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Multi-Criteria Modeling to Select the Best Sites for Constructing Wind Power Plants in Al-Batnan Region - Eastern Libya

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Abstract: Choosing the optimal location for a wind farm is a complex and recurring process, as it depends on various criteria known as "site selection criteria". Determining the relative weight of each criterion, which is a multi-criteria decision-making (MCDM) process, is of utmost importance during this process. The current study deals with selecting the optimal location for developing an onshore wind farm in the eastern regions of Libya using Geographic Information System (GIS). Seven different criteria were considered for site selection: wind speed, wind density, vegetation cover, temperature, elevation, slope, and urban areas. The Analytic Hierarchy Process (AHP) was used alongside triangular numbers as an MCDM tool to obtain criterion weights and make the optimal site selection decision. A suitability map for the wind farm was prepared for the entire area and it was found that the best location is in the western part of Tobruk city near coastal areas west of Ain Al-Ghazala region. This area was highly suitable due to its high wind speeds. Meanwhile, a large part of the area fell under the category of high suitability, especially in the southern regions where wind speeds are lower. The remaining study area fell under moderate and low suitability categories, especially in the northern regions near the coast.

Key words: Site selection criteria · Multi Criteria Decision Making (MCDM) · Wind density · Analytic Hierarchy Process (AHP) · Suitability map

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INTRODUCTION

Energy is one of the fundamental elements of the renaissance of developed countries that have helped to achieve their development and the well-being of their peoples. The global demand for energy resources, especially for traditional resources (oil, coal and gas), has therefore increased significantly in recent years thanks to the great development that the world is experiencing at the industrial and technological level; In light of the growing demand and consumption of traditional energy sources, problems and disadvantages of these sources have begun to appear, such as their high price, non-renewability and inexhaustibility and their negative impact on the environment. Focus on production and provision of energy from renewable sources due to low price, sustainability and environmental protection. These renewable energies include wind energy, because wind energy is one of the renewable energy sources that man has used since ancient times. Interest in this resource has increased with the increase in population and economic activity. Wind has become one of the strategic options for electricity production.

Wind is air in motion. It is caused by the uneven heating of the Earth's surface by the sun. Today, wind energy is mainly used to generate electricity. A wind turbine is used to harness the kinetic energy in wind to generate electricity. A typical wind machine consists of blades, generator, cable and a tower. The blades are connected to a drive shaft that turns an electric generator to produce electricity [1]. Wind energy production depends to a large extent on the wind speed and direction

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to know its production capacity, but apart from that there are several criteria and other factors that affect the wind speed and thus the energy productivity, so these criteria must be taken into account and between these criteria include the topography of the land in terms of height Slope, density of vegetation cover, temperature, wind intensity, distribution of the road network and urban areas, each of these factors has an effect on the wind speed and the success of establishing wind energy projects. In order to find suitable locations for establishing wind energy projects, it is necessary to rely on the multi-criteria decision-making method (MCDM) in conjunction with geographic information system techniques and select a site in the so-called spatial suitability, where spatial suitability is one of the functions (GIS) that aims to select a suitable spatial location for the performance of a specific function.

Baseer *et al*. [2] presented through their research at Saudia Arabia an analysis of the suitability of the wind farm site using a multi-criteria decision-making approach (MCDA) based on Geographic Information System (GIS) modeling. AHP was also used to assign appropriate weights to the criteria and the central and southern regions were identified. Eastern to be unsuitable mainly due to the scarcity of wind resources, the lack of settlements and the lack of connectivity to roads and electrical networks. Mentis *et al*. [3] studied in their research the potential of onshore wind energy in the African continent. This study relied on VORTEX as a source for providing wind data and NASA was also relied on to provide wind speed data at an altitude of 10 meters above sea level.The researchers drew wind maps and derived the speed and potential of wind energy at an altitude of 80 meters. In this study, the locations of wind farms were determined through a comprehensive analysis of the geographical information system. Based on the analysis, it was found that there are some countries with a high production capacity of annual wind energy, such as South Africa andSudan, Algeria, Egypt, Libya, Nigeria, Mauritania, Tunisia and Morocco, while Equatorial Guinea, Gabon, Central African Republic, Burundi, Liberia and Togo report lower wind energy potential. Bennui *et al.* [4] followed in their research an approach based on Geographic Information System (GIS) integrated with multi-criteria decision-making (MCDM) to choose the effective site for large wind turbines in Thailand, where this study included several different criteria and exclusion factors and concluded this research. To divide the study area into five appropriate categories, which are very suitable areas with an area of 143.842 hectares, high suitable areas with an area of 198.763 hectares, the third category was of medium suitability and the fourth category with low suitability.

