Iraqi National Journal of Earth Sciences, Vol. 21, No. 1, pp. 1-16, 2021

Selection of the Optimum Sites for the Wind Turbines Installation in Nineveh Governorate by using GIS

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(Received 24/10/2020 , Accepted 27/4/2021)

ABSTRACT

Green energy, including wind energy, becomes a vital component of reducing air pollution and enhancing its sustainability. Wind energy production increases rapidly due to its significant turbine technologies, compatible with sources of energy-environment friendly in reducing Carbon emissions. This paper presents an evaluation of wind power potential of Nineveh governorate in the northern part of Iraq based on the GIS technique using 20 years daily wind speed and direction at elevation 10m, 50m on earth surface covering the period of 2000 to 2019 obtained from NASA agency. It is observed that Nineveh Governorate and its surrounding have a wind speed between 2.8 and 3.7m/s at 10m, and wind speed between 3.9 and 5.3m/s at 50m. The annual mean power density ranges from 54 to 124 W/m^2 at 50m.These results indicate that the monthly variation recorded for the speed is maximum 3.7m/s at 10m and a value of 5.3 m/s at 50m in the northwest direction in Hadhar site which matched with the results obtained by GIS/ IDW interpolation map of the power density.

Keyword: GIS, Wind power density, Windographer, Nineveh, wind turbines.

اختيار أفضل المواقع لنصب توربينات الرياح في محافظة نينوى باستعمال نظم المعلومات الجغرافية

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قسم الطاقات الجديدة والمتجددة
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الملخص

تعد الطاقة الخضراء، بما في ذلك طاقة الرياح، مكونًا حيويًا للحد من تلوث الهواء وتعزيز استدامته، حيث يزداد إنتاج طاقة الرياح بسرعة بسبب تطور التقنيات الخاصة للتوربينات التي تتوافق مع مصادر الطاقة الصديقة للبيئة في تقليل انبعاثات الكربون. يقدم هذا البحث تقييما لإمكانات طاقة الرياح لمحافظة نينوى في الجزء الشمالي من العراق بالاعتماد على برامجيات نظم المعلومات الجغرافية باستخدام بيانات 20 سنة من سرعة الرياح واتجاهها على ارتفاع 10 م، 50 م على سطح الأرض وتغطي الفترة من 2000 إلى 2019 تم الحصول عليها من وكالة ناسا. اظهرت النتائج أن محافظة نينوى والمناطق المحيطة بها تتراوح سرعة الرياح فيها بين 2.8 و 3.7 م / ث عند 10 م، وسرعة الرياح بين 3.9 و 5.3 م/ ث عند 50 م. و اظهرت النتائج ان كثافة القدرة المتوسطة السنوية

تتراوح من 54 إلى 124 وات / م 2 عند 50 م ، وتشير هذه النتائج إلى أن التغير الشهري المسجل للسرعة هو 3.7 م / ث كحد أقصى عند 10 م وقيمة 5.3 م / ث عند 50 م في الاتجاه الشمالي الغربي في موقع الحضر والذي يتطابق مع النتائج التي تم الحصول عليها من خريطة النظم المعلومات الجغرافية لكثافة القدرة.

الكلمات الدالة: نظم المعلومات الجغرافية، كثافة قدرة الرياح، برنامج (Windographer)، محافظة نينوى، توربينات الهواء.

INTRODUCTION

Green energy, also known as clean energy in many studies, originates from continuously regenerating natural sources or processes, for example, sunshine or wind continues shining and blowing, even though it depends on weather and time. The environmental and economic advantages of using renewable energy include: generating energy that does not produce emissions of greenhouse gases from fossil fuels and reducing other sources of air pollution. Sustainability of supply of energy and elimination of dependency on imported fuels is one of the key policies adopted by countries in developing their economies (Yang, Q., et al., 2011). Electricity generation from renewable resources is quickly recognized as a significant supply option for many countries' energy systems and future energy policies. Wind energy is regarded to be one of the most successful renewable energy sources in many countries around the world and applied wind energy techniques instead of fossil fuels to generate electricity (XU, J., et al., 2018). Owing to the cubic relationship between velocity and power, just a little change in wind speed would cause a considerable change in power. Modeling and wind speed prediction are the primary goals in the sitting and sizing of wind power applications. Therefore, the choice of a wind site must take into account an initial exploration of the mean wind speed and the wind potential. So, the analysis of the wind resources data through GIS is a crucial factor to be undertaken (Dimitrios, M., 2013). Also, the collection of data is a useful parameter for the optimization and management of wind energy systems. Many types of researche have been made to develop models through which wind distribution can be assessed. The design of the wind energy site requires data on the speed range available for maximizing energy extraction, which requires knowledge of the wind speed frequency distribution (Hatata, A. Y., et al., 2015). There are a lot of researchers estimated the wind energy resources for electricity generation determining the wind potential and assessing the electricity generation in many regions of the world (Çetin G., et al., 2006) and (Alvaro R. J., et al.,2012). The growth of wind power continues to be impeded by a lack of wind resources information and the lack of reliable and accurate data on wind speeds in most places of Iraq. Articles were made to analyze the wind power potential of Iraq (Aedah M. M., et al., 2019) and (Mohammed, B., et al., 2020). Each of these articles examined different sites and presented analyzes to justify their study results. This study aims to assess and analyze the monthly wind speed and power density in eight regions, namely, Basheqa, Mosul, Talabta, Talafar, Hadhar, Zummar, Rabeeaa and Sinjar in Nineveh governorate in the northern part of Iraq. The data consists of hourly data on wind speed and wind speed over the period (2000-2019) to explore the characteristics of wind speed and to determine the potential of wind power in each region. Wind power density as a function of height is studied in order to classify wind energy resources in Northern Iraq, using the Geographic Information System (GIS) to map the predicted power density by the Inverse Distance Weight (IDW) interpolation technique and to select the best wind site.

