# GIS TECHNIQUES FOR MAPPING OF WIND SPEED OVER IRAQ

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**ABSTRACT**

**This study was aimed to use GIS techniques in climate studies. Analysis of monthly wind speed data for the period 1981 to 2017, and mapping of monthly, seasonal and annual wind speed in Iraq has been investigated in this study. The area of study was divided into three regions. the results of Mann Kendall test of the middle and southern region reveal a significant decreasing trend in the months of the summer season. While positive trends of mean wind speed were found in the northern region for the whole period. Wind speed value reaches its highest value in (Jun and July), and the lowest value of wind speed was in December. Seasonal wind speeds show the highest values recorded in the summer and spring seasons and the lowest in the autumn and winter seasons. Wind speed maps were obtained using IDW techniques in G I S, the results show that the annual average of wind speed in the northern, middle and southern regions was 2.7 m/s, 3.6 m/s and 4.1 m/s respectively. While the annual average of wind speed in the study area "Iraq" was 3.6 m/s. The winds were low in the northern region compared to the middle and southern regions. The wind speed maps show the appropriate sites for the installation of wind turbines.**

**Keyword: climate, trend , mann–kendall test, interpolation, Iraq.**



## استخدام تقنيات نظم المعلومات الجغرافية لرسم خرائط سرعة الرياح فوق العراق

حنين قصي اديب ياسين كاظم التميمي
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**المستخلص**

**هدفت هذه الدراسة إلى استخدام تقنيات نظم المعلومات الجغرافية في الدراسات المناخية. تم دراسة تحليل بيانات سرعة الرياح الشهرية للفترة من 1981 إلى 2017, ورسم خرائط سرعة الرياح الشهرية والموسمية والسنوية في العراق. قسمت منطقة الدراسة إلى ثلاث مناطق. اظهرت نتائج اختبار مان كيندال في المنطقة الوسطى والجنوبية عن وجود تناقص في الاتجاه وخصوصاً خلال أشهر الصيف. اما في المنطقة الشمالية اظهرت النتائج وجود تزايد في الاتجاه لمتوسط سرعة الرياح خلال فترة الدراسة. بلغت سرعة الرياح أعلى قيمة لها في (حزيران و تموز) ، وأدنى قيمة لسرعة الرياح كانت في ديسمبر. تُظهر سرعات الرياح الموسمية أعلى القيم المسجلة في فصلي الصيف والربيع والأدنى في فصلي الخريف والشتاء. كذلك تم الحصول على خرائط سرعة الرياح باستخدام تقنيات IDW في G I S ، وأظهرت النتائج أن المتوسط السنوي لسرعة الرياح في المناطق الشمالية والوسطى والجنوبية كان 2.7 م / ث ، 3.6 م / ث و 4.1 م / ث على التوالي. بينما بلغ المعدل السنوي لسرعة الرياح في منطقة الدراسة "العراق" 3.6 م / ث. كانت الرياح منخفضة في المنطقة الشمالية مقارنة بالمناطق الوسطى والجنوبية. تظهر خرائط سرعة الرياح افضل المواقع المناسبة لتركيب توربينات الرياح .**

**الكلمات المفتاحية: المناخ، الاتجاه، اختبار مان– كيندال، الاستيفاء، العراق.**

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## INTRODUCTION

The wind is one of the important climatic factors that humans have been interested in since their ancient uses. They have also been interested in climate studies and are more important in explaining the climatic conditions of any site because they affect weather conditions. They also affect other aspects of life. Winds are one of the factors contributing to the transfer of thermal energy from one region to another to balance the distribution of temperature and atmospheric pressure on the surface of the earth, as well as the transfer of water vapor from its sources to other areas lead to increased humidity and rainfall. The analysis of wind speed patterns is also important in estimating the surface energy balance (13). Wind trend analysis is equally important for basic climatic processes such as evapotranspiration and land surface-atmosphere feedback processes, and also for diverse applications such as wind power generation (10). Furthermore, wind speed and direction data are useful in air dispersion modeling and identifying pollutant emission sources (7, 14) Thus, wind speed is an important element in the study of atmospheric variations, hence the justification of this paper. Studies on measured wind speed variations have been carried out (12). These studies observed a decrease in annual wind speed in numerous sites around the globe during the past few decades. The best method of interpolation for estimating the wind speed in the Iraq region is the inverse distance weighted IDW (1). The main purpose of this study is to analyze the monthly wind speed for 39 stations in Iraq, also using GIS for mapping wind speed and chose the best site for wind.

## MATERIALS AND METHODS

### Mann-Kendall Test (MK)

The Mann-Kendall test is widely used in the analysis of the climatic time series such as temperature, precipitation, aridity, evaporation, and atmospheric deposition, as well as in the environmental data series and hydrological data.Simple linear regression analysis could give us an essential sign of existence of trend in times series. MK test needs the assumption of normality, yet the directions of significant trends will only be indicated but not the magnitude.This test is usable in the situations where values xi of a time series may be subjected to (5) :

$$\mathbf{x_i = f(t_i) + \varepsilon_i}$$

The f(t) is continuous monotonic growing or diminishing function with time. while εi presumed to come from same division with zero mean. Thus we can assume that the difference in the division is constant with time. The Mann-Kendall test has many advantages including (6):

1. Data do not need to be compatible with a given distribution and therefore extreme values are acceptable.
2. This procedure is particularly useful since missing values are allowed.
3. Relative magnitudes can be used instead of numerical values that allow the integration of trace data, as they are assigned, a value less than the smallest measured value.
4. It is not necessary to determine whether the trend is linear or not in time series analysis.

