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A Geographical Spatial Analysis on the Benefits of Using Wind Energy in Kuwait

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***Abstract*—**Wind energy is associated with many geographical factors including wind speed, climate change, surface topography, environmental impacts, and several economic factors, most notably the advancement of wind technology and energy prices. It is the fastest-growing and least economically expensive method for generating electricity. Wind energy generation is directly related to the characteristics of spatial wind. Therefore, the feasibility study for the wind energy conversion system is based on the value of the energy obtained relative to the initial investment and the cost of operation and maintenance. In Kuwait, wind energy is an appropriate choice as a source of energy generation. It can be used in groundwater extraction in agricultural areas such as Al-Abdali in the north and Al-Wafra in the south, or in fresh and brackish groundwater fields or remote and isolated locations such as border areas and projects away from conventional power electricity services, to take advantage of alternative energy, reduce pollutants, and reduce energy production costs. The study covers the State of Kuwait with an exception of metropolitan area. Climatic data were attained through the readings of eight distributed monitoring stations affiliated with Kuwait Institute for Scientific Research (KISR). The data were used to assess the daily, monthly, quarterly, and annual available wind energy accessible for utilization. The researchers applied the Suitability Model to analyze the study by using the ArcGIS program. It is a model of spatial analysis that compares more than one location based on grading weights to choose the most suitable one. The study criteria are: the average annual wind speed, land use, topography of land, distance from the main road networks, urban areas. According to the previous criteria, the four proposed locations to establish wind farm projects are selected based on the weights of the degree of suitability (excellent, good, average, and poor). The percentage of areas that represents the most suitable locations with an excellent rank (4) is 8% of Kuwait's area. It is relatively distributed as follows: Al-Shqaya, Al-Dabdeba, Al-Salmi (5.22%), Al-Abdali (1.22%), Umm al-Hayman (0.70%), North Wafra and Al-Shaqeeq (0.86%). The study recommends to decision-makers to consider the proposed location (No.1), (Al-Shqaya, Al-Dabdaba, and Al-Salmi) as the most suitable location for future development of wind farms in Kuwait, this location is economically feasible.

***Keywords*—**Kuwait, renewable energy, spatial analysis, wind energy

I. Introduction

ECONOMIC and social development is highly dependent on the availability of energy sources. Renewable energy sources have gained immense global attention due to the depletion of fossil energy sources and the adverse impacts of carbon emissions which have contributed vastly to climate change. Wind energy is considered one of the fastest growing renewable energies in the world and is aimed at achieving a high level of sustainable development in the field of energy.

In a study conducted by Sahin and Aksakal [1], on the potential of wind power generation in the Eastern Province of Saudi Arabia, the annual data for the East Coast were studied. Weibull was used and compared with Rayleigh's distribution of wind power densities. The researchers found that small-scale power generation systems are suitable for eastern parts of Saudi Arabia for power generation and irrigation uses**.**

In the study done by Al-Nassar et al. [2], the wind characteristics of six locations in the State of Kuwait were assessed. The annual average wind speed for the studied locations ranged from 3.7 to 5.5 m/s with a mean wind power density from 80 to 167 W/m^2 at standard height of 10 m. Using Weibull distribution, the Weibull parameters and power density of each station have been concluded. The wind data at heights 15, 20, 25, and 30 m were attained by extrapolation of the 10m data using the Power-Law. Maximum power density is found at 30 m height which diverges between 130 and 275 W/m^2 with 70% increase from the standard height representing potential wind energy especially in the northern part of the country. The highest potential wind power was found during the summer season which is the peak demand season of electricity in Kuwait.

II. The Problem of the Study

The demand for electric energy in Kuwait is increasing in recent years and this is posing a major challenge for Kuwaiti administration. This increase is a result of increased consumption of fossil energy due to urban expansion and rapid population growth, resulting in adverse environmental and economic consequences. Such factors call for the introduction of an alternative source of energy, coupled with its feasibility of application and to minimize the negative environmental impacts of traditional energy sources. This may be done using GIS applications to conduct spatial analysis for a study area and according to specific criteria for its selection for a wind energy project. The results of the study can contribute positively to the development of spatial standards for decision support in the field of alternative energy projects for the State of Kuwait.