STUDY AREA

Location:

Nineveh Governorate is located in the northwestern part of Iraq. It occupies a large area of (37597.53) km^2 of the total area of Iraq which is (435052) km^2, i.e. 8.64% from the Iraq area, it is bordered on the north by the Duhok governorate, on the west by the Syrian Arab Republic, on the east by the Erbil governorate, and on the west by the Salahuddin governorate and the Anbar governorate Fig.(1). The study area is extended from 340:55’ N to 37^0:03' N and from 41^0:25' E to 44^0:25' E. The expected population size of the Nineveh Governorate for the year 2020 is about (4154658) people (Special Development Plan- Nineveh (2010 – 2020)).

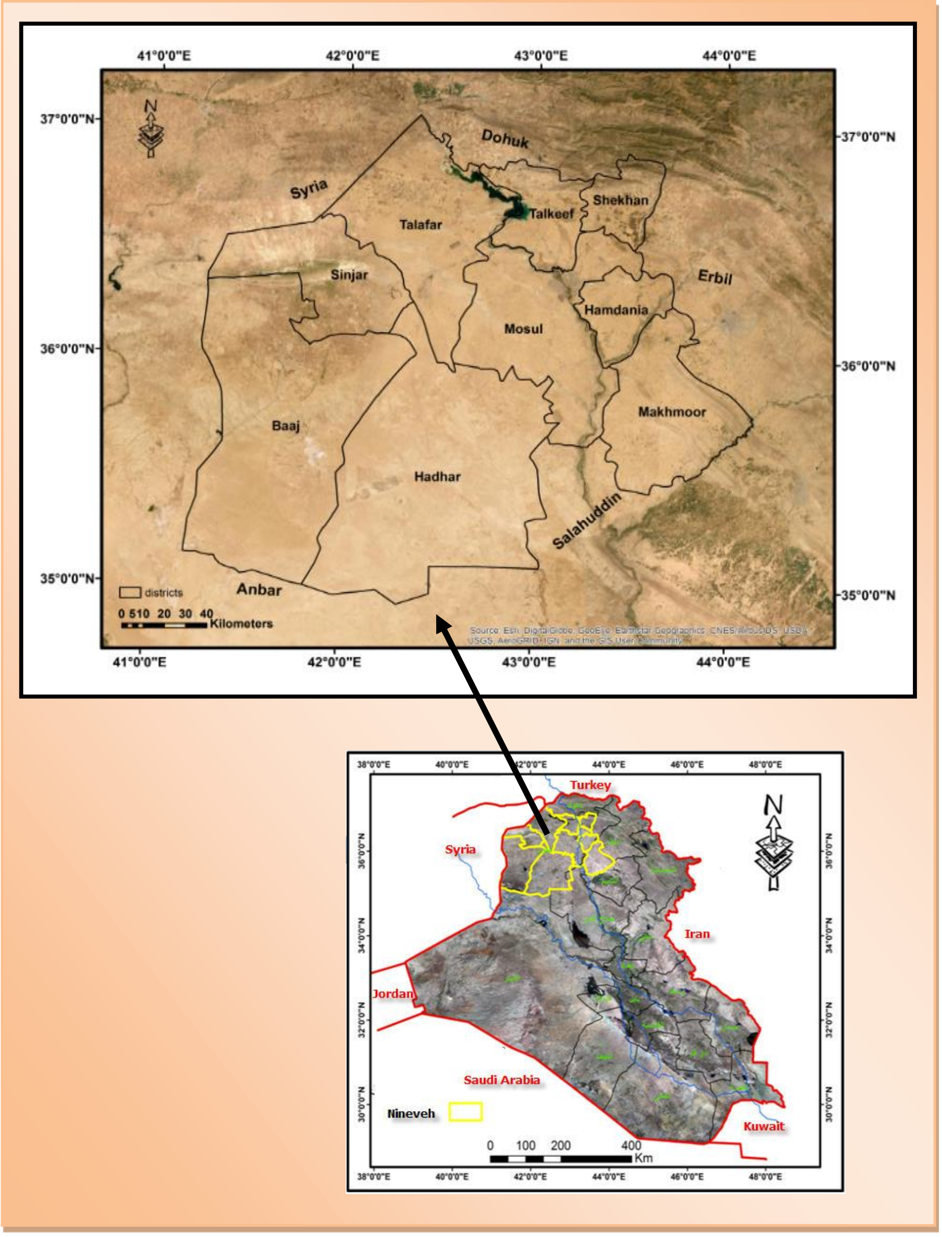

Figure 1: The study area

Topography and wind direction:

The governorate climate varies according to the topography of the surface. Nineveh Governorate is characterized by the diversity of its terrain, these terrains include plateaus, hills and undulating plains, some of which represent a southern border with the undulating region. From Fig. (2) below, it can be seen that the elevation above the mean sea level of the governorate are range from gentle to high slop (69-1646m), the highest elevation directions are generally toward northwest / southeast, with the exception of Mount Sinjar, where the direction is east-west.

