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Analysis of the Trend of Dust Changes in Ardestan Region, Iran

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Abstract

Dust storms in central Iran are a natural hazard, and Tigris-Euphrates alluvial plain has been recognized as the main dust source in this area. In the present study, changes in dust events during the studied months, seasons and years (2000-2013) for Ardestan synoptic station, and their relationship to drought Standardized Precipitaion Index (SPI) were evaluated. The index is an standard indicator for precipitation. Additionally, non-parametric procedures in statistics, including Mann-Kendall and Sen-Stimator, were utilized to identify the changes trend in frequency of days with dust storms on monthly and annual scales. For this purpose, the statistics of selected station was utilized in a 14-year period. Codes extraction related to dust event (06 and 07) and data analysis were conducted using the MATLAB software, and to study the changes trend in monthly and annual time series, non-parametric test statistics were calculated, and then their significance was evaluated at 5 and 1 percentage error. The results showed that may and spring had the most dust events number compared to other months and seasons. Furthermore, results showed that there was a direct relationship between dust event and drought and years having intensive drought, resulted in more duct events. The results indicated that in Mann-Kendall procedure, of total 13 data series, annual data series and in San-Estimator method, August had positive significant trend at 1% probability level and in San-Estimator method, data series in April and June months had an increasing trend at 5% confidence level. The results of spatial analysis of anemometer data using WR plot showed that direction of dominant winds was toward south. The results showed that the integration of dust model and satellite images of dust could be used as an effective system to assess and alert the dust crisis rapidly.

Keywords: Ardestan, Drought, Dust, Mann-Kendall, Sen-Estimator.

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1. Introduction

Initially, appropriate statistical distribution was fitted on long-term precipitation recordings. Then, using equal probabilities, an accumulated function of distribution was converted to normal distribution. Accordingly, they were standardized, and the mean amounts for each area and the intended period were converted to zero. The positive amounts of SPI represent precipitation more than the mean precipitation, and negative amounts represent precipitation less than mean precipitation. According to the procedure, drought period occurred when the SPI index was continuously negative and equal to -1 or less, and ended up when SPI was positive (Beroghani et al., 2013).

Kumar et al. (2015) studied three important dust events in northern India on 2010 during monsoon season using earth and satellite measurements and the estimating analyzing method. Results showed that all of storm rose originated from Taar desert or transferred from it under favorable conditions. Asghari Panah et al. (2015) evaluated and zoned out spatial and temporal changes in dust storms in Khuzestan Province from 1991 to 2010 period using dust storms experimental index (DSI). Results showed that the index amount for Khuzestan Province decreased over time and was equal to 38 DSI index. Bohayrayi et al. (2011) analyzed synoptic statistics of a dust event in Ilam Province, Iran. Their results represented that May and December months at Ilam station had the highest and lowest frequency of dust by 63 and 1 days and July and December months at Dehloran station had the highest and lowest dust frequency by 22 and 7 days. Hahnenberger and Nicoll (2012) studied event properties in the east of Utah region in the United States. The results showed that the highest dust frequency was observed in the spring season at afternoon hours in which wind velocity was the highest.

In one study, the trend in dust event occurrence in west parts of Iran was evaluated using non-parametric statistic methods. In the study, the data for 16 synoptic stations in the west of Iran with a 55-year period were utilized. According to the results, the west of Iran was not a homogenous area in terms of

