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An Investigation of the Inter-Annual Wind Changes In Iran

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ABSTRACT

In this study, an attempt has been made to evaluate long-term average variation and fluctuation of wind in Iran. For this purpose, wind database network was initially formed over Iran. Then, data from the base of a 30-year period, the daily period of 1/01/1982 to 31/12/2012, was supposed as the basis of the present study, and a cell with dimensions of 15 × 15 km of the studied area was spread. In order to achieve the wind three past decade's changes in Iran modern methods of spatial statistics such as, Moran global spatial autocorrelation, Moran Local insulin index and Hot spots, by using of programming in GIS environment, were accomplished. The results of this study showed that the spatial distribution of wind in Iran has the cluster pattern. In the meantime, based on Moran local index and Hot spots, wind patterns in the South, South-East, East, South West and West, have spatial autocorrelation positive pattern (too much windy pattern), and parts of the Caspian Sea coast, north and center of the country have negative spatial autocorrelation (low wind pattern). During the study period, a large part of the country (almost half of the total area) had a significant pattern or spatial autocorrelation.

Keywords: Wind, Spatial Autocorrelation, Local Moran, Global Moran, Iran.

I. INTRODUCTION

Result of the interaction of local factors and long-term circulation patterns, wind patterns each type and geographic reach will determine the pattern. Knowledge of the spatial distribution of wind in geographical areas will underlie the environmental planning and right policy. One of the important elements that have deniable effect on human activities and natural processes on climate, especially in the arid and semi-arid, is wind. The Horizontal movement of air is said wind that its speed of one meter per second, not less (Masoudian, 2011). Wind which is produced by the deference between the pressures among the adjacent units that have same pressure, on the surface of the Earth which is assumed immobilized, is supposed as the factors that causes balance (Rajaee, 2006). Five windy zones are seen in Iran, depending on the rise, peak and death patterns are produced in some parts of the country in the definite period of time, and culminate and disappear. These windy areas will vary on the issue of time and area of activity, intensity and wind direction and include: quiet zone, an area of low wind, wind zone, high windy zone, and extremely high windy zone. Unfortunately, research has ever been done about the wind spatial statistics in the country. But in the case of wind and wind resources surveys conducted under a few of them exist., including wind energy potential survey in Kermanshah (Mohammadi et al., 1391). Using data on wind direction and speed during three hours from the synoptic stations of Kermanshah, West Islamabad, Ravansar, Kangavar and Sarpolzahab during 1997 -2006 indicates that three stations Ravansar, Sarpolzahab and Kangavar have the potential for wind energy production. West Islamabad region in case of high wind turbines utilization is suitable to implement wind energy and Kermanshah doesn't have such potential.

Potential of west regional wind energy was surveyed using Geographic Information System (Noorollahi et al., 2010). In this study, to measure wind potential, specified criteria (technical, environmental, economic and geographic) discuss with the same importance and significance. These studies have shown that the assumption of using turbines Gamesa G58, we can generate maximum 1897 MW wind power in the study area, which is considered as 26% of the electricity supply in the region in 2025. Entezari et al (2012) using data of three-hour wind speed and continuity from synoptic stations of Sabzevar investigated wind energy potential and estimated electrical power generated by wind turbines. As well as overseas researches have been done in relation to spatial statistics as below. Killeen et al (2007), who have examined have wet and dry spots in the Anode region. Diffenbaugh and Giorgi (2008) examined the climate changes and Hot spots in the United States. They evaluated a few scenarios to identify climate changes of Hot spots in the United States. The results showed that modeling Hot spots in the structure of the GCM model was detected with high sensitivity. Ohayon (2011) through using the parameters of the climatic average monthly temperature, Average maximum and minimum temperature over a period of 37 years in the Palestinian occupied territories in comparing the results of statistical spatial and traditional methods. His study showed that a temperature in the study area follows a complex pattern. Del Río et al (2011) also used OLS (ordinary least square) method which is an optimal method for modeling spatial relations, in spatial statistics. Chao-bing and Ning (2011) studied the Hot spots of heating islands China. Allard and Soubeyrand (2012) in a study for Colmar area located in North East France for weather data and models of distribution of epidemiology of plant species benefited applied approach of spatial statistics and have identified sensitive areas to climatic changes. Robeson et al (2014) in a research using the function of K Ripely, evaluated the World Meteorological Stations and introduced the best type of this function. Since the time – place changes of precipitation is one of the most important applied climatically subjects, There are many studies that include studies (Homar et al., 2010; Ageena, et al., 2013; Nemec et al., 2013; Kim and Singh, 2014) as Indicators from hundreds of design templates and other selected pattern. Summing up the history of research shows that despite the high potential of spatial data analysis capabilities and analytical functions such as Hot spots analysis and cluster analysis and non-analysis in climatic studies in the country has not been mentioned. This approach using spatial analysis functions Spatial Statistics, focus identifying windy areas of the country.