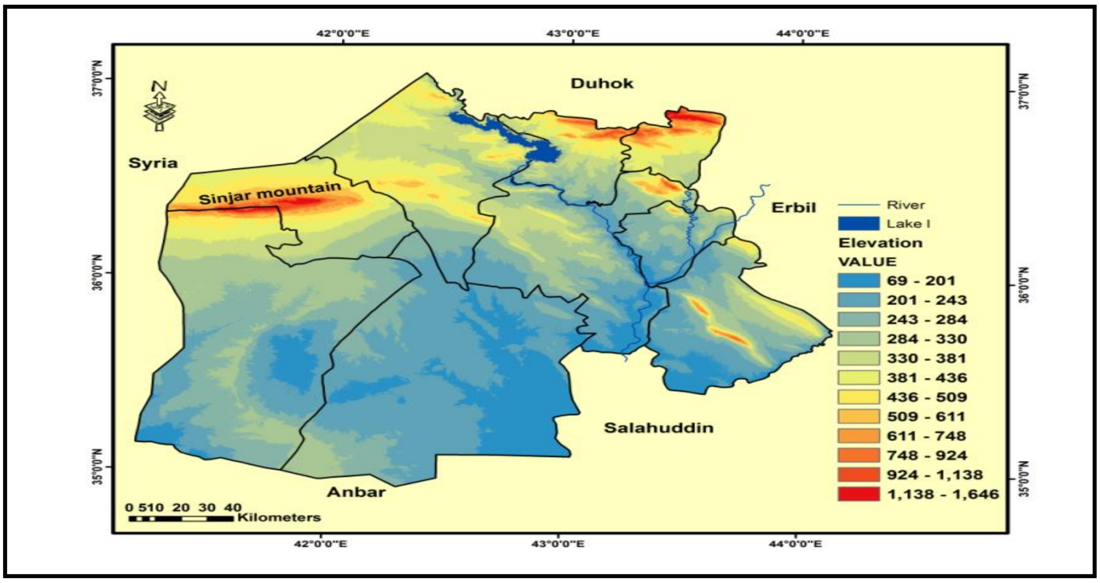

Figure 2: The elevation map of the Nineveh Governorate

These changes in terrain will certainly have a major impact on the climate elements prevalent in the Governorate, including the wind direction. The direction of the prevailing winds in Nineveh Governorate is the direction of the northwest, depending on the two forms of air pressure, one of which is north on the Anatolian Plateau (high pressure) and the other is subtropical, prevailing over the Arabian Sea and the Arabian Gulf region (low pressure), and the other winds come from the southeast and northeast with little impact on the Governorate (Al- Daghastani H. S. 2006).

Land Cover of the Study Area:

In terms of area, the study area is Iraq's second- largest unit, which has led to diversity in the types of land and land cover. As shown in the map, many types of land cover have been classified by (Ameen, *et al.*, 2020) based on satellite images, as shown in Fig. (3). With regard to vegetation cover, it's found that there is an increase in plant density in the northern and northeastern parts of the governorate due to the increase in rainfall and the suitability of good soil for cultivation. These lands are invested in irrigated agriculture, in particular wheat and barley. In the southern and southwestern parts of the governorate, they are typically areas of desertification and sand dunes, due to prevailing climatic conditions, which minimize plant density.

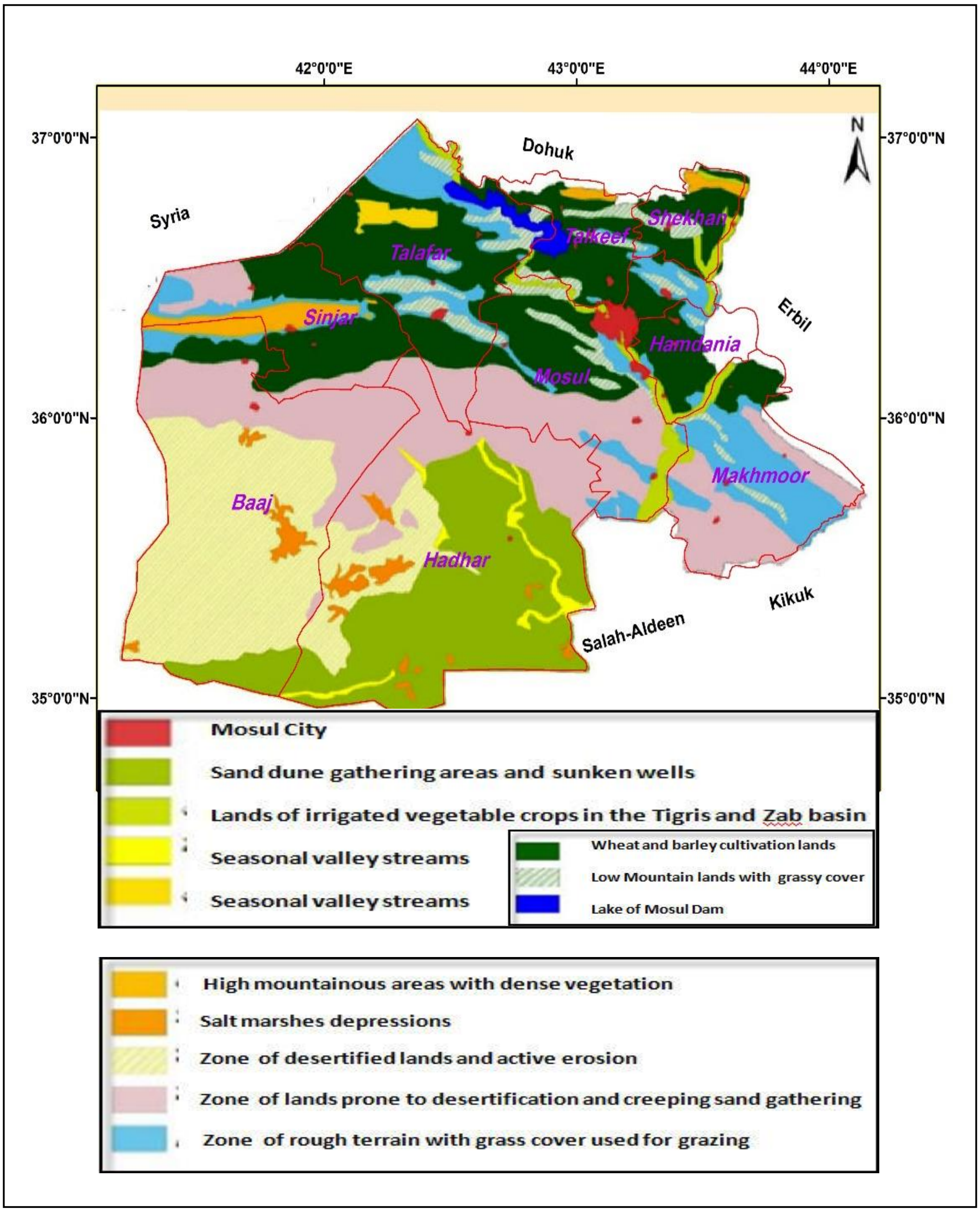

Figure 3**:** Land Cover Classification Map (Ameen, *et al*., 2020)