A dust storm is defined by the World Meteorological Organization (WMO, 2008) protocol as strong winds leaving a large amount of dust particles, reducing visibility from 200 and 1000 m. It is a major weather event playing an important role in the Earth̛s atmosphere and ocean levels (Dunion & Velden, 2004). Dust storms affect the sea phytoplankton (Bishop et al., 2002), soil physical and chemical properties in the environment and deposition areas (Mctainsh & Strong 2007; Naiman et al., 2000), climate and radioactive (Gunaseelan et al., 2014), economic loss (ADB, 2005), and human health (Kaiser, 2005). Most of them are from plains and playas across North Africa, the Middle East and Asia. One of the main sources of dust is relatively recent flood sediments deposited after the end of the third decade. Asia, with almost 60% of the population of the world, is an important source of dust affecting the climate globally. Iran is located in arid and semi-arid belt in the world, so that it is subjected to various regional and trans-regional dust systems (Rashki et al., 2013; Goudi, 2014). Wang and Fang (2006) statistically and synoptically studied distribution and translocation of dust particles in Eastern Asia and found that synoptic systems blowing toward desert areas of northern Asia, if creates winds more than 6 m/s velocity, resulted in intensive dust storms. Yang et al. (2007) studied dust storms occurrence frequency in northern China regarding climate change in the past 1000 years. Ice cores, tress segments and historical documents were utilized. They showed that storms formation was controlled by the precipitation factor. Chan and Yu (2008) studied dust storms on air pollution of large cities in China. O'Loingsigh et al. (2014) studied wind erosion using meteorological data from 1965 to 2011 in Australia. Results indicated that precipitation had considerable impact on dust formation so that in years with decreasing precipitation, dust storms occurrence increased. The SPI index for each area was calculated based on long-term precipitation records.

addition, there was a decreasing trend from 1984 to 1999 in the dust event, and the trend was inverse from 2000 to 2007. Kang et al. (2015) studied dust events occurrence in Tibet Plateau in the statistical period of 1961-2010 and found that frequency of dust event occurrence had a significant decreasing trend from the 1970s, being associated with a decrease in wind velocity and an increase in vegetation cover in the area. The purpose of the present study is to analyze the synoptic systems and relationship of drought to dust event occurrence as well as studying the changing trends in day numbers with dust storms in a 14-year period (2000-2013).

The goal of this study, which was conducted in almost the center of Iran, was to investigate remote sensing data capability in extracting quantitative and qualitative parameters of dust phenomena.

day numbers with dust and days with dust annually increased from north to south of Iran. The results showed that all of the studied stations, except Khoy station, had a trend in terms of dust event occurrence. Among them, the trend in 8 stations was significant, which in three stations. there was a decreasing trend and an increasing trend observed in five other stations (Ansari Renani, 2011). Rasouli et al. (2010) analyzed the dust event occurrence trend in the west of Iran using non-parametric statistical methods and found that regarding the nature of entered data, Mann-Kendhall and San-Estimator procedures were efficient in analyzing dust event trends, and they recognized that all of the studied stations had a trend in terms of dust events. Taan et al. (2014) studied dust storm intensity in China from 1980 to 2007. The results showed that the most dust events occurred in 1983. In

2. Methods and Materials

2.1. Study Area

The study area is located in the north of Isfahan Province, Iran, south of salt desert at 33°23' N latitude and at 52°22' E longitude. The area is surrounded by a salt desert on the north, Isfahan town on the south, Naeen town on the west, and Kashan and Natanz on the east. The area is totally a desert, and its south is a mountainous area. The area has limited water sources due to natural dryness and considerable evaporation, and has hot and dry climate. The mean annual temperature and precipitation are 17.54°C and 122mm, respectively. In addition, the mean minimum and maximum annual temperature are 10.14 and 25.6°C, respectively. Fig. 1 shows the location of the study area, which is in the central desert of Ardestan, Iran