If the data is less than 9, MK test calculated as (6):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(xj - xi)$$

Where:n: the number of the data point. Xi, Xj: data values in time series i and j (j>i), respectively.

Sgn(Xi, Xj): the sign function as:

$$\operatorname{sgn}(xj - xi) = \begin{cases} +1. \text{if } xj - xi > 0 \\ 0. \text{if } xj - xi = 0 \\ -1. \text{if} xj - xi < 0 \end{cases}$$

When n is 10 or more, MK test calculated as:

Compute the variance S by the following equation:

$$VAR(S) = \frac{1}{18}\left[ n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5) \right]$$

Where:q: Is the number of tied groups and tp is the number of data values on the $p^{th}$ group.

VAR(S) are used to compute the test statistic Z as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{cases}$$

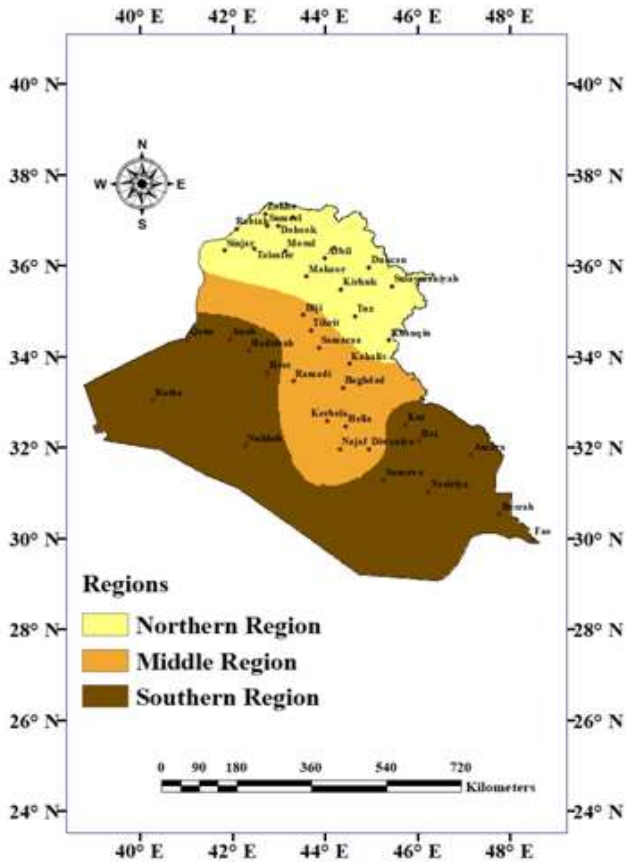
A positive (negative) value of (S) indicates an upward (downward) trend [8].

**Study area and data acquisition**

The Study area is represented via Iraq which located in Southwest of Asia, the total area (437072 $km^2$), where the land area is (432162 $km^2$) while the area of water bodies is (4910 $km^2$)(3). Iraq is located in the northern hemisphere specifically in the northeastern. Iraq have a borders with Turkey from the north with a length of 367 km, Iran from the east with a length 1599 km, Kuwait to the southeast about 255 km, Saudi Arabia to the southeast about 814 km, Jordan from the west with a length 179km and finally Syria northwest about 599 km .Iraq consisting of the Great Mesopotamian alluvial plain of the Tigris and the Euphrates rivers (Mesopotamia means, literally, the land between two rivers)[4]. The Tigris and Euphrates rivers, flowing northwest to southeast before merging into the Shatt-Al-Arab and flowing into the Arabian Gulf. Other significant bodies of water nearby are the Mediterranean Sea, Black Sea, and Caspian Sea. Iraq's climate is semi-dry. Average temperatures in Iraq range from (50 C°) in summer, and in winter range (0 C°). Most of the rainfall occurs between December and April and the annual rainfall rate is "100-180 mm", the mountainous region in northern Iraq has a higher rainfall than the central and southern regions. . Cyclones moving across Iraq are coming from the west;their source is the Atlantic Ocean. They are usually moving east toward the Mediterranean Sea and then in the direction of Cyprus, Lebanon and Jordan finally toward Iraq, or the Arabian Gulf or the Caspian sea. The numbers of cyclones vary with seasons, months and places over which they are passing. Usually they are increasing in the winter, decreasing in the autumn and finally disappear completely in the summer. Also the number of cyclones moving over the south is greater than that moving across both zone of mountains and foothills. For instance, the annual number of cyclones in the south is about 75 while in the north is reaches 40. However, the north and northeast of Iraq usually receive higher amount of rain than the south. This is because the precipitations in the north are orographic as much as it is cyclonic (9). Data have been acquired mainaly monthly average of wind speed from two sources, firstly derived from ECMWF reanalysis project (ERA-40) Data and secondly monthly average of wind speed from the Iraqi Meteorological Organization and seismology (IMOS). The long-term data of monthly average of wind speed for the time period 1980-2017 were collected from 39 stations located at different regions of the country.

**RESULTS AND DISCUSSION**

The mean of wind speed varies from one station to another within the study area, so the wind speed over the study area was divided into three regions depending on k-means methods. The northern region include the stations (Emadiyah, Salahaddin, Sulaymaniyah, Sinjar, Duhook, Zakho, Arbil, Rabiah ,Taleafer, Kirkuk, dukcan , Mosul, Khanqin , and biji), the middle region include the stations (Najaf, Kerbela, Hella, Diwaniya, and Baghdad) and the southern region include the following stations (Nukheb, Rutba, Anah,Hadithah, Hai, Samawa,Amara, Nasiriya, Basra, and Fao).