II. METHODS AND MATERIAL

CASE STUDY

In this study the data of 145 synoptic stations with a period of 30 years (1982-2012) were used. Figure 1 shows the distribution of the studied stations. In this study, the data point using Kriging interpolation method in ArcGIS 10.2.2 software mapping data was extended to the cells with dimensions of 15 × 15 km. To speed up the process of calculation, application programming capabilities GS + and Spss were used. Regarding that the information related to the wind has local correlation. Therefore, it can be obtained using Spatial Statistics wind model, and then through using the cluster and Outlier statistics and evaluating Hot spots analysis was done.

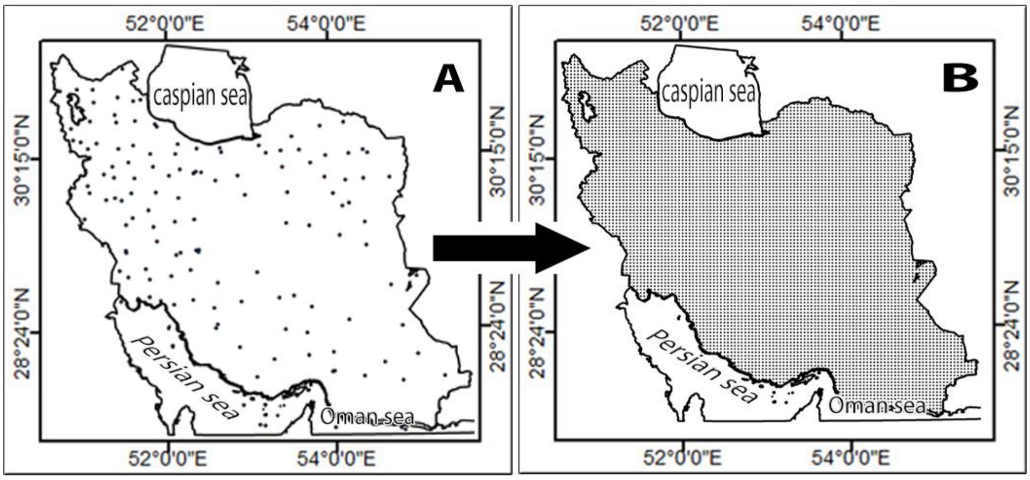

Figure 1: Synoptic and climate stations (A) and 15 × 15 km cells (B).

Spatial Auto-Correlation

To examine the prevailing pattern in Wind in Iran during the period under study it was used the modern spatial methods such as spatial autocorrelation (local Moran and global Moran) and HotSpot. Recognition of patterns and discovery of existing process in spatial data are of importance (Diggle, 2003; Waagepetersen and Schweder, 2006), because before any analysis of map in spatial statistics, it must engage in this prejudgment that how the data have been distributed in the space and what pattern and rule is used for distribution of data in the space (Illian et al. 2008).