III. Objectives of the Study

(1) To recognize the importance of the use of alternative energy in the State of Kuwait in economic and environmental terms.
(2) Employment of GIS applications through the identification of a set of appropriate criteria for selecting

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the most suitable locations for the establishment of wind energy projects in the State of Kuwait.

(3) To aid decision-makers and planners in the field of energy production in utilizing the results of the research to identify optimum locations that can be utilized for developing future alternative energy projects.

Fig. 1 Kuwait State (study area)

IV. Methodology

The study area covers the State of Kuwait in general with a focus on areas surrounding urban lands. The study was performed on daily climatic data of winds which was in turn used to assess the daily, monthly, quarterly, and annual wind energy available for utilization by humans. Data were recorded on Excel spreadsheets. The climatic data were obtained through the readings of monitoring stations of KISR namely: Al-Abdali, Al-Sabiyah, Al-Mutlaa, Al-Salmi, KISR, Umm Al-Hayman, Al-Zour, Al-Wafra, Um emara and Al-Taweel.

The study criteria for the state of Kuwait were carefully selected by reviewing several previous studies in the use of ArcGIS applications to determine the most suitable locations for wind farms. In this study, the researcher applied the Suitability Model to analyze the study under question within the ArcGIS program. Carr and Zwick 2007 [3] define the Suitability Model in its general meaning as “a measure to determine the relative importance of certain areas of land for using them for specific purposes." In the other words, it is a model of spatial analysis that is based on comparing more than one location based on grading weights to select the most suitable one. This technique is based on the approach of including all the different spatial criteria within the structure of the study’s methodology to obtain results to select the most suitable locations for the development of wind farms.

The study criteria were chosen based on the characteristics of natural and human study areas and by reviewing several similar studies like Miller and Li [4] and Rodman and Meentemeyer [5].

The current study adopted several criteria, the most important of them are:

(1) The average annual wind speed.
(2) Land use.
(3) Topography of land.
(4) Distance from the main road networks.
(5) Urban areas.
(6) Distance from sensitive areas (military, oil fields, and natural reserves).

The study criteria have been developed in the form of Spatial Information Layers, where each topic includes a map used in the spatial analysis process.

The current study criteria are as follows:

(1) The average wind speed is the decisive factor in the production of electric power from wind since the ideal location is conditioned to constant wind flow throughout the year at a rate of not less than 4.5 m/s. Wind data were collected for the period 2000 - 2010 from eight monitoring stations. Data conversion and reclassification were performed suitably based on the average annual wind speed using ArcGIS. The scale of the classification ranged from 1 to 4 where level 1 indicates the least possible location for the wind energy project and level 4 refers to an optimal location.

Accordingly, a map of annual wind rates in Kuwait was drawn in Table I and Fig. 2.

TABLE I
Wind Speed Criterion

m/s speed wind Average	Degree	Description
4>	4	Excellent
3	3	Good
2	2	Average
2<	1	Poor

(2) Land use is one of the most important criteria in monitoring stations determining the suitability of locations for establishing wind energy projects, the selection of these locations will not come in conflict with current and future land uses. The study uses the land use map of Kuwait, issued by the Kuwait Municipality (Map of the National Plan) by which the weight for each class of study was determined.

(3) The geomorphological forms are one of the criteria that the study took into consideration as it affects the efficiency of wind turbines. Many studies indicate that the gradient should not be severe and should not be more than 7%. A map of Kuwait's topography was prepared to be used as criteria for the study. The desert environment of Kuwait is characterized by sand dunes which may reduce the efficiency of the wind farms. Therefore, sand dunes have been excluded as a criterion for determining the most suitable locations for wind farms.

(4) Road networks are vital to the development of any region; hence, they have been placed within the study criteria. To avoid the negative impacts of wind farm projects, the study suggests that the buffer zone area around the roads represents the appropriate distance from the main roads, so that these distances are suitable for reaching the wind farm locations and overcoming the disadvantage of

developing the areas around those roads. On another hand, the distance must be appropriate to reduce the cost of access to wind farms for the transportation of required equipment and for periodic maintenance as well.