**Figuer1. The geographical location a feature of study area (Iraq)**

Figure1. The Mann-Kendall trend test has been applied to monthly wind speed which revealed substantial changes. table 1 shows that the northern region is less affected than the rest of the country, with 76% of the stations have increasing trends in monthly wind speed, while 22% of the stations

presenting decreasing trends in monthly wind speed. Khanqin and Taleafer stations faced a decrease in a trend in all months of the year. In the middle region, all significant trends are downward. about 75% of thestations have decreasing trends in monthly wind speed, while 24% of the stations presenting increasing trends in monthly wind speed. In the southern region, about 52% of the stations have increasing trends in monthly wind speed, while 48% of the stations presenting decreasing trends in monthly wind speed. The results show that the middle and Southern regions are witnessing decreasing the average wind speed, especially during the summer of the year. which is consistent with the scientific studies indicating the decrease of speed wind surface in several parts of the world during the last decades.

**Table 1. magnitude of the significant trends of Mann-Kendall trend test for the study area.**

| Region | Station | Jan. | Feb. | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Northern | Emadiyah | 0.007 | 0.002 | 0.006 | 0.008 | 0.01 | 0.007 | 0.002 | 0.002 | 0.004 | 0.005 | -0.001 | 0.008 |
| | Salahaddin | 0.009 | 0.002 | 0.01 | 0.01 | 0.009 | 0.002 | 0.002 | 0 | 0.003 | 0.005 | 0.002 | 0.011 |
| | Sulaymaniyah | 0.006 | 0.003 | 0.013 | 0.012 | 0.01 | 0.003 | 0.002 | 0.001 | 0.006 | 0.006 | -0.003 | 0.008 |
| | Sinjar | 0.005 | -0.002 | 0.007 | 0.006 | 0.006 | 0.009 | 0.002 | 0.003 | 0.01 | 0.005 | -0.001 | 0.007 |
| | Duhook | 0.006 | 0 | 0.004 | 0.006 | 0.008 | 0.007 | 0.002 | 0.003 | 0.004 | 0.004 | -0.003 | 0.007 |
| | Zakho | 0.005 | -0.001 | 0.003 | 0.004 | 0.005 | 0.007 | 0.002 | 0.004 | 0.004 | 0.003 | -0.004 | 0.005 |
| | Arbil | 0.011 | 0 | 0.01 | 0.009 | 0.005 | 0.004 | 0.002 | -0.001 | 0.002 | 0.005 | 0.001 | 0.011 |
| | Rabiah | 0.011 | 0.02 | 0.013 | 0.022 | 0.023 | 0.054 | 0.044 | 0.04 | 0.039 | 0.032 | 0.028 | 0.033 |
| | Taleafer | -0.037 | -0.047 | -0.029 | -0.021 | -0.034 | -0.037 | -0.046 | -0.036 | -0.024 | -0.023 | -0.023 | -0.015 |
| | Kirkuk | 0.033 | 0.023 | 0.018 | 0.008 | 0.001 | 0.003 | 0.006 | -0.001 | 0.015 | 0.014 | 0.014 | 0.02 |
| | dukcan | 0.008 | -0.089 | 0.013 | 0.012 | 0.011 | 0.005 | 0.003 | 0.001 | 0.006 | 0.007 | -0.001 | 0.011 |
| | Mosul | 0.046 | 0.026 | 0.032 | 0.038 | 0.032 | 0.029 | 0.025 | 0.027 | 0.038 | 0.032 | 0.029 | 0.033 |
| | Khanqin | -0.042 | -0.066 | -0.059 | -0.064 | -0.064 | -0.071 | -0.054 | -0.05 | -0.043 | -0.061 | -0.051 | -0.046 |
| Middle | biji | 0.018 | 0.002 | 0.003 | 0.003 | -0.007 | -0.016 | -0.017 | -0.022 | 0.004 | 0 | 0.008 | 0.011 |
| | Najaf | -0.012 | -0.018 | -0.016 | -0.026 | -0.025 | -0.032 | -0.034 | -0.038 | -0.02 | -0.018 | -0.017 | -0.013 |
| | Kerbela | -0.006 | -0.017 | -0.005 | -0.015 | -0.021 | -0.021 | -0.04 | -0.051 | -0.013 | -0.013 | -0.014 | -0.01 |
| | Hella | -0.01 | -0.019 | -0.027 | -0.014 | -0.019 | -0.028 | -0.029 | -0.039 | -0.027 | -0.028 | -0.027 | -0.02 |
| | Diwaniya | -0.053 | -0.059 | -0.062 | -0.058 | -0.062 | -0.085 | -0.098 | -0.078 | -0.04 | -0.045 | -0.047 | -0.056 |
| | Baghdad | 0.005 | 0.004 | 0.003 | 0.005 | 0.003 | 0.005 | 0.003 | -0.007 | 0.017 | 0.01 | -0.002 | 0.011 |
| | Nukheb | 0.006 | 0.003 | -0.002 | -0.005 | -0.018 | -0.004 | 0.003 | -0.021 | 0.003 | 0.01 | 0.02 | 0.019 |
| | Rutba | -0.005 | -0.028 | -0.017 | -0.02 | -0.011 | -0.011 | -0.01 | -0.028 | -0.012 | -0.004 | -0.002 | 0.003 |
| | Anah | 0.006 | -0.004 | 0.01 | 0.001 | 0.007 | 0.009 | 0.012 | -0.009 | 0.012 | 0.004 | 0.002 | 0.005 |
| | Hadithah | 0.021 | 0.012 | 0.008 | 0.005 | 0.003 | -0.018 | -0.02 | -0.036 | 0.002 | 0.013 | 0.01 | 0.019 |
| Southern | Hai | -0.052 | -0.061 | -0.066 | -0.071 | -0.076 | -0.071 | -0.084 | -0.09 | -0.053 | -0.061 | -0.075 | -0.064 |
| | Samawa | 0.027 | 0.01 | 0.011 | 0.014 | 0.022 | 0.031 | 0.026 | 0.016 | 0.034 | 0.022 | 0.015 | 0.019 |
| | Amara | 0.003 | -0.001 | 0.005 | -0.005 | -0.021 | -0.041 | -0.058 | -0.066 | -0.01 | -0.011 | -0.016 | -0.006 |
| | Nasiriya | -0.036 | -0.048 | -0.05 | -0.057 | -0.079 | -0.103 | -0.107 | -0.091 | -0.047 | -0.052 | -0.053 | -0.043 |
| | Basra | 0.032 | 0.026 | 0.025 | 0.026 | 0.013 | 0.027 | 0.02 | -0.002 | 0.037 | 0.033 | 0.019 | 0.033 |
| | Fao | 0.002 | 0.011 | 0.012 | 0.014 | 0.009 | 0.022 | 0.017 | -0.01 | 0.035 | 0.013 | -0.003 | 0.008 |