Ali *et al*. [5] aimed to identify the best sites for coastal wind farms in South Korea by following the (MCDM) approach, which depends on selecting several decision-making criteria and giving relative weights to each of them in a process called multi-criteria decision-making, in conjunction with GIS techniques. Through this study, a multi-criteria decision approach was followed in conjunction with the Geographic Information System (GIS) and this approach was applied to the eastern region of the State of Libya in order to reach the best sites for establishing wind farms.

Therefore this research aims to identify and select the best locations for setting up a wind power project by studying the aforementioned criteria affecting the use of wind as an energy source and assigning a weight to each factor that shows the extent of its impact through stakeholder and specialist opinion and analysis of wind potential through acquisition It uses data from satellites and analyzes it to estimate wind speed and direction and then analyzes and studies satellite images to determine the best areas for setting up a wind farm.

MATERIALS AND METHODS

Study Area: The study area is located between latitudes (30°26'40.6) and (32°27'33.48)N and longitudes (25°9'1.8) and (22°44'9.7)E. It is located in the northern part. It borders the Arab State of Egypt to the east, the Arab State to the east, the Mediterranean Sea to the north, the Umm Marzam region to the west and the sandy desert areas to the south. and in this way it covers an area of 32,981 square kilometers.

Data Sources:

Climatic Data: The Vortex website was referred to obtain surface wind data (80 m altitude).

Satellite Images: Satellite images from the US satellite (Landsat 8) with a spatial resolution of 30 to 60 meters to extract some variables such as vegetation index and surface temperature.

Using a digital elevation model (DEM), a digital elevation model for the ASTER satellite was used to extract the elevation, grade and slope direction points.

Field Study: This study will involve contacting the specialized authorities of the road network related to the

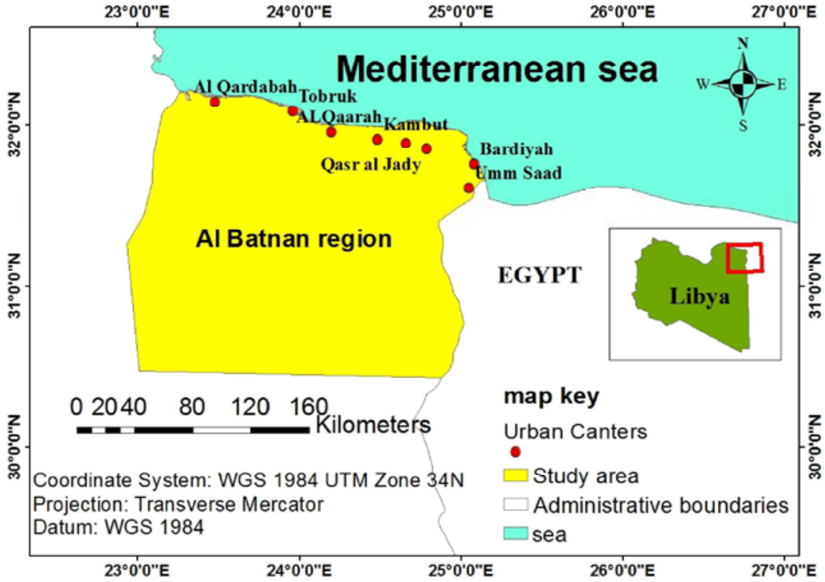

Fig. 1: The astronomical and geographical location of the study area
Source: Prepared by the researcher based on Google Earth Pro data

study area and creating an electronic questionnaire to determine the weights of each of the criteria used in the study.

Data Processing: The Normalized Difference Vegetation Index (NDVI), which is an index of vegetative differences, calculated using the equation [6]:

NDVI=(B1-B2)/(B1+B2)

- Surface temperature: Earth surface temperature values will be extracted in several stages as follows:

The first stage is the conversion of visible cells from electronic numbers to radiation values, which are denoted by the symbol L_λ (watts per square meter per radian (W/m^2ster µm) and the following equation [7].

$$L_\lambda = LMIN_\lambda + \left(\frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX_\lambda - QCALMIN_\lambda}\right) * (DN - QCALMIN) + QCALMIN_\lambda$$

The second stage is to extract brightness values using constants from the file attached to the visual for thermal wavelengths and according to the following equation [8].

$$T = \frac{K2}{In\left(\frac{K1}{L_\lambda} + 1\right)}$$

The third stage is to separate each of the surface temperatures and radiative power from the corrected thermal bands using the following equation [9].

$$\varepsilon = 0.004P_V + 0.986$$

A ((P)_(V)) represents the percentage of vegetation (extracted from the Normalized Difference Vegetation Index (NDVI) value) through the following two equations [10].