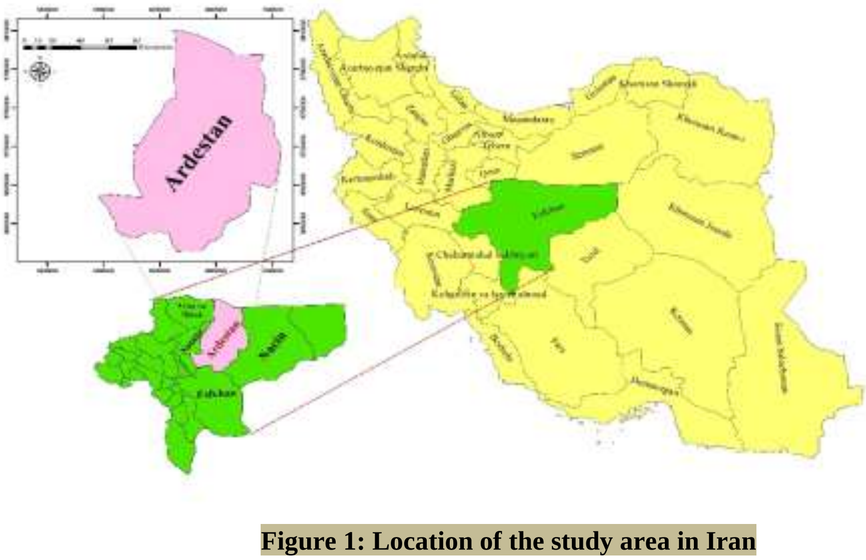

Figure 1: Location of the study area in Iran

2.2. Methodology

To study the dust events, the dust data obtained from the Meteorological Organization based on daily measurement at 8-hour surveying as special codes in a 14-year period (2000-2013) from the selected station in the studied area with a proper statistical period, were analyzed using statistical procedures. Extraction of dust days was conducted using meteorological codes, including 06 and 07 and analyzed by the MATLAB software.

Code 06 implies suspended dust particles in the air transferred into the station from distant areas via sandstorms and code 07 implies dust or sand particles aroused via wind in the station and/or its proximity (Zanganeh, 2014). In the present study, monthly, annual and seasonal frequencies of dust days were extracted at the horizontal visibility of less than 10km. To calculate the SPI index, initially, the precipitation data were obtained from 2000 to 2013 annually. Then, the data were prepared as a notepad file, and the SPI index was calculated for the station using the DIP software. Finally, the relation between drought and dust events occurrence in the studied period was determined. Until now, various statistical methods have been developed to analyze time series, which are generally classified into parametric and non-parametric classes.

Literature review shows that non-parametric procedures have more extensive and wide application than parametric ones. In the present study, since most of the series had no normal distribution, two non-parametric methods, including Mann-Kendall and San-Estimator methods, were utilized. After statistical survey in the selected station, total annual and seasonal storms in the statistical period were analyzed. Furthermore, to convert anemometric data format into utilized format (Lake) in WRPlot, the WD convert software was used, and then the annual and seasonal storm roses were plotted using the WRPlot software (Ver. 8) and analyzed.

3. Results

3.1. Dust Statistical Analysis

Table 1 presents the results of statistical analysis of day numbers having dust and their means in different months of the year in Ardestan station in the studied period. The annual frequency of days with dust event in the studied area was evaluated using the data from sthe elected station. Totally, 286 days were reported as days having dust events from 2000 to 2013. As Table 1 shows, the results showed that dust events frequencies had an increasing trend from 2007 to 2013. In addition, the results indicated that there was a decreasing trend from 2000 to 2007. The statistical analysis results showed that the most dust events occurred in 2013 by 48 days. The monthly survey of the dust event during the studied time showed that the highest dust event frequency in Ardestan station was observed in May by 53 days, and the lowest frequency was in December by 2 days.

As Fig 2 shows, the most dust events were recorded on May by 18.53 percent, and the fewest events occurred on December by 0.67 percent and January by 0.13 percent. The monthly evaluation of dust events showed that 68.82 percent of whole dust events occurred on March, April, May and June months. The seasonal evaluation of the dust events presented in Fig 3. Fig. 3 shows that the most dust events were recorded on spring and summer seasons by 54.55 and 20.98 percent, respectively. Furthermore, winter and autumn seasons had the fewest dust events by 17.48 and 6.99 percent frequency, respectively.

Table 1: Frequency of days having dust events and their means at various months from 2000 to 2013

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Mean
2000	2	1	6	8	5	4	1	0	3	0	2	0	32	2.66
2001	0	0	0	1	0	0	0	0	0	0	0	0	1	0.083
2002	0	0	0	1	0	0	1	0	0	0	0	0	2	0.16
2003	0	0	4	0	1	0	0	0	0	0	2	0	7	0.58
2004	0	2	0	0	2	0	0	0	0	0	0	0	4	0.33
2005	0	1	1	2	2	1	0	1	0	0	0	0	8	0.66
2006	0	2	1	2	0	0	1	0	0	1	2	0	9	0.75
2007	1	0	1	1	0	0	0	0	0	0	0	0	3	0.25
2008	0	3	9	4	8	7	6	1	1	0	0	0	29	3.25
2009	0	4	4	6	4	1	5	1	2	0	1	0	28	2.33
2010	0	2	2	5	7	6	7	1	1	0	0	1	32	2.66
2011	0	0	4	11	3	8	1	4	0	3	0	0	34	2.83
2012	1	3	10	5	11	5	4	0	0	0	0	0	39	3.25
2013	0	1	4	6	10	11	3	8	1	3	0	1	48	4
Sum	4	19	46	52	53	43	29	16	8	7	7	2		
Mean	0.28	1.35	3.28	3.71	3.78	3.07	2.07	1.14	0.57	0.5	0.5	0.14		