**Monthly wind speed analysis**

Figure 2, shows the average monthly wind speed for Northern, Middle and Southern regions covers the study area. Wind values start to increase from January and reaching the highest values in Jun and July, and then start to reduce till December. The results showed that all curves of monthly wind speed have a bell-shaped histogram for all stations. The wind speed in all study area was 3.6m/sec, in the northern region; the average wind speed reached 2.7m/sec, which is less than the general Average. In the middle region, the average wind speed was 3.6 which is equal to the average of the wind speed of the study area.in the southern region, the average of the wind speed was 4.4 m/sec It is higher than the average of the study area. The results showed

that the month of June recorded the highest rate of wind speed, while the lowest rate of wind speed recorded in December during the study period.

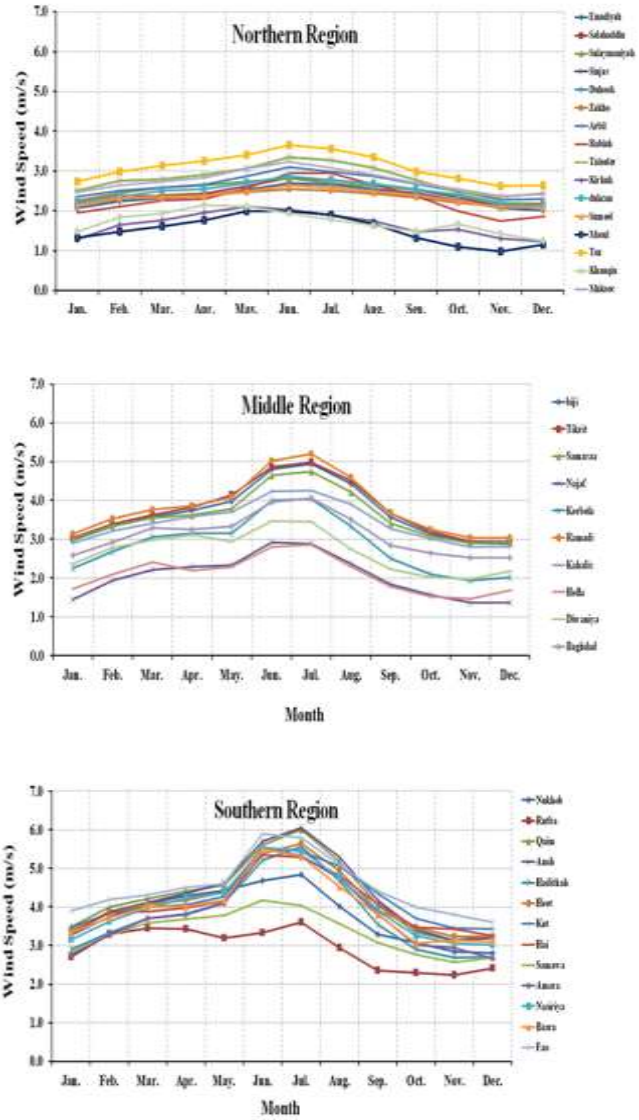
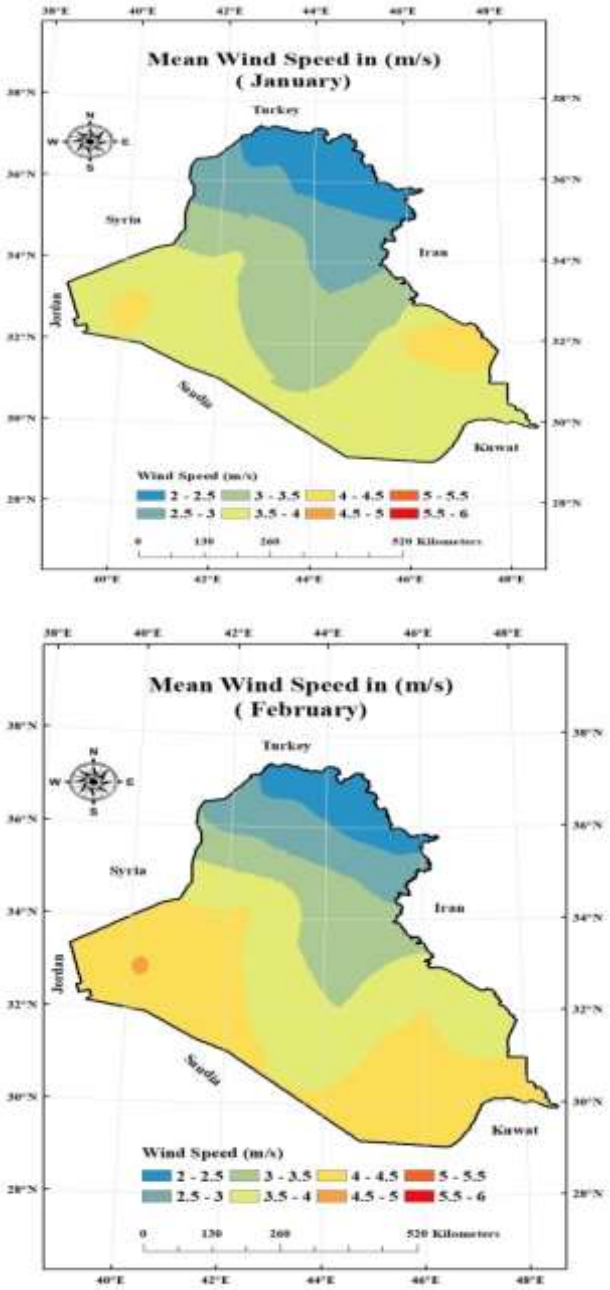