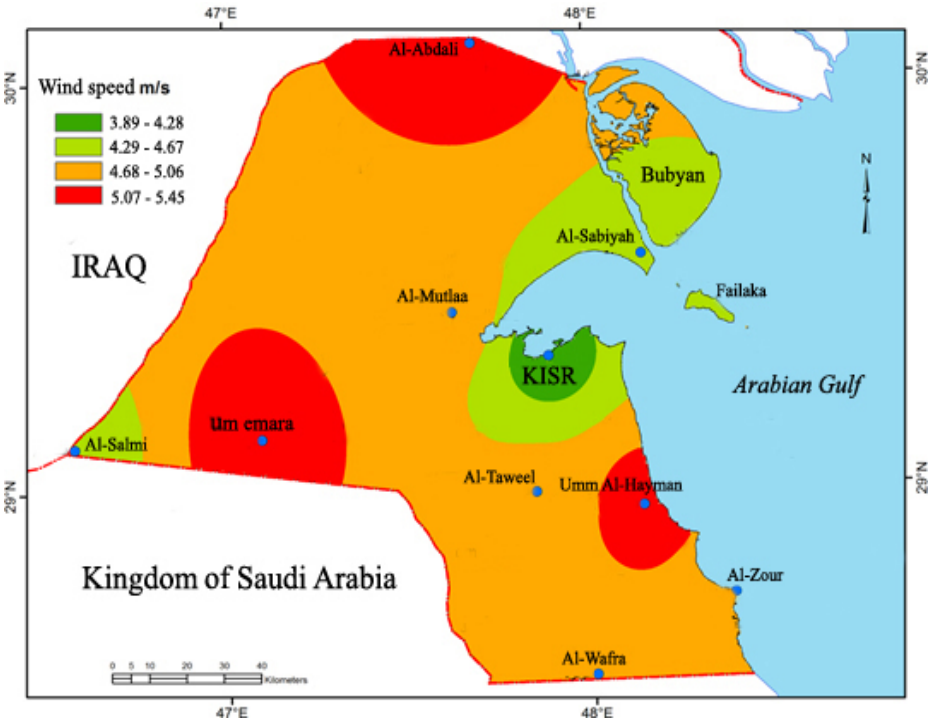
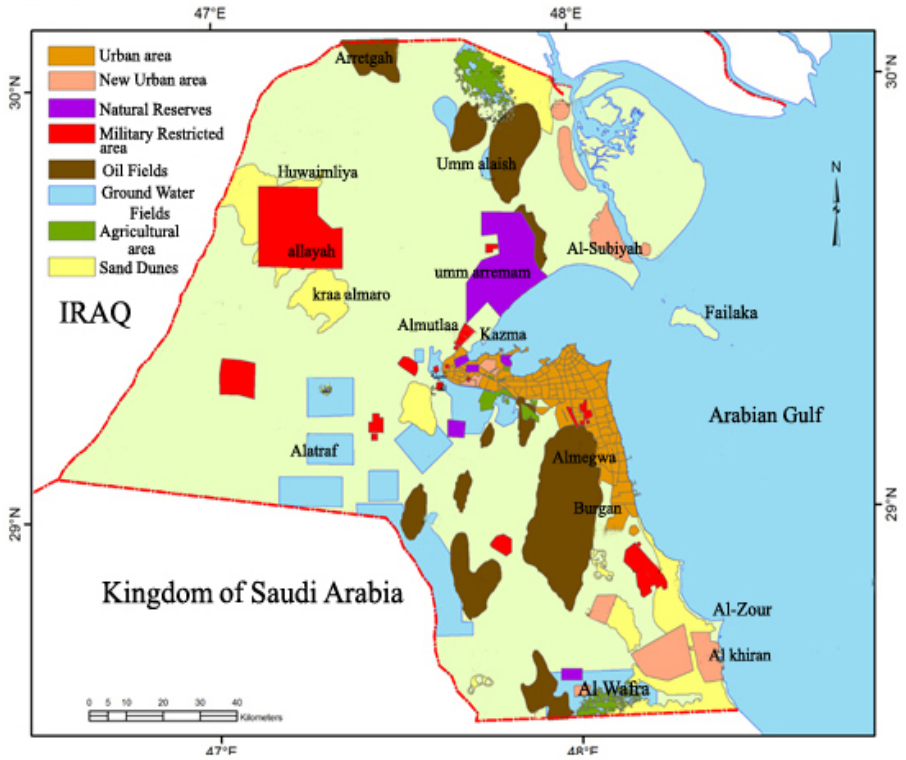