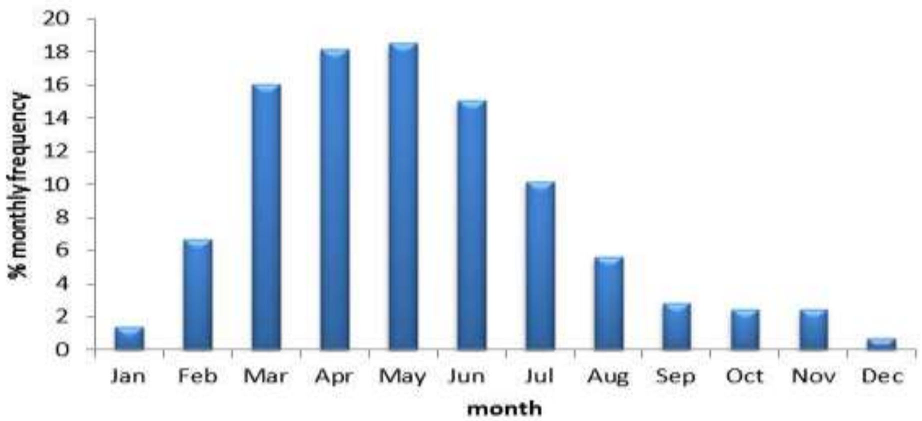

Figure 2: Monthly frequency of days having dust events from 2000 to 2013

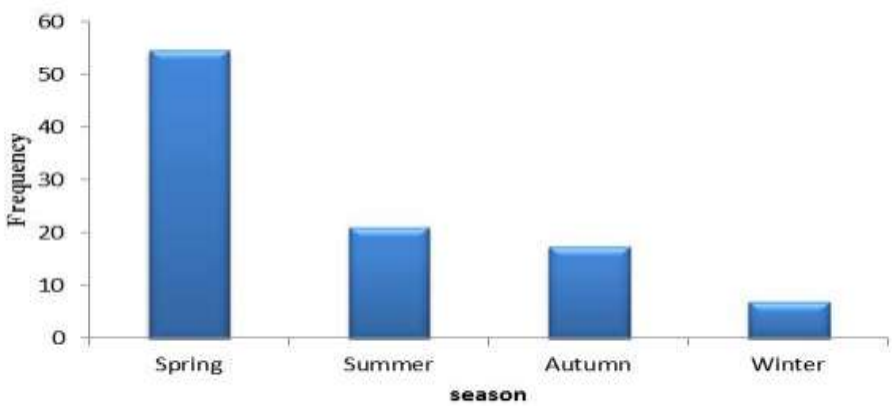

Figure 3: Seasonal distribution of dust in Ardestan synoptic station during a 14-year period (2000-2013)

3.2. Drought and its Relation to Dust Events

Fig. 4 illustrates the results of change in drought using the SPI index over the studied period. As the figure shows, changes do not follow a regular trend, and drought varies in different years by changes in precipitation intensity. In addition, the results represent that 2013 was the driest and 2002 was the rainiest year over the studied period.