In previous research analysis method of Moran local pattern has been used, for a better understanding of data and accurate decision making about the confidence level. In recent decades, a variety of scenarios concerning analysis of spatial data patterns have been expanded in spatial database. For this it can use Global Moran Index which is well known to Global Moran I. This index obtains numerical statistics (z-score) through which it can measure degree of scattering in spatial data in the space (Getis A, Ord, 1992; Levine, 1996, Mitchell, 2005, Wheeler, 2007, Illian et al. 2008).

Moran wind spatial autocorrelation is examines spatial autocorrelation based on dispersion area of two amounts and analyses, the considered characteristics of geographical condition in that area (Griffith, 1987). To calculate Moran index, firstly z-value and p-value is calculated, and in the next stage is considered the evaluation and significance of index. To calculate spatial autocorrelation, Global Moran Index is used equation 1:

$$I = \frac{n}{s_o} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{i,j} z_i z_j}{\sum_{i=1}^{n} Z_i^2} \qquad (1)$$

The Global Moran's I statistic provides a measure of the degree of spatial autocorrelation based on both the locations of events and the values associated with the events at the same time. It indicates the degree of spatial concentration or dispersion for a given point pattern (Scott & Janikas, 2010). The index, *I*, is calculated as follows:

Where z_i is the deviation of an attribute for feature *I* from its mean $(x_i - \overline{X})$; $W_{i,j}$ is the spatial weight between features i and j; n is equal to the total number of features; finally, S_o is the aggregate of all the spatial weights (Mitchell, 2005).

In general, if the amount of Moran index is close to +1, data will experience spatial autocorrelation, and if the amount of Moran index is close to -1, data will experience discrete pattern.

Maps of clusters: a function which has been mentioned in analysis of pattern implies the general statistics which seek to give a response to this question "whether a significant spatial dispersion exists between the data or not?"; cluster maps help to identify where the clusters have been formed at the region under study and where are the borders in this region. In this study, cluster and outlier analysis (Anselin Local Moran's I) and Hotspot Analysis have been used to study patterns and Spatial-Temporal variations in wind. The cluster and outlier analysis which is well known to Anselin Local Moran's I is regarded as an optimal pattern to display statistical distribution of phenomena in space(Anselin, 1995, Getis A, Ord, 1995, Getis A, Aldstadt, 2004, Anselin, 2009, Wheeler D, Paéz, 2009).

To analyze cluster and outlier analysis (Anselin Local Moran's I) per any condition existing in layer, amount of local Moran index, Z-Value and P-Value which represent significance of index are calculated. Local Moran's I can be calculated based on:

$$I_i = \frac{x_i - \bar{x}}{s_i^2} \sum_{j=1, j \neq 1}^{n} w_{i,j} w_{i,j} (x_i - \bar{x}) \qquad (2)$$

Where x_i represents the characteristic of i, $\bar{x}$ represents mean of the given characteristic, and $w_{i,j}$ represents the spatial weight between features i and j. Value of s_i is calculated based on equation 3:

$$s_i^2 = \frac{\sum_{j=1, j \neq 1}^{n} w_{ij}}{n-1} - \bar{x}^2 \qquad (3)$$

Where, n equals to the number of all features. z_{Ii} is calculated using equation below:

$$z_{I_i} = \frac{I_i}{\sqrt{V[I_i]}} \qquad (4)$$

To calculate V [I_i], the equations 5 are used:

$$V[I_i] = E[I_i^2] - E[I_i]^2 \quad (5)$$

$$E[I_i] = -\frac{\sum_{j=1, j\neq 1}^{n}}{n-1} \quad (6)$$

Hotspot Analysis uses (*Getis-OrdGi**) for all the existing features in the data (Rogerson, 2009). Z-value represents that where the data have been clustered with high or low values. Conceptual framework of this analysis works out in this way that if there is a high value, this will be an interesting point, yet this does not imply that a spot is hot. Hotspot is called to a condition that the Feature and its neighborhood Features be significant. Z-value will be obtained for the final output when the local sum of the Feature and the Features in its adjacency are compared with the total sum of Features (Anselin, 1995, Getis A, Ord, 1995, Getis A, Ord, 1992, Zhang et al. 2008). The statistics (*Getis-OrdGi**) is calculated using equation 7:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} - x\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{[n\sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2]}{n-1}}} \quad (7)$$