METHODOLOGY

In the current study, the ArcGIS10.3 / Inverse Distance Weight (IDW) method was used for mapping the predicted map of the power density for the selected stations in the study, the methodology including the following stages:

Data Collection:

In this paper, wind power potential assessment is performed for eight locations within the Nineveh Governorate. Fig. (4) shows the locations of the selected sites as given by Iraqi Agrometeorological Network (Iraqi Agrometeorological Network, 2019), while Table (1) lists the geographical locations and the elevations of each site.

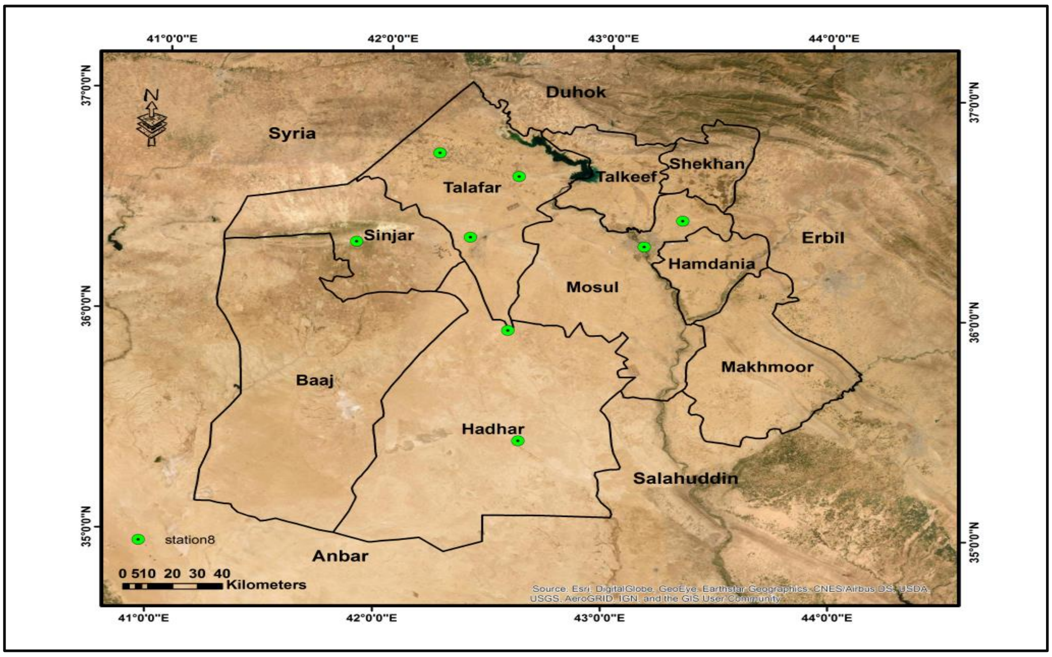

Figure 4**:** The geographical locations of the selected sites

Table 1**:** Geographical features of the selected stations**.**

Name of station	Latitude (degree)	Longitude (degree)	Elevation (m)
Basheqa	36.45	43.33	344.18
Mosul	36.33	43.16	344.18
Talabta	35.94	42.56	235.08
Talafar	36.36	42.38	343.05
Hadhar	35.44	42.62	200.79
Zummar	36.64	42.59	527.84
Rabeeaa	36.74	42.23	450.69
Sinjar	36.33	41.87	382.58

The records of wind speeds (measured in meter per second) used in this study at a height of (10 and 50m) with its station coordinates were downloaded from NASA Agency (NASA Agency, 2019). The wind speed data every day were taken over a period (2000-2019). Meteorological data were used to identify and analyze the characteristics of wind energy and to classify the position with the highest potential for wind energy.

Mean wind speed and Wind power density:

In this research, data on wind speed were obtained daily for twenty years at the site of the study and used to calculate the wind potential. Mean monthly and annual wind speed values have been assessed using (Sathyajith M., 2006).

$$v_m = \frac{1}{n}\sum_{i=1}^{n} v_i \qquad \text{………… (1)}$$

Where n is the number of observation and v_i is the speed of the wind at the time stage i.

Power / area referred to as the potential for wind power or the density of wind power is given by Eq. (2) (Sathyajith M., 2006):

$$\frac{P}{A} = 0.5\rho v^3 \qquad \text{……………….. (2)}$$

ρ is the air density (1.225 kg/m3), A is the swept area (m2).

Wind Rose:

The wind rose can be constructed from wind data collected over a given period of time. When constructing or interpreting wind roses, it is necessary to understand that wind direction refers to the direction from which the wind is blowing. The wind rose figure is created using a suitable scale to represent the percentage of wind direction frequencies and suitable index shaded to represent different wind speeds (Varma, S.A.K., *et al*. 2013).

Windographer Program:

Windographer is a software package for the analysis of wind resource data, whether measured by a met tower, Sonic Detection and Ranging (SoDAR) or Light Detection and Ranging (LiDAR). It quickly imports raw data files, displays the data in sophisticated interactive graphics, provides powerful quality control capabilities and performs comprehensive statistical analysis, and generates high-quality output. In the present study, the download raw data was processed using Windographer, version 4.2.11 (Windographer, 2019).

RESULTS AND DISCUSSION

The data has been analyzed using Windographer to get the statistical summary. The monthly and annual mean wind speed and its direction for eight locations in the Nineveh Governorate at (10 and 50 m) has been determined, tables (2 and 3). Table (2) indicates that most stations have an annual mean wind speed of more than 2.8 m/s at height 10m, while, table (3) indicates that most stations have an annual mean wind speed of more than 3.99 m/s at height 50m.