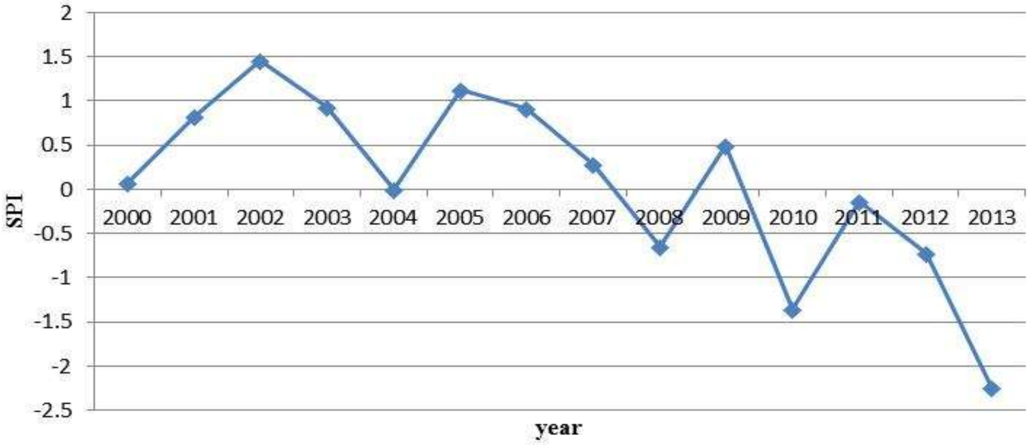

Figure 4: Changes in the SPI drought index over the study period

Table 2 shows the results of changes in dust events and the SPI drought index. The results show that in the studied period, years with drought status in the station had increasing dust events, and in years with higher precipitation, there was a decreasing trend in dust events. Furthermore, the results indicated that 2013 was the driest year in the studied station in which the most dust events occurred.

Table 2: Changes in dust events and the SPI drought index from 2000 to 2013

In dust events	SPI Index	Precipitation	Year
32	0.08	137.8	2000
1	0.83	172.8	2001
2	1.46	205.6	2002
7	0.93	177.6	2003
4	0	134.7	2004
8	1.13	187.8	2005
9	0.91	176.7	2006
3	0.29	147.2	2007
39	-0.65	108.8	2008
28	-0.49	115	2009
32	-1.36	85	2010
34	-0.13	129.2	2011
39	-0.72	106.4	2012
48	-2.25	60.5	2013

Table 3 shows the Z statistics for day frequency with dust storms from 2000 to 2013 for Ardestan station. The results of the Mann-Kendall test for storm rose show that of total 13 monthly and annual data series of days with dust event, annual data series had a positive significant trend at 1% probability level. The highest Z statistic for annual data is +3.07. A data series, including October had an increasing trend, but it is not significant at 1 and 5% probability level, and the remaining data series had no detectable trend. Mann-Kendall Z statistic amounts in January and December data series could not present correct results, so that according to the test, these months have an incremental trend, which is irrational. Therefore, the San-Estimator test was applied to analyze the data series. In Table

3, Q is the trend line slope, M1 and M2 are 95 percent of upper and lower limits of the confidence interval at 95 percent level, and M1 and M2 are 99 percent. Being positive or negative slope of the trend line indicates an decreasing or increasing trend, and their significance is determined via upper and lower limits of the confidence interval at 95 and 99 percent levels. According to Table 3, of total 13 monthly and annual data series having days with dust storms, August data series had an increasing trend at 1 percent level, and April and June data series had a decreasing trend at 5 percent confidence level.

March, May and July data series had an increasing trend, which was not significant at the interested confidence level, and the remaining data series had no trend. January and December had irrational results due to repetition of zero (0) in the Mann-Kendall test, and had no trend in the San-Estimator test.

Table 3: Results of the Mann-Kendall and San-Estimator Z statistic amounts for frequency of days having dust storm (2000-2013)

Sen,s Estimator						Data series
99%			95%	Q	Z	
M2	M1	M2	M1			
0	0	0	0	0	0.15	Jan
-0.115	0.5	0	0.333	0.125	0.142	Feb
-0.204	0.919	0	0.667	0.33^{+}	0.179	Mar
0	1	0.134	0.806	0.5^{*}	2.38	Apr
0.176	1.235	0	1	0.5^{+}	1.89	May
0	1.166	0	1	0.5^{*}	2.52	Jun
0	0.804	0	0.592	0.25^{+}	1.82	Jul
0	0.5	0	0.342	0.125^{**}	2.61	Aug
0	0.125	0	0.088	0	0.58	Sep
0	0.173	0	0	0	1.17^{+}	Oct
-0.181	0	-0.059	0	0	1.26	Nov
0	0	0	0	0	1.73	Dec
0.504	5	1	4.8	3.5	3.07^{**}	Yearly