NDVI=(B1-B2)/(B1+B2)

where B1 represents infrared wavelengths and B2 represents red bands [9].

$$P_V = \left[\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}\right]^2$$

The final stage is to extract the LST surface temperature in Kelvin and then convert it to degrees Celsius using the following equation:

$$LST = \frac{BT}{1} + W * 1(BT \setminus P) * In(\varepsilon)$$

Suresh *et al*. [11].

Extracting Urban Areas: by analyzing the satellite imagery using the following equation:

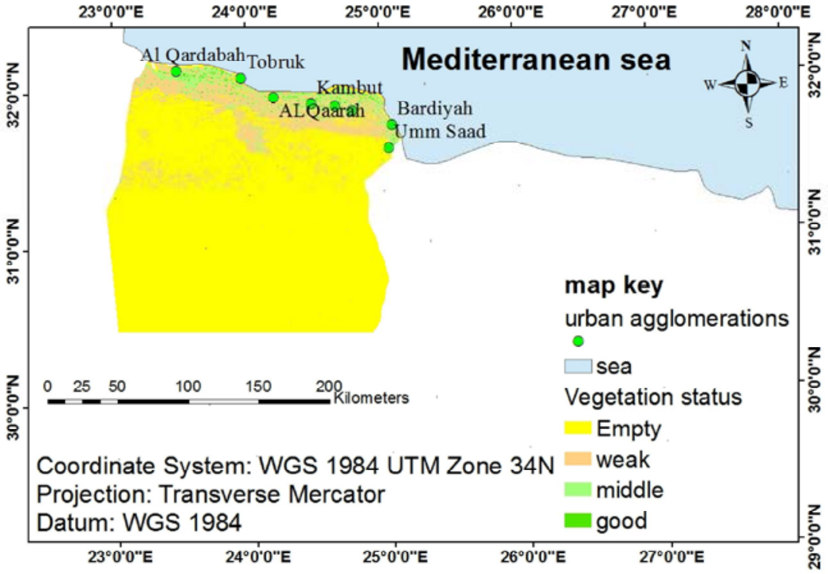

Fig. 2: Status of vegetation cover in the study area, 2021
Source: The researcher worked on the Landsat 8 satellite and using ArcMap 10.5

Data: Landsat 8:

NDBI= SWIR - NIR / SWIR + NIR

Sample Selection: A series of points (1000 points), Figure 2 were randomly selected to cover the entire region, then the data of the studied variables were derived to be prepared for statistical analysis and used to calculate weighted geographic regression models.

Fourth: Data Analysis

Spatial Modeling: This is done by studying and analyzing the criteria affecting wind speed in the study area and assigning each criterion an indicator according to the degree of its impact based on the opinion of experts; And the ability to simulate reality and give a model for these standards mathematically using technical and statistical processing in geographic information systems (Spatial Statistics Tools), to reveal mutual relationships and correlations leading to the construction of a geographic spatial model that simulates reality. An electronic questionnaire will also be used to obtain variable weights by experts in this area.

Spatial Analysis: Using a geographic weighted regression (GWR) model to find spatial differences in wind speed by analyzing the relationship between wind and the natural factors that influence it. Which can be shown on the map and the model can be formulated using the following equation: [12].

$$y_i = \beta_0(ui,vi) + \sum_{k\beta\kappa}(ui,vi)X_{ki} + \varepsilon_i$$

Statistical Analysis: A Pearson correlation analysis between wind speed and the factors influencing it will also be performed using the V.20 statistical package (SPSS) for the social sciences program.

RESULTS AND DISCUSSION

Spatial Informatics Criteria for Research with the Environmental Requirements of the Site: The process of selecting the most appropriate site depends on environmental planning methods, which include various scientific and spatial information fields, including urban, geological, environmental, botanical, and others.