Table 2**:** Mean monthly and annual wind speed (m/s) and its direction at (10 m).

Month	Stations							
	Hadhar	**Basheqa**	**Mosul**	**Rabeeaa**	**Sinjar**	**Talabta**	**Talafar**	**Zummar**
Jan.	2.99	2.549	2.549	2.652	2.937	2.814	2.801	2.536
Feb.	3.121	2.534	2.534	2.672	3.003	2.887	2.844	2.562
Mar.	3.488	2.673	2.673	2.765	3.172	3.174	3.037	2.659
Apr.	3.509	2.763	2.763	2.83	3.285	3.232	3.127	2.744
May.	3.925	2.987	2.987	3.071	3.572	3.592	3.434	2.956
Jun.	4.891	3.478	3.478	3.509	4.273	4.353	4.075	3.34
Jul.	5.078	3.496	3.496	3.281	4.171	4.41	3.989	3.219
Aug.	4.479	3.36	3.36	3.201	3.887	4.029	3.77	3.141
Sep.	3.826	3.009	3.009	2.958	3.53	3.539	3.409	2.886
Oct.	3.257	2.789	2.789	2.738	3.042	3.082	3.004	2.701
Nov.	2.856	2.48	2.48	2.416	2.724	2.689	2.63	2.395
Dec.	2.99	2.538	2.538	2.627	2.926	2.805	2.798	2.519
annul mean	3.70	2.88	2.88	2.89	3.38	3.39	3.24	2.81
wind direction	292.5^0	292.5^0	292.5^0	270^0	270^0	292.5^0	270^0	270^0

Table 3**:** Mean monthly and annual wind speed (m/s) and its direction at (50 m)

Month	Stations							
	Hadhar	**Basheqa**	**Mosul**	**Rabeeaa**	**Sinjar**	**Talabta**	**Talafar**	**Zummar**
Jan.	4.4	3.845	3.845	3.822	4.215	4.149	4.073	3.647
Feb.	4.624	3.858	3.858	3.918	4.397	4.311	4.222	3.719
Mar.	5.16	4.104	4.104	4.105	4.708	4.769	4.561	3.891

Apr.	5.056	4.208	4.208	4.179	4.811	4.765	4.637	3.995
May.	5.563	4.515	4.515	4.485	5.199	5.235	5.062	4.263
Jun.	6.869	5.226	5.226	5.027	6.126	6.299	5.919	4.72
Jul.	7.097	5.191	5.191	4.667	5.955	6.35	5.763	4.49
Aug.	6.443	5.001	5.001	4.538	5.604	5.907	5.478	4.366
Sep.	5.666	4.525	4.525	4.242	5.191	5.317	5.059	4.041
Oct.	4.728	4.157	4.157	3.925	4.39	4.52	4.371	3.823
Nov.	4.178	3.727	3.727	3.476	3.934	3.948	3.819	3.415
Dec.	4.41	3.837	3.837	3.793	4.225	4.148	4.08	3.622
annul mean	5.35	4.35	4.35	4.18	4.90	4.98	4.75	3.99
Wind direction	292.5^0	292.5^0	292.5^0	270^0	292.5^0	292.5^0	292.5^0	270^0

Fig. (4) shows the monthly average wind speed for all stations at a height of 10 m. The speed of the wind has a maximum value of 5.35 m/s at Hadhar in July and a minimum value of 3.99 m/s at Zummar in November. These results are consistent with the average wind speed results in three Iraqi cities (Baghdad, Basra, and Mosul) which was indicated that the average speed of the wind not reaching 5 m / s (Aedah M. M., et al., 2019). Also, in Fig. (5), it can be seen, the high wind speeds occur in the summer season.

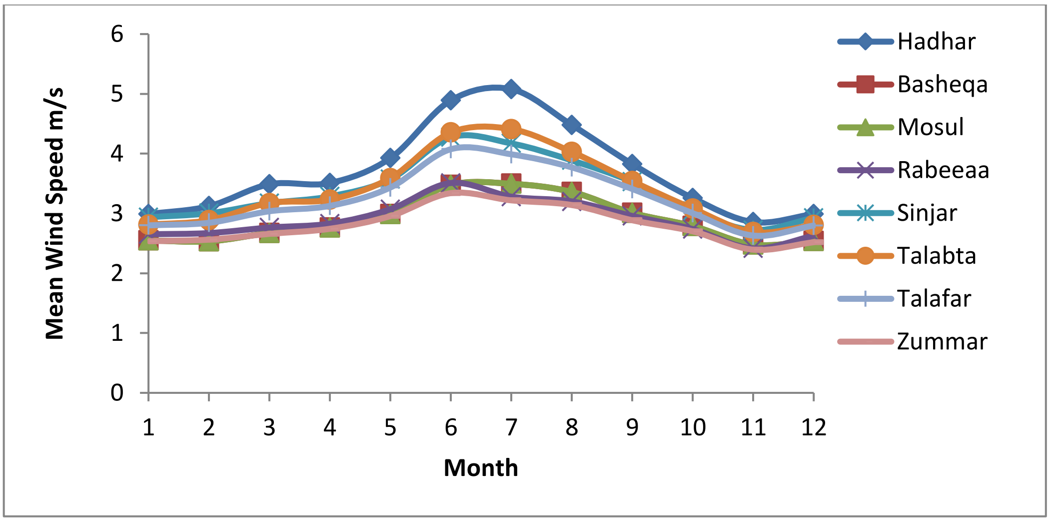

Figure 5**:** Monthly mean change of wind speeds in years (2000-2019) for chosen stations (in the height of 10 m).