3.3. Results of Storm Rose

To analyze storm rose, Fryberger velocity classes were utilized, and according to these classes, the erosive wind status in the area was evaluated. Fig. 4 shows the seasonal and annual storm rose graphs in Ardestan synoptic station. As Fig. 4 shows, the dominant wind direct is southward. Approximately 70.8 percent of dominant winds in the area are calm, and about 0.2 percent have more than 16.5 m/s (33 not) velocity. Based on the results of annual storm rose, it was determined that frequency of winds less than the threshold velocity of wind erosion was equal to 70.8 percent, indicating that storm and dust producing winds comprise approximately 30 percent of winds in the area. The highest wind blowing was associated with the spring season by 0.4 percent and the lowest one was related to the autumn season.

Table 4: Distribution percent of wind velocity classes annually based on various seasons in the year in Aredestan synoptic station

>=16.5	13.5-16.5	10.5-13.5	8-10.5	6-8	% Calm wind	Speed Classes
0.2	0.7	1.7	11.2	15.4	70.8	Yearly (2000-2013)
0.4	0.9	2.3	13.6	19.2	63.6	Spring
0.1	0.8	2.2	17.7	20.8	58.4	Summer
0	0.1	0.4	5.8	10.8	82.9	Autumn
0.2	0.8	1.9	7.6	10.5	78.9	Winter