In equation above, x_j represents the amount of characteristic for Feature j, $w_{i,j}$ represents spatial weight for the Features i and j, and n represents total number of Features. To calculate S, equation below is used:

$$S = \sqrt{\frac{\sum_{i=1}^{n} x_j^2}{n} - (\bar{x})^2} \quad (8)$$

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n} \quad (9)$$

As G_i^* is considered as a z-value, calculation of z has been avoided.

III. RESULTS AND DISCUSSION

Analysis of pattern of the inter- annual wind changes

Outputs of Global Moran's Wind spatial autocorrelation have been represented in table 1. In general, if Moran index be close to +1, data will have spatial autocorrelation and clustering pattern, and if the Moran index be close to -1, data will be discrete. According to Global Moran, null hypothesis has been grounded on this point that there is no spatial clustering between values of the element associated to geographical Features. Yet, when the p-value is so small and the calculated z-value is so large, it can reject the null hypothesis.

If Moran index be greater than 0, data will represent a type of spatial clustering. If Moran index be less than 0, geographical Features under the study will have a scattered pattern. As shown in table 1, Global Moran index for the periods under study will be above 0.94. This point represents that wind at the country at the periods under study at level 95% and 99% indicate a high clustering pattern, concerning Global Moran index. Nonetheless, the highest Global Moran index with the value (0.971328) has associated to months.

Z-value for periods under study is high ranging from 254 to 262. Hence, to sum up, based on Global Moran index, it can deduce that wind changes during these months at country follow high clustering pattern. Hence, with regard to high z-value and low p-value, it can reject null hypothesis based on lack of spatial autocorrelation among data at the periods under study. If it was supposed spreading wind in a normal way at the periods under study, Global Moran index will be equal to -0.000139.

TABLE 1

OUTPUT OF MORAN (MORAN'S I) STATISTICS DURING PERIODS UNDER STUDY.

Month	Moran index	Expected Moran index	Variance	z-score	p-value
Jan	0.968553	-0.000139	0.000014	261.297814	0
Feb	0.971328	-0.000139	0.000014	262.043414	0
Mar	0.968741	-0.000139	0.000014	261.345506	0
Apr	0.959152	-0.000139	0.000014	258.758179	0

May	0.945035	-0.000139	0.000014	254.958950	0
Jun	0.956508	-0.000139	0.000014	258.079939	0
Jul	0.962094	-0.000139	0.000014	259.594079	0
Aug	0.960235	-0.000139	0.000014	259.101801	0
Sep	0.964608	-0.000139	0.000014	260.263092	0
Oct	0.968106	-0.000139	0.000014	261.173499	0
Nov	0.960964	-0.000139	0.000014	259.247996	0
Dec	0.967982	-0.000139	0.000014	261.143261	0