Fig. (5) shows the monthly mean of wind speed for all stations at a height of 50 m. The wind speed has a maximum value of 3.7 m/s at Hadhar station in July, and a minimum value of 2.8 m/s at Zummar in November. Also, in Fig. (6), it can be concluded that high wind speeds happen during the summer season.

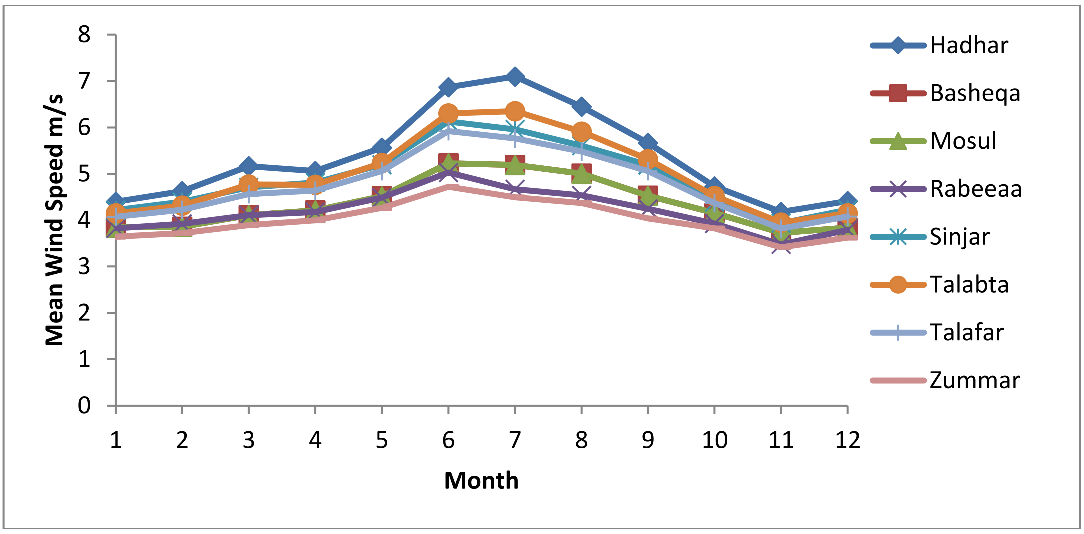

Figure 6**:** Monthly mean change of wind speeds in years (2000-2019) for chosen stations (in the height of 50 m).

The highest value of the monthly mean of wind speed for all stations in July and the lowest value in November that corresponds with the reference (Adeeb H. Q., Al-Timimi Y. K.**,** 2019). Figure (7) shows the annual mean wind speeds at a height of 10 m for all stations. The wind speeds decrease at Mosul, Bahsika and Rabeeaa, while, there is a relative increase in the wind speed at Hadhar station. Generally, Fig. (7) shows that, Hadhar station has the highest wind speeds at a wind speed greater than 3.5m/s.

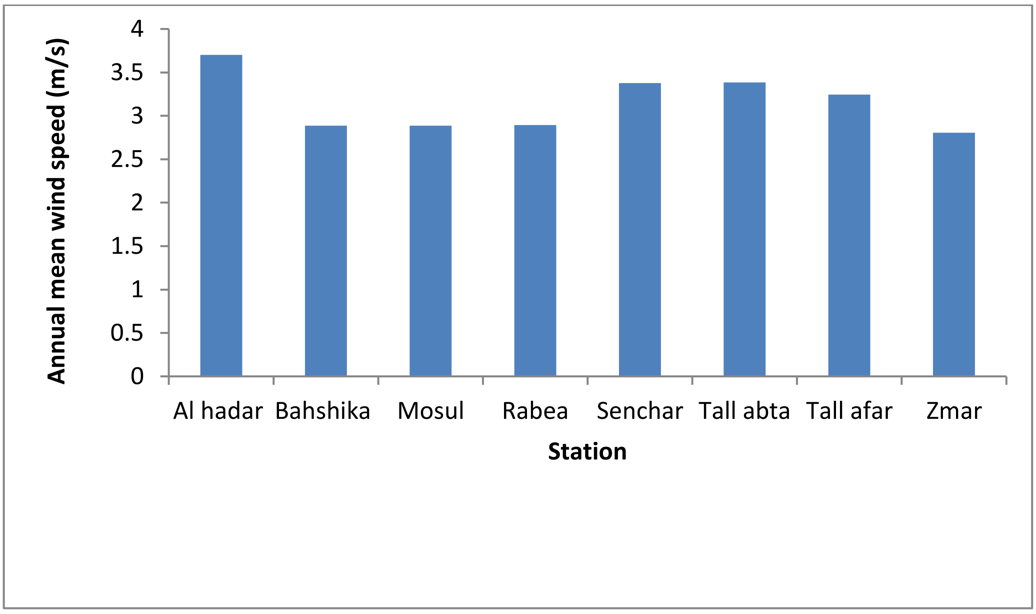

Figure 7**:** The annual mean of wind speed for chosen stations in the height of 10 m.

Fig. (8) shows the annual mean wind speeds at a height of 50 m for all stations. The wind speeds decrease at Mosul, Basheqa and Rabeeaa. The relative increase of the wind speed at Hadhar station. In general Fig. (8) shown, Hadhar station has the highest wind speeds at a wind speed greater than 5.0 m/s.