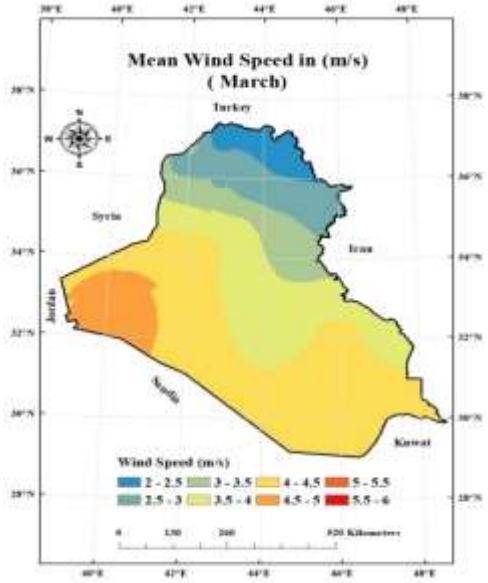

**Figure2. Monthly Averaged wind speed for the period (1981-2017) for study area**

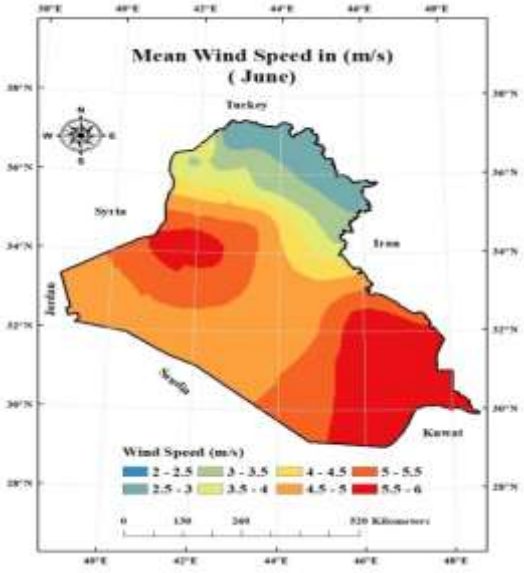
**Spatial analysis of monthly wind speed**

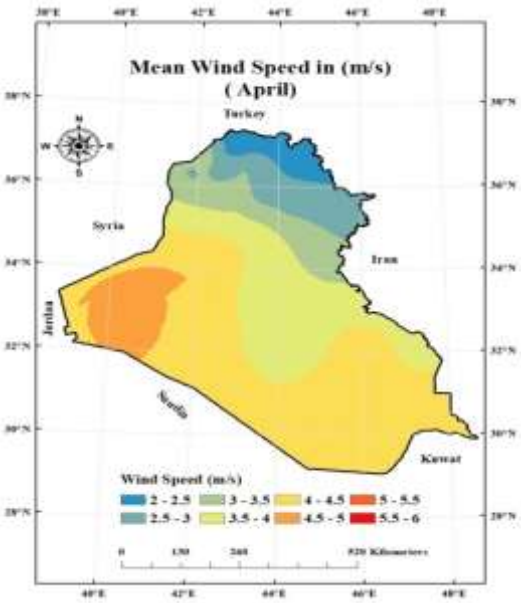
The spatial analysis of monthly wind speed during the period study is shown in Figures 3 and 4. During the winter months (December-February) it can be seen that the study area can be divided into six categories depending on the monthly average of wind speed ranging from (1- 4.5)m/s. The northern region usually includes two types of wind speed, the first class is (2 – 2.5) m/s, and the second class has a mean wind rate of 2 to 3.The middle and southern regions consists of four classes range from (3- 5) m/s, and covered three quarters of the study area. During the spring months (March-May), the northern region consists of three classes from 2 to 3.5 m/s, which covers about 27% of the country. The middle and southern regions consist of three classes range from (3.5- 5) m/s , and covered 73% of the study area. During the summer months (June-August), the northern region consists of three classes from 2.5 to 4 m/s, which covers about 27% of the country. The middle and southern regions consist of three classes range from (3.5- 5) m/s , and covered 73% of the study area.