As observed, spatial autocorrelation of Global Moran index just specifies the type of pattern. For this reason, local Moran during the periods under study has been used to display the spatial distribution pattern of wind in Iran. The results indicate that whether the Features have been distributed in random, scattered or clustering in the space. If I value be positive, this will imply that the considered condition has been dominated by the similar Features. Hence, the considered Feature is a part of that cluster. If I-value be negative, this will imply that the considered Feature has been enclosed by the dissimilar Features. This Feature is called Outliers. The value of this statistics has been calculated in the framework with the standard score, and p-value can be analysed. In this statistics, HH represents clusters with positive spatial autocorrelation at 99% confidence level, LL represents clusters with negative spatial autocorrelation at 99% confidence level, HL represents Outliers in which a high value has been enclosed via low values, and LH represents single-cells in which the condition enjoys a low value, enclosed via high values. Figure 2 represents the variations during years with spatial autocorrelation in the clustering pattern of wind during the periods under study (1982-2012). In three month of the spring (January, February, and March) in most part of the country high wind samples and low wind samples exist, in other words, they have had cluster pattern. . This status have been equally distributed with the amount of 10.54% in the three months of winter across the country (Figure 2). In January 23.97, February 28.49 and March 29.43 percent of the country, mostly in the south, South-East, East, West and East North West(In January due to westerly winds), representing synoptic stations Ardebil, Lorestan, Kurdistan, north of Hamedan, North East of Kermanshah, Sistan and Baluchestan, Hormozgan, the southern half of South Khorasan; Central, East, North East and South East of Kerman, south of Fars province has a cluster of high value (positive spatial autocorrelation) is dominated. In this period of the year wind pattern or quantities of low value (negative spatial autocorrelation) that represent low wind pattern have been respectively distributed, in the months of winter 28.53, 27.24 and 24.64 percent; And as a tab, the coast of the Caspian Sea to central areas of the country have been drawn up (Table 2). In the spring the amount winds of wind with positive high spatial autocorrelation have been decreased compared to the winter 6.12 percent. And also in terms of location it have been changed and areas of the North West and South have been changed from the high wind pattern to the lack of solidarity and low wind pattern (Figure 2). So that clusters with high value have been back warded in the form of strip to the East. And in June northwest region and some parts of the south of the country completely lost their wind pattern and wind distribution is limited to the East beam. In summer, the changes of low wind patterns (negative spatial autocorrelation) has been increased, in this manner for the months of July, August and September, respectively, the values of 26.90, 27.42 and 28.28 percent, have been shown. As can be seen at this season of the year from to the area of low wind patterns (spatial autocorrelation negative) slightly increased and in the terms of place have been experienced some changes. . In the summer the areas that have no pattern compared to the previous season and the highest numeric value to 50.81 percent. As seen in Table 2, the fall season accounted for the lowest percentage of areas without pattern, and an average of the three months of October, November and December 44.15 percent of the country does not follow any spatial pattern. Totally regarding that the values with positive spatial autocorrelation in four season of the year and with a downscale look in all 12 months of the year are limited to south east areas and in some months of the year (Fig 2) are limited to the eastern beam. So it can be concluded that local factors play a significant role in the distribution of the spatial distribution of wind scattering in Iran.