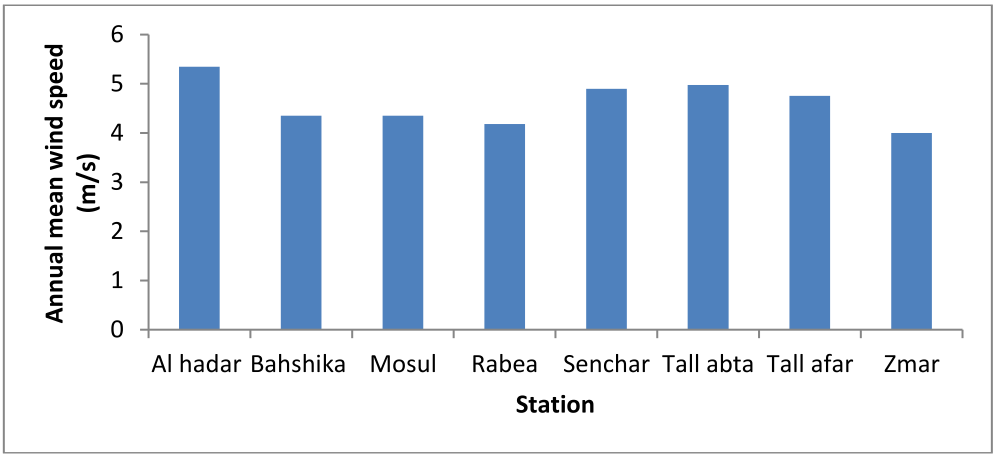

Figure 8**:** The annual mean of wind speed for chosen stations in the height of 50 m.

Wind direction was also documented for each location chosen during the study period. For a total of 16 directions, the wind frequencies for these directions are shown in Fig. (9) at height (10 m and 50 m). The dominant wind direction for Hadhar, Mosul, Basheqa, Talabta, and Talafer was observed to be west-northwest (WNW) with frequency values of 24%, 13.6%, 13.6%,20.86% and 17.39% at height (50 m) respectively, and 23.71%,12.61%, 19.61% and 15.88% at height (10 m) respectively. Also, the wind direction with the most significant frequency for Rabeea and Zummar was the west direction (W) with frequency values of 13.96% and 11.47%, respectively at height (50 m) and 13.85% and 12.10%, respectively at height (10 m). For Sinjar, the wind direction at the highest level is west-northwest (WNW) with a frequency value of 17.55% at height)50 m) and west (W) with a frequency value of 18.05% at height (10 m).

Table (4) lists the values of the wind power density estimated based on the mean wind speed for each location. The mean wind power density is found to be between 54 w / m^2 and 124 w / m^2. Hadhar station has a higher mean wind power density and higher mean wind speed of 5.35 m/sec compared with the other locations. The locations chosen may be considered to be Power Class 1, which has a low potential for wind energy. Commercial high-capacity wind turbines (MWs) are not suitable for use in all locations. Consequently, the available wind energy potential of the stations chosen can be exploited through the use of small-scale wind turbines. (Mohamad M. A., *et al.,* 2018). The results revealed that the wind turbine (ATB Riva calzone 500kw) was the best wind turbine for the selected locations in Iraq (Mohammed, B., *et al*., 2020).

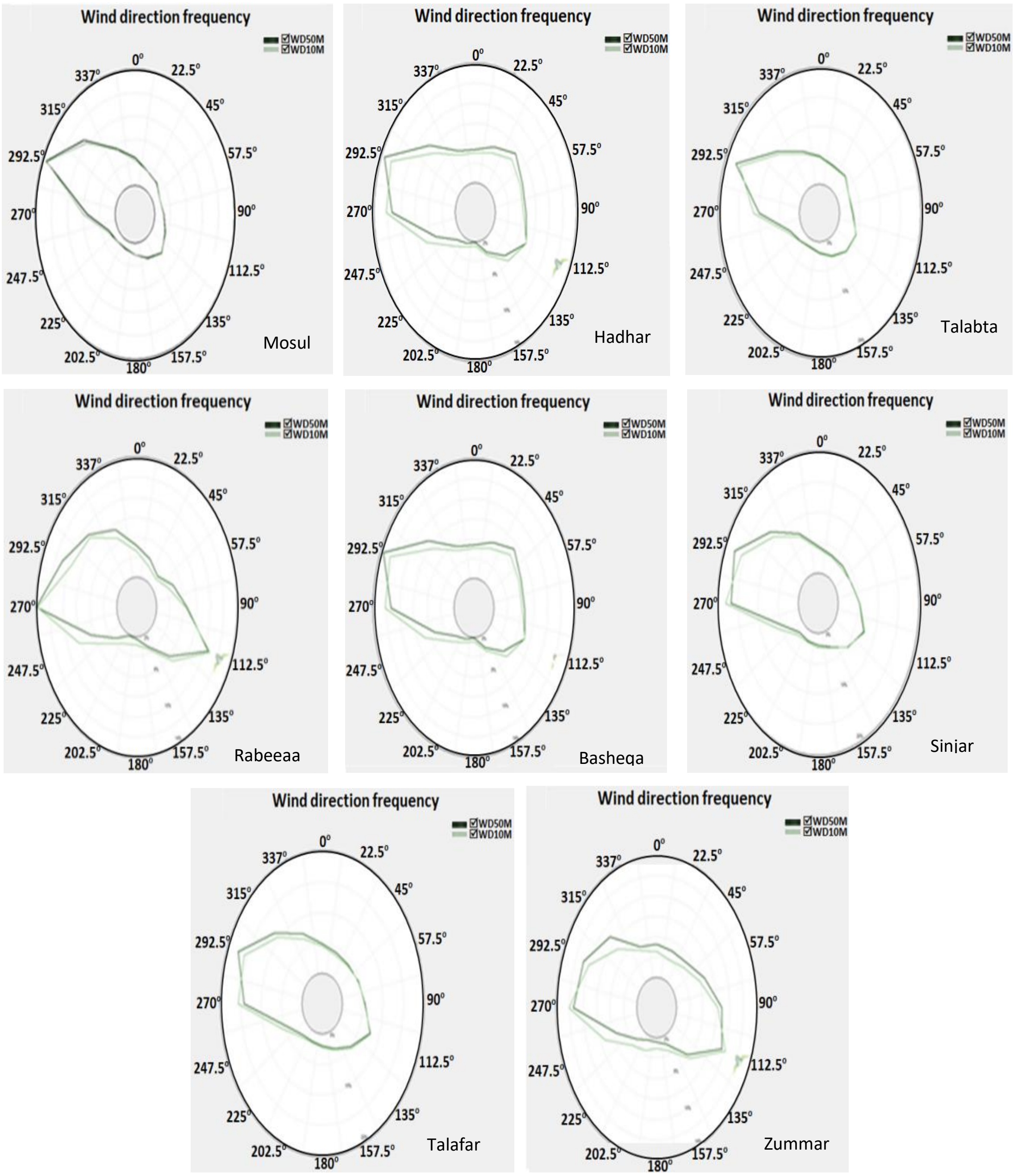

Figure 9**:** Wind rose throughout the year for selected stations at (10, 50 m).