First: Surface Appearances:

1- Vegetation Cover Index: NDVI

The study area is poor in terms of vegetation, due to the nature of the soil formations, as well as its location in a semi-arid climate. Figure 2 shows that the distribution of this cover is largely near the coastal areas, and it usually includes fast-moving annual grasses with some Dwarf shrubs in many locations and are evergreens adapted to semi-arid climates.

Altitude: The direction and speed of winds are greatly affected by the height of the site because wind turbines are usually installed in very high areas to capture higher wind speeds [13] and according to Figure 3 it was found

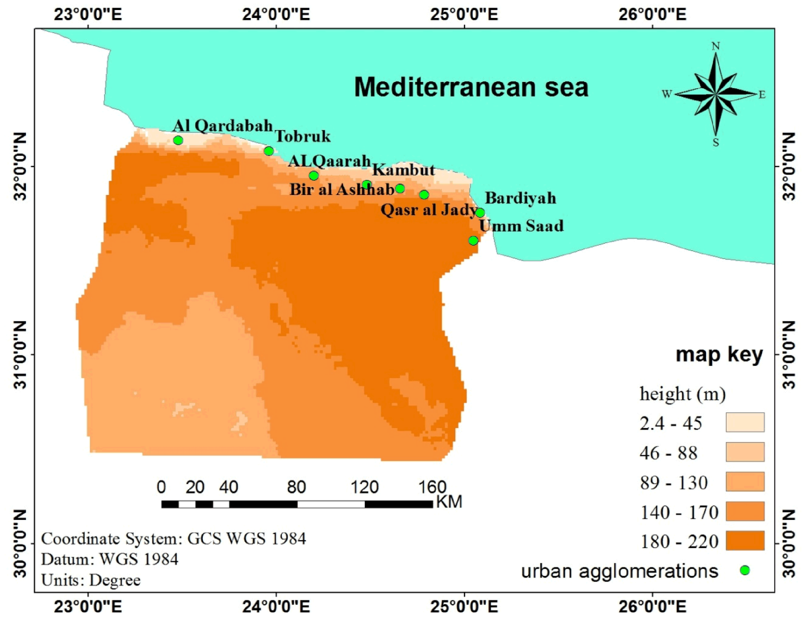

Fig. 3: Altitude distribution in the study area
Source The researcher worked on DEM from ASTER and using ArcMap 10.5

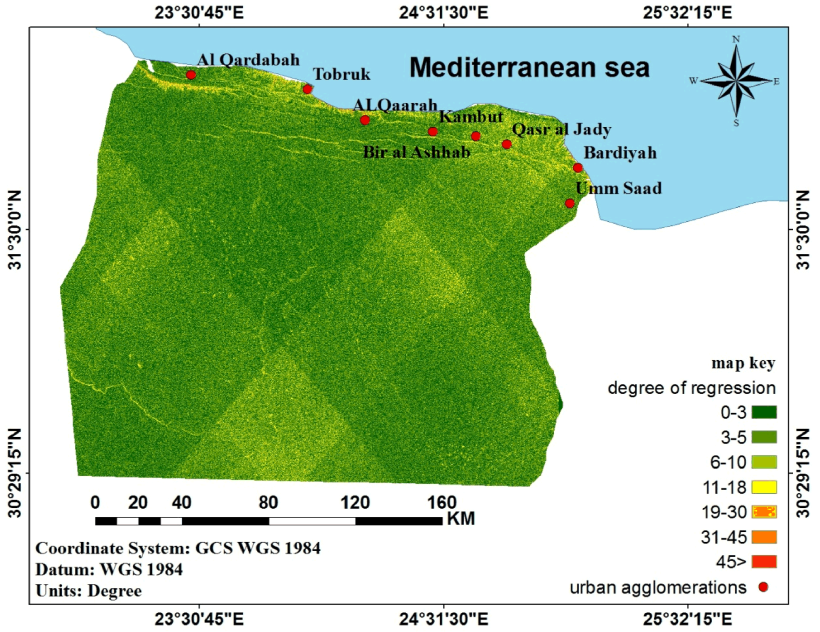

Fig. 4: Levels of slope in the study area according to Young
Source The researcher worked on DEM from ASTER and using ArcMap 10.5

that the study area is uneven in height as the height varied between 2.4 meters and 220 meters.