Fig. 2 Spatial classification of average annual wind speed at monitoring stations



F Fig. 3 Land uses (including Natural Recourses and the Existence of Natural and Human Obstacles)

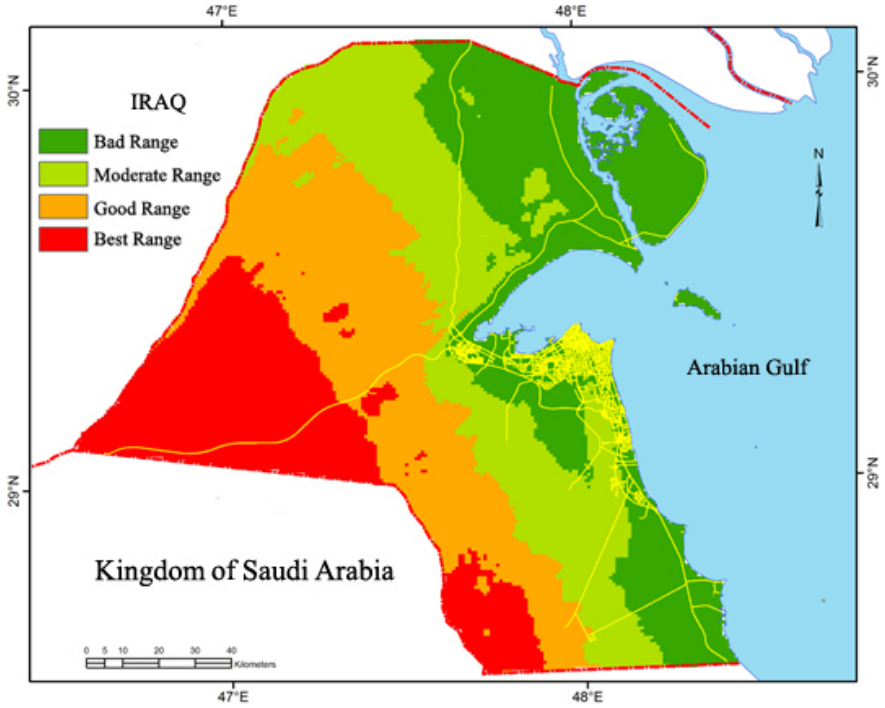


Fig. 4 The spatial classification of heights related to sea level

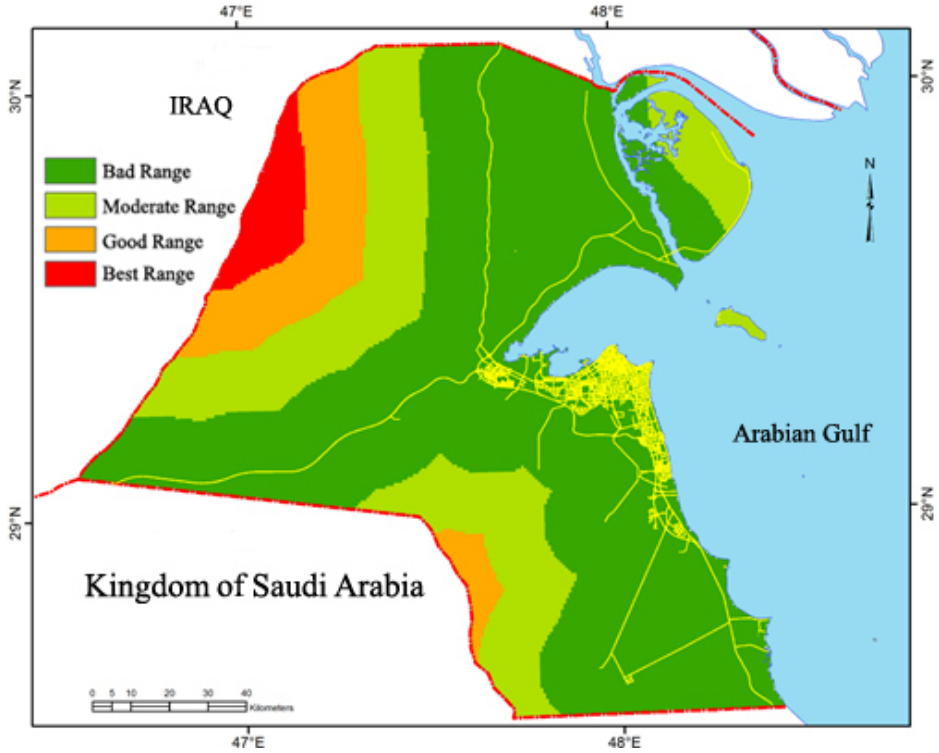


Fig. 5 The spatial classification of the suitable distance from the built-up area to the main roads

(5) Urban areas and areas of population density are considered important criteria when planning wind farm projects. Studies also indicate the need for separating areas between wind farms and urban and residential areas and their infrastructure from transportation sites, airports and other means of facilities so that they may not impede future development or hinder the development of wind farm projects. Fig. 5 shows the spatial importance of the

criteria divided into four gradients based on their relative importance and suitability for establishment of wind farms. This criterion was established within the criteria of spatial analysis of the study.

(6) The study considered the distance criteria between proposed wind farms and some sensitive locations of the natural environment (such as natural reserves), of a military nature, or those related to the national economy (oil fields and oil facilities). Several studies have pointed out the need for a buffer zone to protect the pathways of migratory birds that use these protected areas as safe havens during their cessation. The electromagnetic effect of wind farms influences radars and flight paths at military airports close to these locations. Consequently, environmental and security considerations are among the most important criteria used to determine the locations of wind farms.