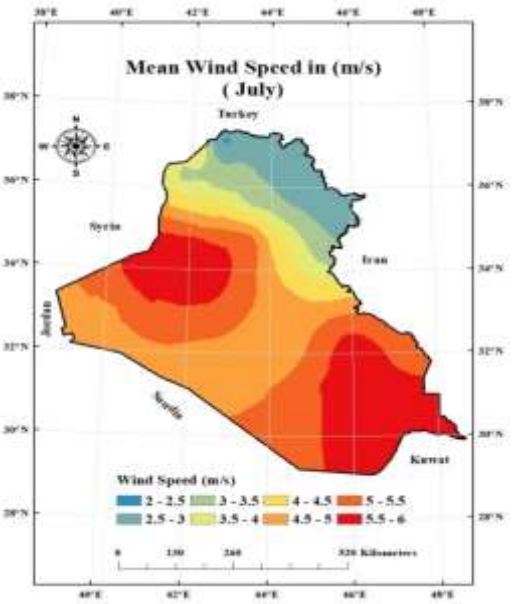


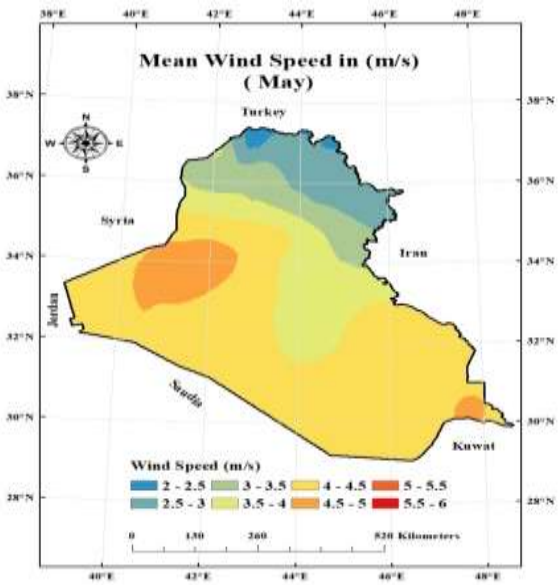

**Figuer3. Spatial distribution of wind speed for January –December during the period (1981-2015).**

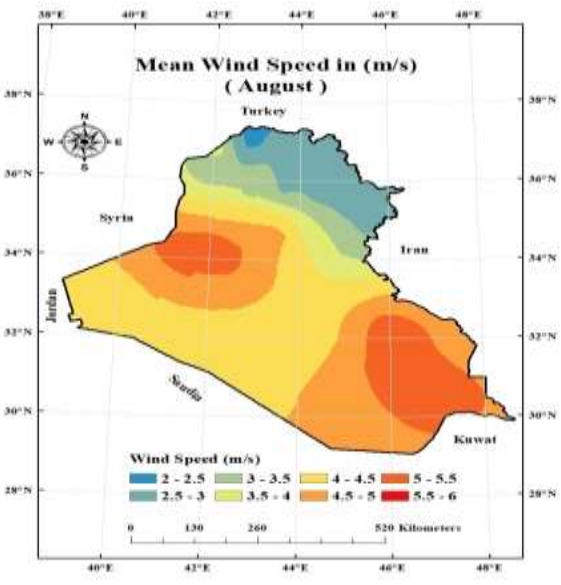
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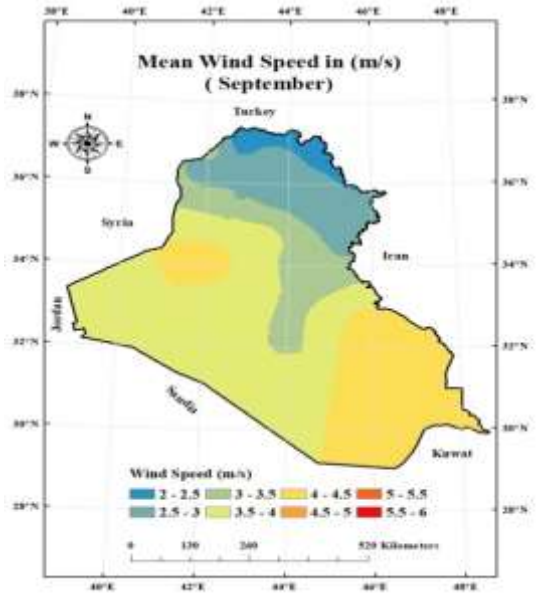