SLOPES: Slope is an important technical indicator for the construction of wind farms, because areas with steep slopes are not suitable for the installation of wind turbines due to the increased cost of construction and maintenance of the project and flat terrain is exposed to higher and more stable winds. Speed compared to the steep terrain [14]. Figure 4 shows that the slope of the study area is mostly flat areas that do not have many slopes, while there are some slopes in some areas along the coastal belt north of the study area and these slopes ranged between a gentle slope and a cliff.

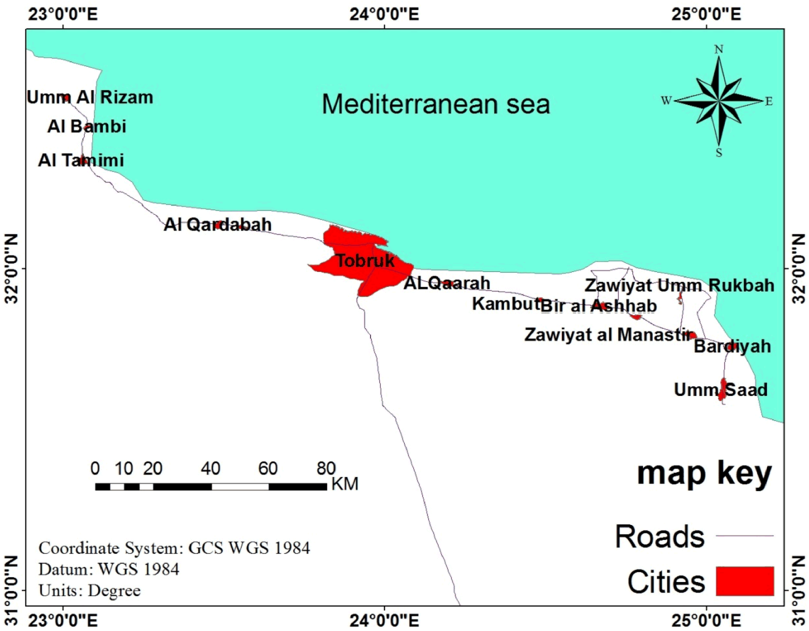

Fig. 5: Distribution of urban areas in the study area 2021
The source is the researcher's work based on Google Earth Pro and using ArcMap 10.5

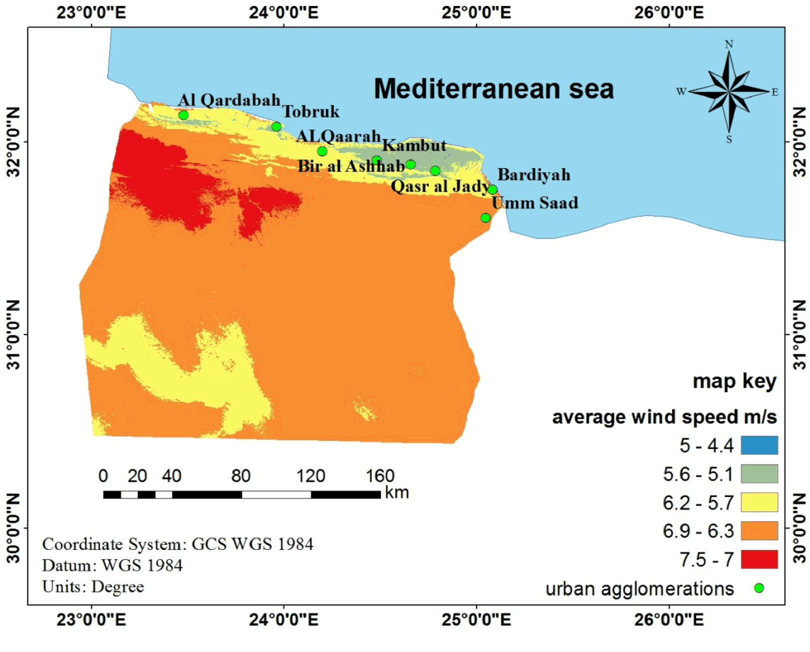

Fig. 6: Distribution of average wind speed at an altitude of 80 m
Source: Satellite image from Vortex website using ArcMap 10.5

Urban Areas: Wind farms have various harmful effects on people near them, such as noise and visual impairment. To reduce these negative effects of wind farms, a minimum distance from cities and residential areas must be taken into account. On the other hand, a reasonable distance from settlements must also be taken into account so that the loss does not increase. Transmission capacity and transport costs. Figure 5 shows that most urban centers are spread along the coastal strip, starting from the Umm al-Razam area in the west to the Mas' ad area in the east with the Egyptian border and are separated by various distances ranging from 20 km to 50 km.