Table 4: The estimated power density according to the wind speed (m/s).

Name of station	Latitude (degree)	Longitude (degree)	Elevation (m)	power density at 50 m (w/m2)	mean wind speed(m/sec)
Basheqa	36.45	43.33	344.18	66	4.35
Mosul	36.33	43.16	344.18	66	4.35
Talabta	35.94	42.56	235.08	100	4.98
Talafar	36.36	42.38	343.05	88	4.76
Hadhar	35.44	42.62	200.79	124	5.35
Zummar	36.64	42.59	527.84	54	4.0
Rabeeaa	36.74	42.23	450.69	63	4.18
Sinjar	36.33	41.87	382.58	96	4.9

The values of the power density listed in Table (4) were used in the GIS/IDW interpolation, Fig (10) shows the resulted prediction map which also indicates that Hadhar station is the best one for turbine installation for electrical energy generation. As shown by Fig. (3) above, that the Hadhar District was characterized by the existence of sand dune gathering area and desertified lands which's gives a best selection not only for wind turbine installation but also for solar farms. Wind and solar installations covering the desert areas contribute to local temperature rises and more than double precipitation increases, due to increased surface friction and reduced albedo (Yan L., *et al.*, 2018).

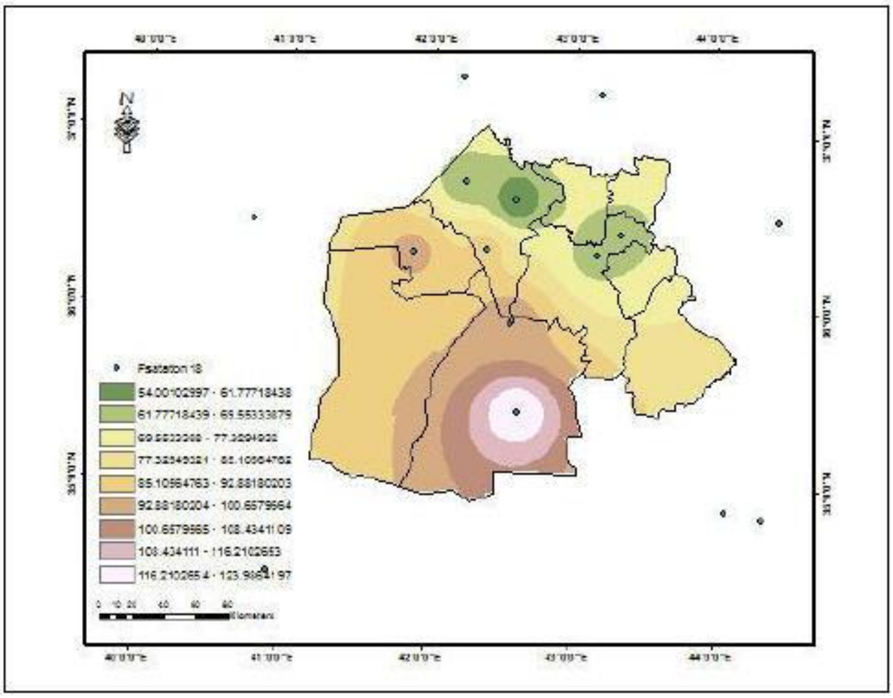

Figure 10**:** The predicted map of the power density for the selected stations

CONCLUSION

The work presented in this research assesses wind energy at eight locations in the governorate of Nineveh to select the best location for the installation of wind turbines, from the output study, it can be concluded that:

1. The average annual wind speed at a height of (10, 50 m) was calculated to be 3.70, 2.88, 2.88, 2.89, 3.38, 3.39, 3.24 and 2.81 m/s at 10 m height and 5.35, 4.35, 4.35, 4.18, 4.90, 4.98, 4.75 and 3.99 m/s at height 50m for Hadhar, Basheqa, Mosul, Rabeeaa, Sinjar, Talabta, Talafar, and Zummar stations, respectively.
2. The dominant wind direction for Hadhar, Mosul, Basheqa, Talabta and Talafar is west-northwest (WNW) at height (50 m), and the wind direction with the most significant frequency was west (W) for Rabeeaa and Zummar at height (50 m). For Sinjar, the wind direction with the highest rate is west-northwest (WNW) at height (50 m) and west (W) at height (10 m).
3. The data observed indicate that the highest wind speeds for all locations are in June / July. Hadhar estimated the highest potential for wind power at 124 W / m2 at an altitude of 50 m. Output results indicate that this station was the best station to install the wind turbine in the study area.
4. The application of GIS for wind energy makes a simplified site selection process and obtains suitable maps relating to wind energy projects in rural areas including the location of the best turbine installation site
5. Difficulties forced in this study were not accessible to the actual wind speed data for the Nineveh Governorate, because the Nineveh weather stations were broken down. Instead, wind speed data for the Nineveh governorate were collected from the NASA agency.
6. A future study on the Weibull distribution function used to explain the variance in wind speed, as it gives a specific and sensible description of the wind speed data noted in the upper air and surface.

ACKNOWLEDGMENT

We would like to show our gratitude to the University of Mosul/ College of science and Remote Sensing Center for their provided facilities, which helped to improve the quality of this study.

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