The criteria chosen in the study are based on a set of maps using ArcGIS, converted into RASTER DATA and categorized into levels (1-4). Based on analysis of the study criteria, each weight in the criterion reflects the relative importance of the most relevant locations pertaining to decisive factors. The appropriate distance of the study area has been determined by reviewing several similar studies. By combining the weights used for each criterion, the study produced a general map showing the results of spatial analysis by determining the most suitable locations for the establishment of wind farms in Kuwait. Table II shows the appropriate study criteria.

TABLE II
THE CRITERIA OF STUDY FOR THE SUITABILITY MODEL FOR SELECTING THE OPTIMAL LOCATIONS FOR WIND FARMS IN KUWAIT

Degree of preference	Wind speed rate (m / s)	Regression rate	Distance from urban areas	Distance from main roads	Distance from sensitive areas
Excellent (4)	4>	%7<	1-5 km	1-3 km	10-20 km
Good (3)	3		5-10 km	3-4 km	20-30 km
Average (2)	2		10-15 km	4-5 km	30-40 km
Poor (1)	2<		>15 km	>5 km	>40 km

V. RESULTS

Fig. 6 shows the proposed locations for the establishment of wind farm projects in the study area. The figure also indicates four locations according to the criteria used by the study. It is based on the weights of the degree of suitability (excellent, good, average, and poor) and the percentage of areas that represent the most suitable locations with an excellent rank (4) embody 8% of Kuwait's area. They are relatively distributed as follows:

TABLE III
LOCATIONS WITH AN (EXCELLENT) RANK

Area	Percentage
1) Al-Shqaya-Al-Dabdeba–Al-Salmi	5.22%
2) Al-Abdali	1.22%
3) Umm al-Hayman	0.70%
4) North Al-Wafra and Al-Shaqeeq	0.86%

Al-Shqaya, Al-Dabdaba, and Al-Salmi are the most recommended locations, as they are the largest areas located in the western part of the State of Kuwait. Al-Abdali farm area in the north of Kuwait occupies the second place. In the third place is Umm al-Hayman area. In the southern region are North Wafra and Al-Shaqeeq which occupy the fourth place.

According to the criteria presented in the final map, these locations include the most suitable places for the establishment and development of wind farm projects to enhance electrical power supply in Kuwait.