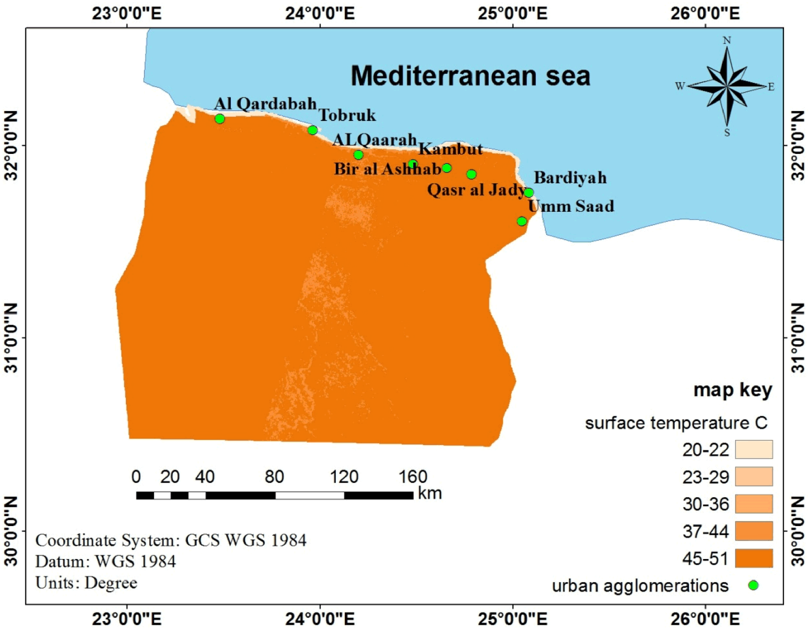

Fig. 7: Distribution of average wind intensity at an altitude of 80 m
Source: Satellite image from Vortex website using ArcMap 10.5

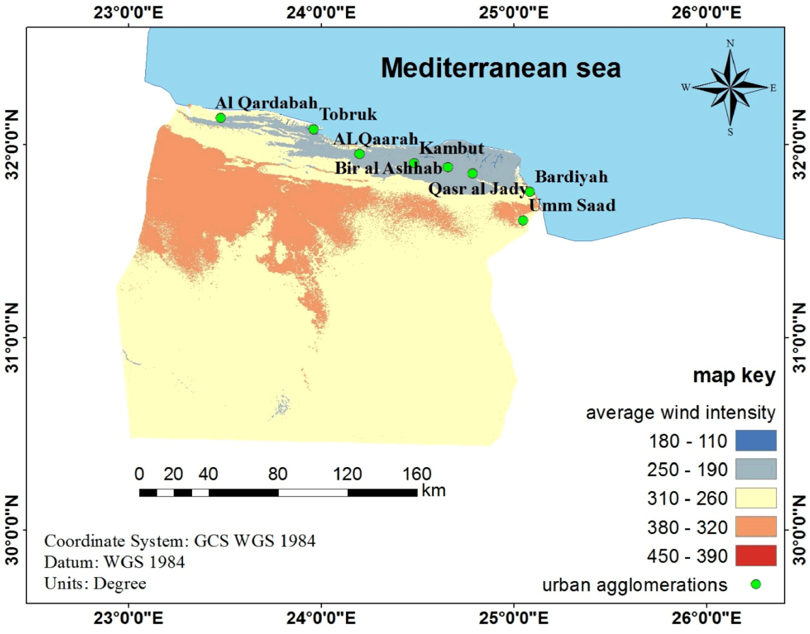

Fig. 8: The prevailing wind direction in the study area
Source: https://power.larc.nasa.gov/data-access-viewer

Second, Climatic Conditions

Wind Speed at a Height of 80 m (WIND SPEED): Wind speed is one of the most important criteria for planning a wind farm project and areas with an average wind speed of less than 3 m/s are not suitable for wind farm construction. In addition, sites with speeds higher than 20 m/s are excluded due to potential damage. Figure 6 shows that the study area is a promising area in terms of average wind speed, since the highest speed was 7. 5 m/s, while the lowest speed was 4.4 m/s, wind energy farm.