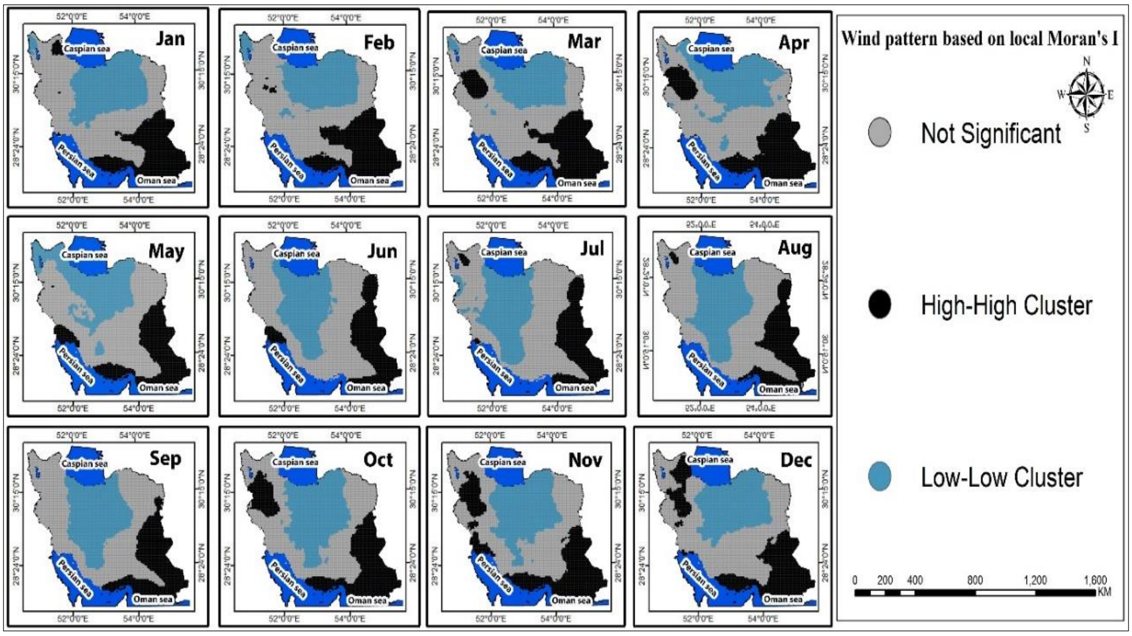

Figure 2: The results from scattering of Anselin Local Moran's I

TABLE 1

PERCENT OF THE AREA UNDER COVERAGE OF PATTERN DERIVED FROM ANSELIN LOCAL MORAN'S I

Type of wind pattern	Jan	Feb	Mar	Apr	May	Jun
High clustering pattern(HH)	23.97	28.49	29.43	29.92	23.82	22.03
Low clustering pattern (LL)	28.53	27.24	24.64	26.78	26.86	26.05
Without pattern	47.50	44.27	45.93	43.30	49.32	51.92
Type of wind pattern	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
High clustering pattern (HH)	21.45	21.50	21.94	28.46	28.44	27.08
Low clustering pattern (LL)	26.90	27.42	28.28	29.43	27.74	26.39
Without pattern	51.65	51.08	49.78	42.11	43.82	46.53

With regard to what mentioned above, those areas of country with positive and negative spatial autocorrelation were specified, yet Hotspots index or GI* have been used to assure from the areas with clusters with high and low value, that the results have been represented in figure 3 and table 3. Statistic GI* which is calculated for existing condition in the data is a z-value. For positive Z score, the more score is greater, high values have been clustered to a large extent, developing hotspot. For negative score, the more score is small, there will be lower amounts, indicating cold spots. As shown in figure 3, January in winter the high windy sample, at a significance level of 99%, in North West, west, south west and south east representing synoptic stations, east of eastern Azarbaijan, Ardebil, Zanjan, Guilan, east of Kurdestan, North of Hamedan, South of southern Khorasan, Sistan and Balouchestan, South west of Khoozestan, East of Kermanshah, south east of bushehr, the southern region of Fars, Hormozgan and Kerman. Respectively in January, February and March form 27.37, 30.47, and 34.10 percent of the country. In the same season of the year regions that represent low windy samples (at 99%) north of eastern Azarbaijan, Eastern Azarbaijan, the Caspian Sea coast, North East and center of the country. So that the synoptic stations provinces of Mazandaran, Golestan, Khorasan, the western half of Khorasan Razavi province, North East, South Khorasan province, northeast of Yazd, Semnan, Tehran, Qom, Qazvin, Isfahan, ChaharMahal and Bakhtiari probably 99% wind patterns low wind samples has been detected and in the northern of provinces they form low windy samples at 95 percent of probability. Areas that have no significant pattern in winter respectively have been calculated 26.80, 24.90, and 22.19 percent for January, February and March. Cluster sample has the high amounts of spatial autocorrelation or in other words the high windy sample in spring at 99 percent has been increased.

