversation and visualization. Moreover, according to Effat and Hegazy (2013) and Effat (2014) constraint standard has assigned as a threshold.

Shoreline Setback: The Wind farms must be far away from any residential areas. Moiloa (2009) and DEAP (2006) suggested the distance for the wind farm is to be far away from the coast for about 4 km. Around the shoreline, identical buffer zone was applied taking in consideration the paths for bird flight and future marine activities for tourism.

Land-Use—Land-Cover: Land such as airports must be kept away from any wind farms as the operations can affect navigation. A setback for about 25 km between the wind farm and the airport is identified by CNdV Africa (2006).

Standardization of the Criteria: Saaty's (1980) identified that the suitable standardized scale is to be from 1-9 converting the original values to a suitability value. Bartnicki and Williamson (2012) suggested that the high score will be for higher suitability.

Results and Discussion

The study accomplished by using Geographic Information System (GIS) for mapping the suitable location in Suez Governorate for sitting wind farms. In the analysis, the modelling framework based on multi-criteria of GIS is identifying the suitable sites for wind farms installation with cost effective techniques. Engineering, socio-economic and environmental criteria were taken into considerations. Based on results and output of the maps in Figure 3, these criteria should identify the best location for wind farms according to each factor. The design of weighting and scoring was based on literature review and related studies. Other criteria such as utilities, governmental agencies, and demand investor were added for the modelling framework to be more accurate and to develop the layers of geospatial for those criteria.