Wind Intensity at a Height of 80 Meters (Wind Density): Wind Power Intensity (WPD) is an important factor because it provides information about the most suitable

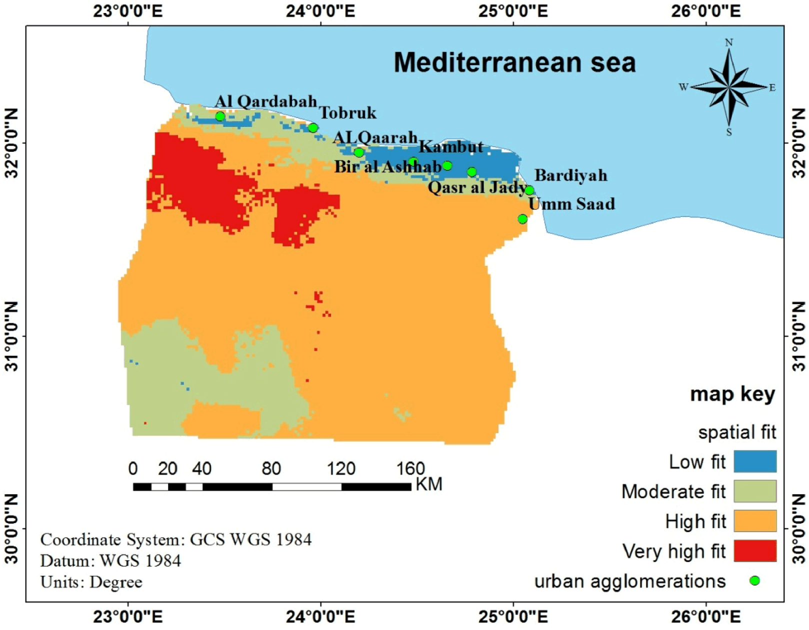

Fig. 9: Distribution of surface temperature (°C) in the 2021 study area
Source: The researcher worked on the Landsat 8 satellite and using ArcMap 10.5

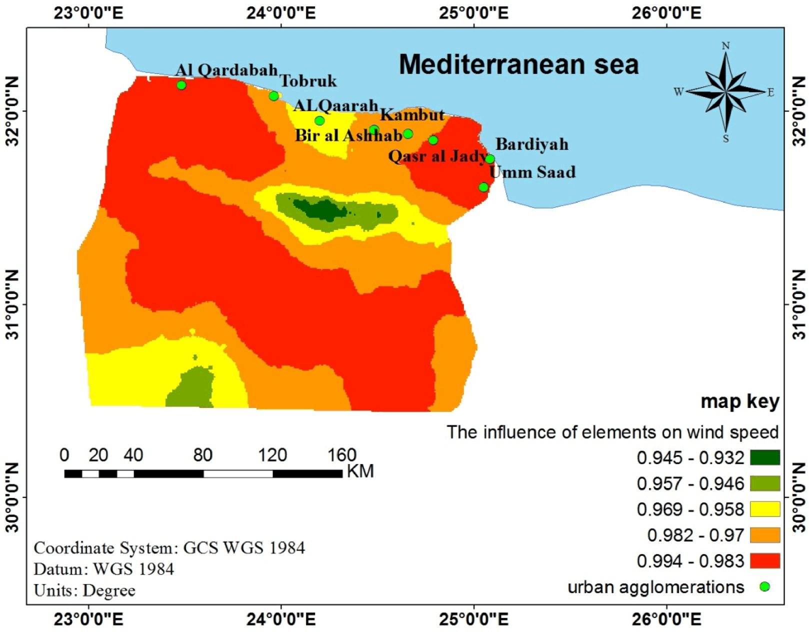

Fig. 10: The appropriate parts for establishing wind energy farms in the study area.
Source: Standards spatial fit database by ArcMap 10.5

and profitable areas in the region with regard to the establishment of wind farms in the study area [15], through Figure 7 we note that the study area has different proportions in terms of the amount of energy distributed throughout the region between 110 w/m² and 450 w/m². The highest rate was observed in the northwestern parts of the study area.

Wind Direction: Through Figure 8, we notice that the prevailing wind direction in the study area is the northerly direction coming from the Mediterranean Sea.