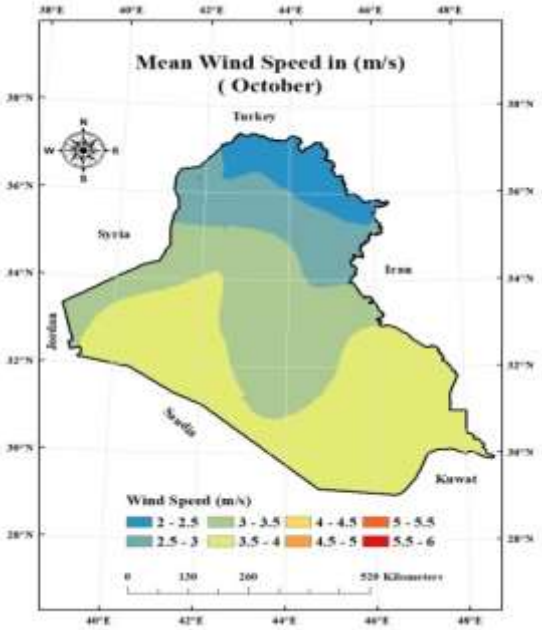


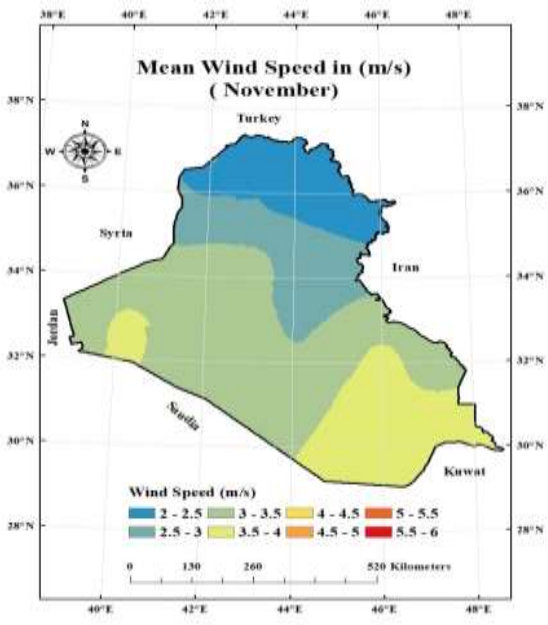


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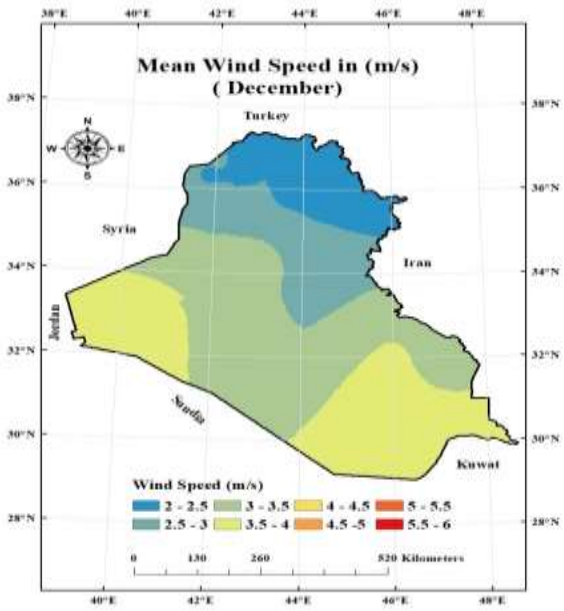
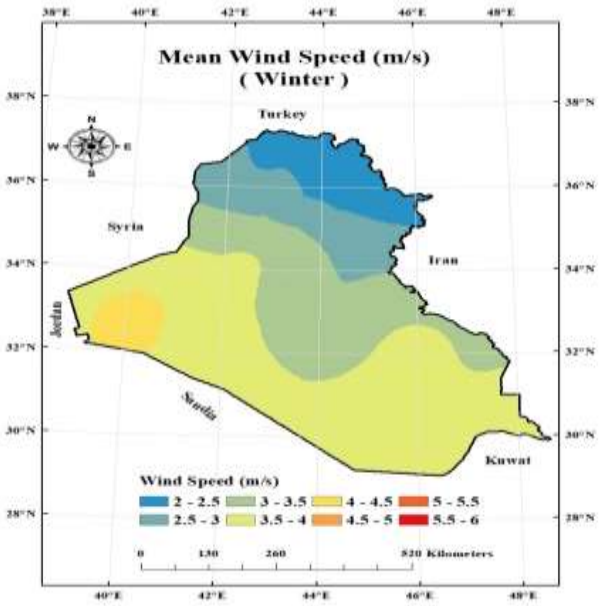
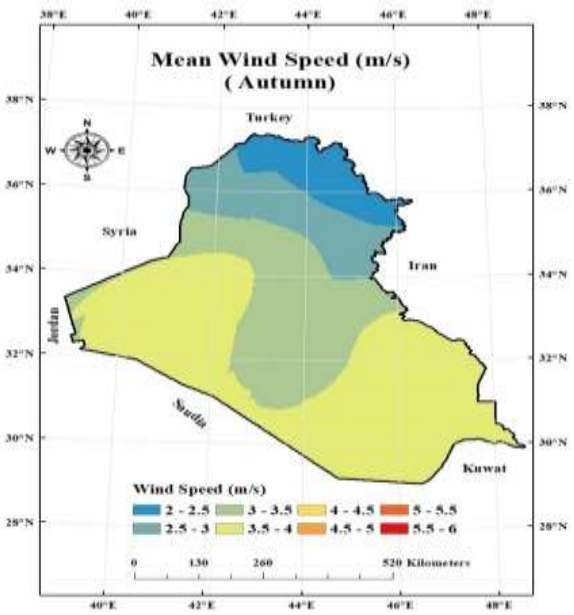