(Table 3) and in terms of place there had been some changes in January and February. So that the areas with positive spatial autocorrelation at a confidence level of 90% and 95% of the capital advanced and West regions of the country to be more positive in terms of spatial autocorrelation is (Figure 3). In spring, the area with negative spatial autocorrelation compared to winter has been a significant change in terms of location, so low wind patterns Wind by 95 and 99 percent of East Azerbaijan province fully drawn toward the center. As is clear from Table 3 also areas with no significant pattern in the spring than three months ago has increased 5.01, So for April 24.26, 27.82 and June 26.82% of the total area of the country, statistically had no significant pattern (Figure 3). The cluster pattern of high amounts of spatial autocorrelation has been increased in the summer is significant at 99% confidence level. (Which is due to the beginning of the 120-day winds of Sistan); and in terms of location also had significant changes (Table3 and Fig3). High windy samples in summer compared to 9 month had a large stretch to the east of the country. But also in west northern part of the country due to the mountainous region in North West the high windy samples have been emerged. Low windy patterns at different confidence levels in the months of July, August and September, have been stretched to the West and the interior parts of the country. Changes of spatial autocorrelation of wind in the country in fall based on the GI index compared to winter have had a lot of challenges. Totally in October 33.90, in November 31.37, and in December, 30.23 percent of the country had negative spatial autocorrelation or other word had low windy patterns. Regions with positive spatial autocorrelation totally in October 30.96, November 33.27, and in December 31.68 formed the total area of the country. (Increasing the areas with positive spatial correlation than in winter is due to the beginning of the westerly winds in the mountain dam of Alborz and Zagros).In autumn the percentage of non- significance has been reached to the minimum amount. (Totally the three months 72.41 percent of the total area of the country) this amount compared to the average of winter have been decreased 1.63 percent compared to winter and 6.49 percent compared to summer and compared to spring 1.48 percent. This is caused by less fluctuation of wind in this season of the year.

TABLE 1

PERCENT OF THE REGIONS UNDER COVERAGE OF HOT SPOT ANALYSIS (GETIS-ORD GI*)

Type of wind pattern	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Very low pattern of wind (negative spatial autocorrelation at 99%)	31.99	22.30	29.99	32.12	32.32	31.93
Low pattern of wind (negative spatial autocorrelation at 95%)	3.82	5.05	6.18	4.97	4.75	6.79
Average low pattern of wind (negative spatial autocorrelation at 90%)	2.18	3	2.72	2.24	2.17	4.78
Lack of a significant pattern	26.80	24.90	22.19	24.26	27.82	26.82
Average full pattern of wind (positive spatial autocorrelation at 90%)	3.07	1.93	1.51	1.51	2.14	1.86
Full pattern of wind (positive spatial autocorrelation at 95%)	4.76	4.42	3.86	2.94	3.58	3.28
Full pattern of wind (positive spatial autocorrelation at 99%)	27.37	30.47	34.10	31.96	37.22	24.54
Type of wind pattern	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Very low pattern of wind (negative spatial autocorrelation at 99%)	35.83	32.94	33.02	33.90	31.37	30.32
Low pattern of wind (negative spatial autocorrelation at 95%)	5.71	7.86	4.49	3.75	5.18	4.05
Average low pattern of wind (negative spatial autocorrelation at 90%)	2.22	3	2.44	1.93	2.68	2.40
Lack of a significant pattern	24.80	22.46	29.28	25.19	21.50	25.72
Average full pattern of wind (positive spatial autocorrelation at 90%)	2.53	2.44	1.83	1.69	2.01	2.01
Full pattern of wind (positive spatial autocorrelation at 95%)	3.74	5.28	3.24	2.58	3.99	3.82
Full pattern of wind (positive spatial autocorrelation at 99%)	25.17	26.22	25.69	30.96	33.27	31.68