VI. CONCLUSION

Wind production in recent years has seen more global attention as a clean alternative for fossil energy sources. Many countries have developed alternative energy sources such as wind energy as part of their national energy strategies. The trend towards the use of alternative energy sources is a logical consequence of the desire to rely on sustainable energy and to reduce the carbon emissions from incineration of fossil energy sources. Wind energy is one of the most promising alternative sources of energy.

VII. THE IMPORTANCE OF RESEARCH RESULTS

Based on the results of the study, this type of spatial analysis is vital as a determinant of wind farm project locations and may serve as an important part of regional planning of alternative energy projects. They may also be used as successful models and may be applied to other alternative energy projects within the region.

The study acts as a future vision for decision-makers and officials responsible for the provision of energy in the State of Kuwait. The study hopes that they take into consideration the proposed location No. (1) (Al-Shqaya, Al-Dabdaba, Al-Salmi) which is the most suitable location for the development of wind farms in Kuwait, from the economic perspective. This location is considered economically feasible. The geographical conditions which are represented in the climatic and terrain characteristics contribute in facilitating the engineering and design of the wind farms. The proximity to power transmission lines and roads reduce the cost of construction of these stations. The electricity supply can be used to feed the demand for electric power in the border areas, in groundwater production areas of the Al-Shqaya fields, and some productive industrial activities such as poultry production and farms as examples.

In the long run, the study proposes to use areas that have good or low wind energy weights which may have an excellent ranking when spatial analysis of alternative energy

sources supports wind energy such as solar energy to integrate alternative energy sources to access and achieve energy security through the incorporation of sustainable energy sources.

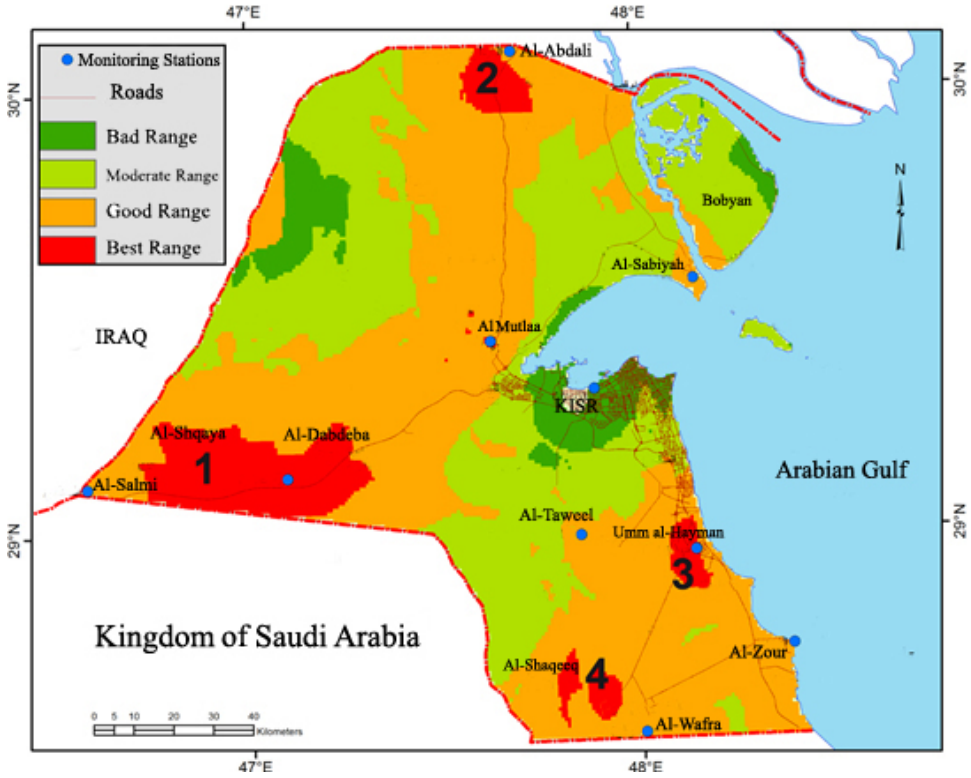


Fig. 6 The optimal spatial distribution for the proposed wind energy production in Kuwait

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