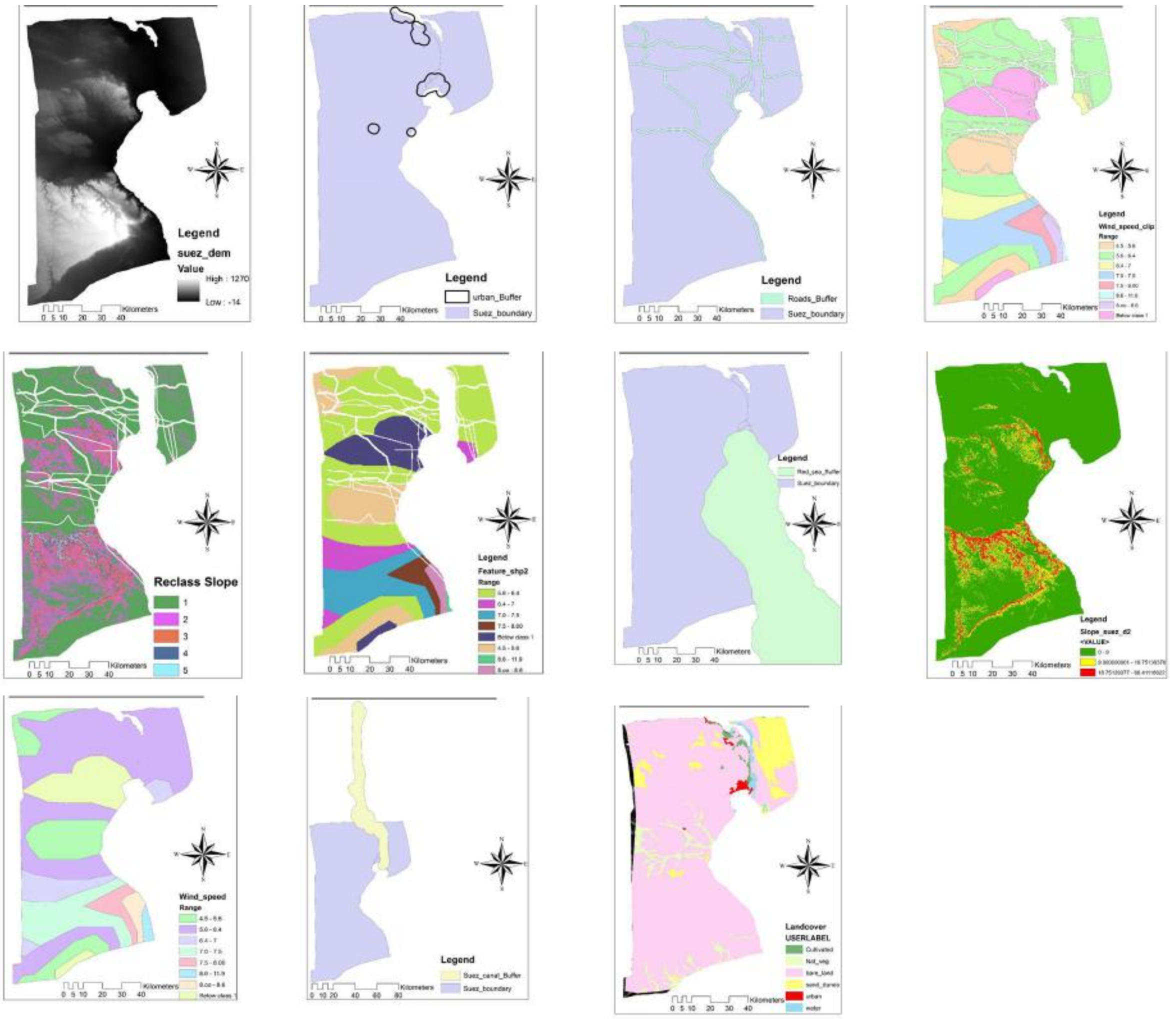

Figure 3. Spatial patterns of suitability scores for each criterion (exclusionary area excluded).

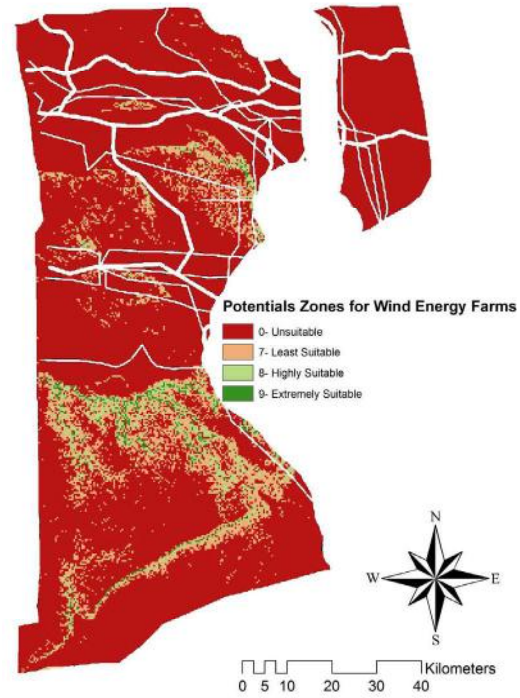

Figure 4. Suitability index for most appropriate zoning of wind farms in Suez Governorate

The results show that the central area of the governorate of investigated region has high wind energy potentials. These zones are proper for locating electricity generating wind turbines. The total exploration area is 53,083 sq. km. Total area classified into extremely suitable, highly suitable, least suitable, and unsuitable. The area of extremely suitable is 548 sq. km, highly suitable is 2002 sq. km, least suitable is 5387 sq. km, and unsuitable is 45145 sq. km. The results show that the Central region, North East, and South region of the Suez Governorate are the quietest rich in wind power potentials. There are some zones that have high suitability score, according to suitability map of wind farms in Figure 4.

Conclusion

The awareness of using wind energy production has increased that as a clean alternative to non-renewable energy. This paper used the land suitability analysis conducted by the geographical information systems (GIS), in which multi criteria could be used to identify the appropriate locations of wind farms in Suez Governorate, Egypt. Different variables affecting the presence of wind farms could be added and overlaid in GIS including wind speed maps, wind directions map, and topography maps. The criteria depended on physical and socio-economic factors to find suitable lands to locate wind farms including the population density, land use, slopes, distance to roads, wind speed and transmission lines. The factors also include ecological purpose that not to be located near cities and airports. The results showed that 548 and 2002 square kms of the total area were extremely suitable and highly suitable respectively. The central and northeast parts of Suez Governorate of Egypt have showed to be the most suitable locations for wind farms development.

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