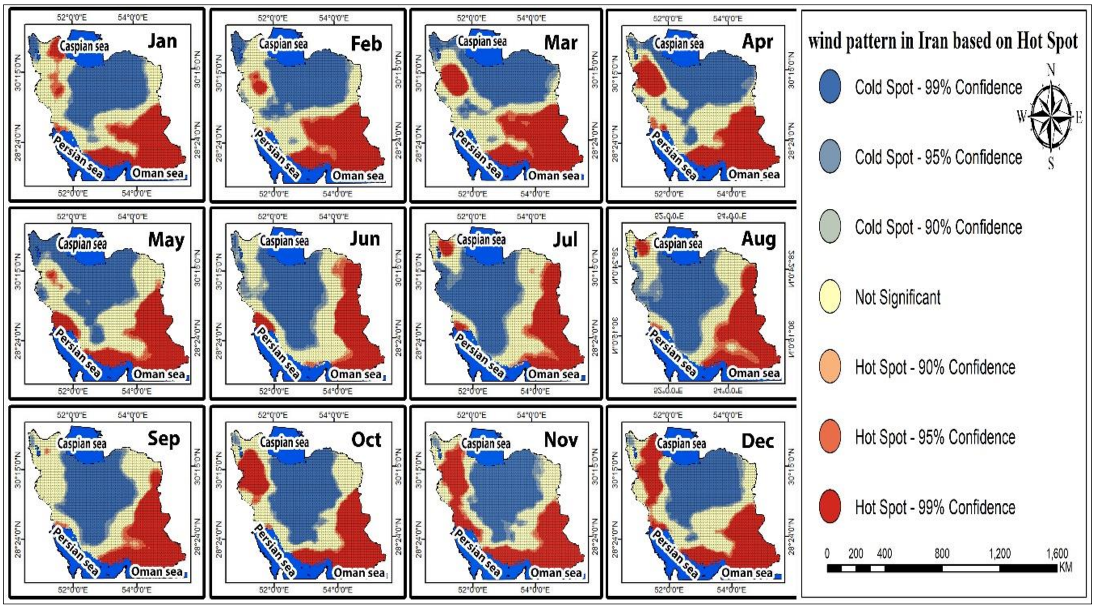

Figure 3: THE RESULTS FROM SCATTERING OF HOT SPOT ANALYSIS (GETIS-ORD GI*).

IV. CONCLUSION

Wind is the most important climatic element in identifying the climate type of each region. Changes in amount and pattern of wind are indication of climate change. Variability and variation are of a particular important in wind related studies, having a major role in climate predictions.

Based on both indices, southern East, East, South, Central and Western on behalf of stations Sistan and Baluchestan, Kerman, Fars, Yazd, South Khorasan, Ahvaz, Lorestan, Kurdestan, had a significant role in shaping high windy patterns, with high cluster pattern, so that these areas of the country had positive spatial autocorrelation. However, that negative spatial autocorrelation areas or in other words low windy patterns are limited to the Caspian Sea coast, north and central part of the country (central area). In general, the fall season (October 30.96, November 33.27, December 31.60) spring (April 31.96, May 33.22, January 24.54), because of the transitional nature of the seasons they have the most high windy pattern patterns. Also in summer (July 25.17, August 26.22, September 25.69) due to decreasing all the effective factors and being active subtropical high pressure in the region it has the lowest high pressure sample. Also a large area of the country have a significant pattern in all four seasons of studied period, or in the other word had statistically significant spatial autocorrelation. The results of this study indicated that wind patterns form under influence of local factors and atmospheric elements in a long-term, yet they play a different role, so that geographical arrangement of wind patterns is formed via local agents especially altitudes and mountains; this is in a way that role of extrinsic factors must not be ignored in formation of wind patterns, because the external factors play a major role in determination of wind regime and wind temporal variations. Looking into wind clusters at the country, it can observe that up and down wind clusters are not the same, indicating effects of General Atmospheric Circulation.

Thus, in general, the wind patterns are developed and influenced under two systems: 1- Local influencing factors (geographical arrangement of wind patterns), 2- External influencing factors (regime of wind patterns).

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