Land Surface Temperature (LST): Figure 9 shows that there are temperature differences in the study area between the northern coastal regions, which have a

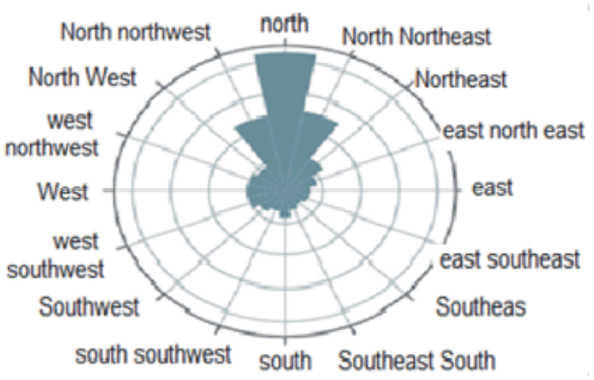

Fig. 11: The effect of independent factors on the dependent factor (wind speed) through weighted geographical regression. Source: Database of selected points using ArcMap 10.5

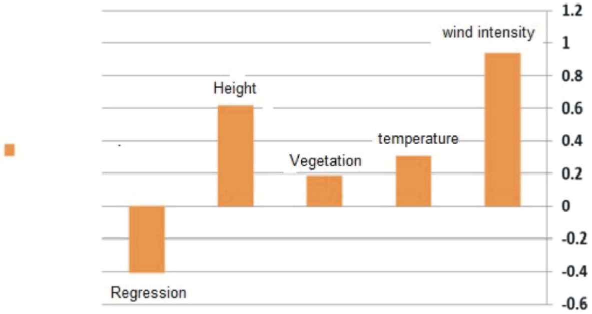

Fig. 12: Correlation values between wind speed and the studied factors

lower temperature and the southern regions, which are characterized by a higher temperature. This is due to the influence of the sea, which appears clear in coastal areas. These differences ranged between 20 - 51 degrees Celsius.

Third: Spatial Suitability: From the suitability map, Figure 10, it is clear that the very high suitability areas extend from the south of Tobruk city in the east to the south of the area located in the south of the Ain Al-Ghazala region in the western part of the study area, while most of the central regions and large parts of the northeastern and southern regions, especially the southeast of the study area, fall into the high suitability category, while large parts along the coastal belt and part of the region on the southwestern side were within the third medium suitability category, while the fourth low suitability category included the northeastern parts of the Coastal belt.

Fourth: Spatial Analysis (Weighted Geographic Regression): Figure 11 showed that the spatial differences in wind speed were affected by the selected factors of wind intensity, vegetation cover, temperature, altitude and slope, as these factors explained about 93% to 99% of these differences in all parts of the region. The independent factors of wind speed as a dependent factor reached 96% in many places of the study area. As for the remaining percentage, it may be the influence of another factor that was not investigated in this research, but its influence is weak, not exceeding 4% on average in most of the researched area.

Table 1: Pearson's correlation coefficient between wind speed and the studied factors

Factor	Correlation value
Wind Density	0.94**
Temprature	0.313**
Botanical cover	0.19**
Height	0.617**
Slope	0.408**

**Correlation is significant at the 0.01 level

Fifth: Statistical Analysis: Pearson's correlation coefficient (SPSS) was used to determine the relationship and measure the correlation between wind speed as the dependent variable and wind intensity, temperature, vegetation, elevation and slope as the independent variablesas described in Figure 12.

Through Table (1) it was shown that there is a strong direct relationship between some variables and a weak relationship with other factors and between wind speed except for the steepness, the relationship between them and wind speed is an inverse relationship and this is due to the wind colliding with the slopes that cause them to strike and reduce their speed

There are great debate regarding the environmental impacts of the negative impacts caused by the installation of wind farms they were generally optimistic about the lack of impacts and did not suffer [16-19].

CONCLUSION

This study aimed to identify the best locations for the establishment of wind energy projects by applying the multi-criteria method (MCDM) in conjunction with spatial techniques (remote sensing - geographic information systems). And by collecting and analyzing data using the method used and using spatial techniques, a suitable map was created for the entire region, showing suitable areas. These areas were divided into four appropriate categories; The first category is the category of very high suitability with an area (1527.17 km²) and includes part of the northwestern region of the study area and the second category (high suitability) with an area of (24074.08 km²) and covers a large part of the study area in the southeastern and southwestern parts. As for the rest of the area, it was divided between the third and fourth categories of suitability categories. It has reached the medium suitability category area (6548.02 km²) and with this area it covers part of the coastal strip along the region and some southwestern areas of the region. As for the territory of the category of low suitability, it was (831.9 km²). Most of them cover the northern part of the studied area.

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