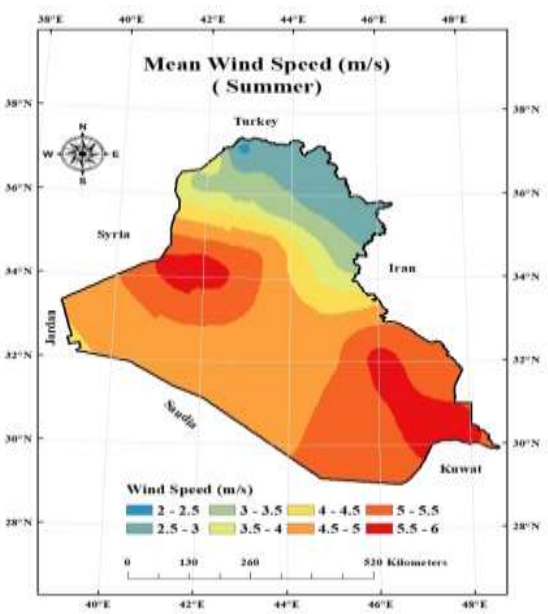

**Followed Figure 3**

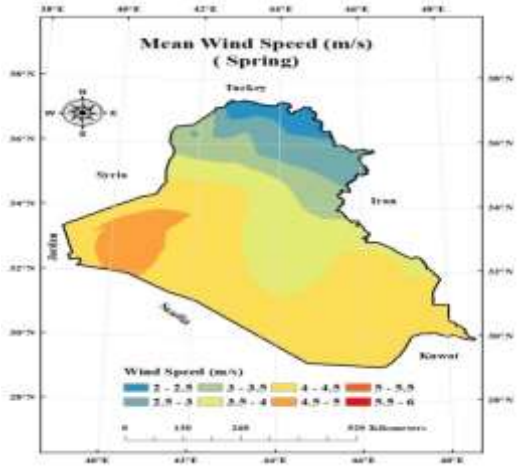
**Spatial analysis of Seasonal wind speed**

The spatial analysis of seasonal wind speed during the period study is shown in Figure 5. It can be seen that the wind speeds have a temporal variation in the study area between winter, spring, summer, and autumn in the year. In winter and autumn, the northern region contains two distinct areas, with a wind speed range from 2-3 m/s, which covers about 29% from the country. the average wind speed in this region has 2.4, 2.8, 3.0, 2.5 m/s during winter, spring, summer, and autumn. The middle and southern regions have three areas, the range from 3-4.5 m/s which covers about 69% of the study area. A significant rising of wind speed values can be observed in Iraq during the spring and summer seasons. Wind speeds rise gradually during spring, reaching in the middle and southern regions, 3.4 and 3.6 m/s respectively. During the summer, the wind speed increases as it reaches 5 and 5.5 in the middle and southern regions, respectively. The Increase wind speed in the summer due to the high-temperature values recorded and affecting the values of atmospheric pressure. Wind speed decreases during the autumn. Seasonal wind speeds show the highest values recorded in the summer and spring seasons and the lowest in the autumn and winter seasons.



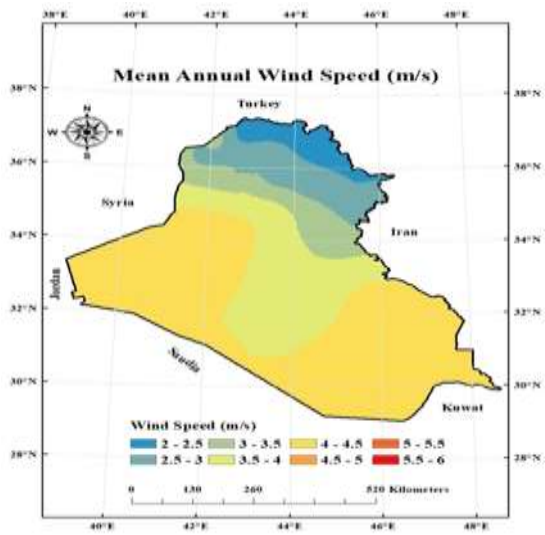




**Figuer5. Spatial distribution of wind speed for season during the period (1981-2015).**

**Spatial analysis of annual wind speed**

The spatial analysis of annual wind speed during the period study is shown in Figure 6. It can be seen that the value of wind speed in the northern region ranged from 2 m/s to 3 m/s. In the middle region, the range of wind speed is between 3 m/s and 4 m/s .while the value of wind speed was in the southern region the range from 4 m/s to 5 m/s. It has been shown that the annual average of wind speed in the northern, middle and southern regions were 2.7 m/s, 3.6 m/s and 4.1 m/s respectively. While the annual average of wind speed in the study area "Iraq" was 3.6 m/s. The winds were low in the northern region compared to the middle and southern regions because the northern region contains high terrain and mountains that block the flow of wind. Also, the wind speed increased in the southern region because of the slope of the surface of the earth and the lack of terrain.




**Figuer6. Spatial distribution of wind speed for annual during the period (1981-2015).**

## CONCLUSIONS

In this study, the monthly wind speed over Iraq was analyzed for 39 stations (1981-2017). Monthly distributions for wind speed show Spatial and temporal variations. The results show that the middle and Southern regions are witnessing decreasing the average wind speed, especially during the summer of the year. which is consistent with the scientific studies indicating the decrease of speed wind surface in several parts of the world during the last decades. wind speed value reaches its highest value in (Jun and July), and the lowest value of wind speed was in December. Seasonal wind speeds show the highest values recorded in the summer and spring seasons and the lowest in the autumn and winter seasons. It has been shown that the annual average of wind speed in the northern, middle and southern regions were 2.7 m/s, 3.6 m/s and 4.1 m/s respectively. While the annual average of wind speed in the study area "Iraq" was 3.6 m/s. The winds were low in the northern region compared to the middle and southern regions because the northern region contains high terrain and mountains that block the flow of wind. Also, the wind speed increased in the southern region because of the slope of the surface of the earth and the lack of terrain.

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