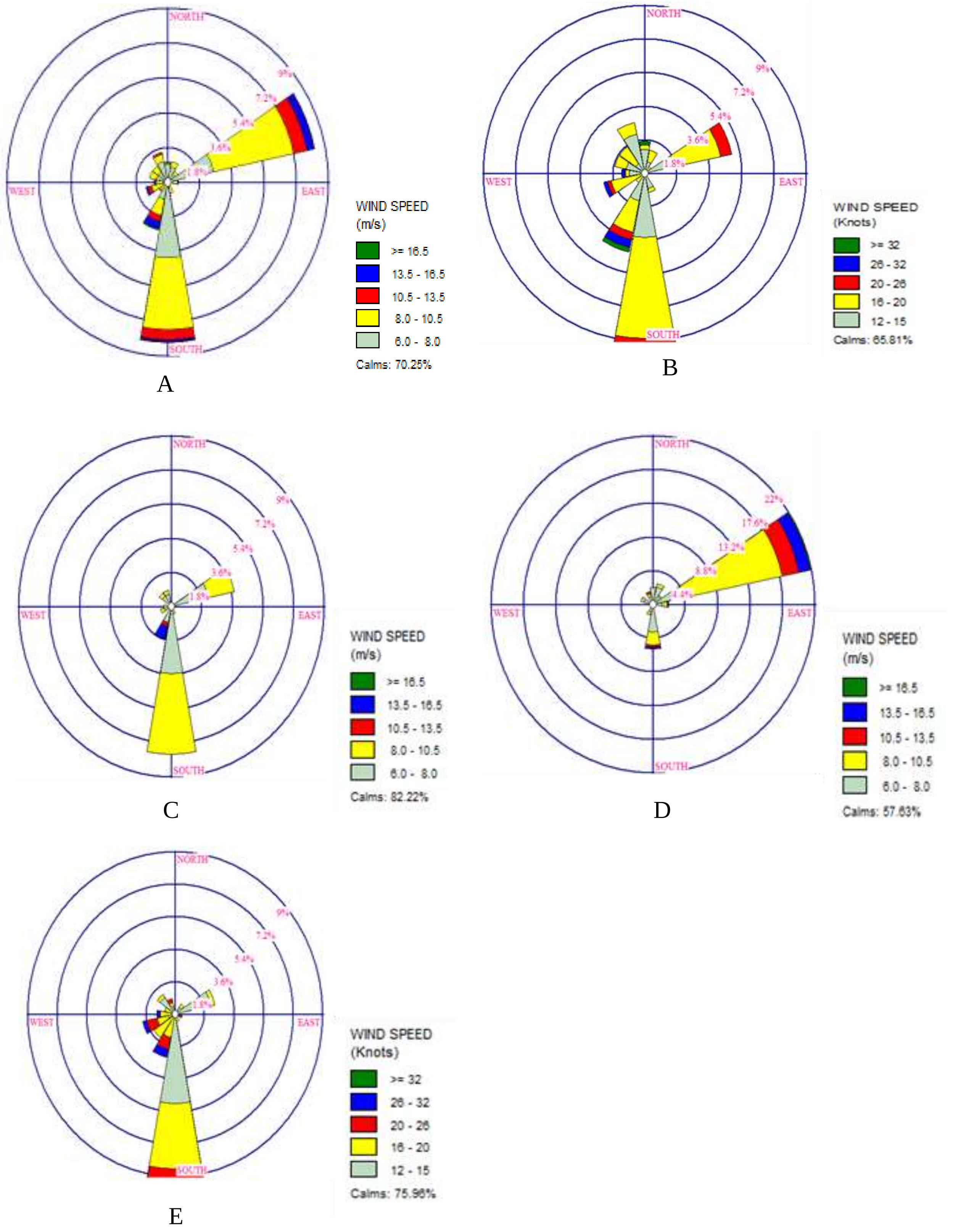

Figure 5: A to E represent annual, spring, summer, autumn and winter storm rose, respectively

4. Discussion and Conclusion

changes in drought did not follow a regular trend and changed according to changes in

The results of studying the SPI drought index for a 14-year period (2000-2013) indicated that severe droughts occurred in 2013 in which the most dust events were recorded. The results of the present study are in consistent with those obtained by Herweijer et al. (2013) and Li et al. (2011) who showed that an increase in drought intensity would increase dust events.

The time analysis of storm roses occurring in the studied area using non-parametric statistical procedures showed that in the Mann-Kendall method, of total 13 data series, a series, including annual data series and in the San-Estimator method, August data series had a positive significant trend at 1% confidence level. Furthermore, in the San-Estimator method, April and June data series had an increasing trend at 5% confidence level. Strom rose resulted from a 14-year period in Ardestan (2000-2013) expressed winds southward, which were the most important winds in formation of dust storms. Totally, wind rose presents an individual analysis of soil properties and represents only windy status and direction of occurred winds in the area or station proximity. While, storm rose binds wind properties into erodibility of lands around the station due to involvement of wind threshold velocity, thereby facilitating identification of storm conditions and direction of erosive winds. The purpose and the main assumption of this research were to analyze the frequency of erosion winds and estimate the final direction of the flow of sand in Ardestan city, using time series data, as well as the direction and wind speed recorded at synoptic stations. With the assumption that wind analysis more than the speed of erosion and the use of the flood more suitable method for storm and round phenomena and dust is toward the windrose at the county level, the function of the pattern is this direction with respect to the stretch The formation of wind erosion is often from the west to east.

precipitation intensity, which could be due to this fact that the index depends on precipitation. During the studied period, 2013 and 2002 were the driest and rainiest years, respectively. The results are consistent with those obtained by Rezaei et al. (2006) and Sakehvand (2013), indicating that drought intensity varies in a spatial and temporal manner. In addition, the results showed that 2013 had 48 days with dust and 2001 had 1 day with dust, which had the most and fewest days with dust event in the station, respectively. Furthermore, the statistical results represent that during the studied 14-year period (2000-2013), totally 286 days along with dust event were reported. Investigations showed that May and December had most and fewest dust events compared to other months, being in consistent with findings achieved by Bohayrayi et al. (2011), and inconsistent with those obtained by Zolfaghari and Abedzahe (2005) in which June had the most dust events, but similar to Zolfaghari and Abedzadeh (2005), December had the fewest dust events. Furthermore, based on the results, the spring season had the most dust events in the studied station, being in agreement with those obtained by Hamidi et al. (2013), indicating the spring season as the one having the most dust events. Totally, with the beginning of the spring season and warm period and then the summer, frequency of days with dust event increases, which could be due to increasing time of daily sunlight radiation, surface warming and presence of some local instabilities. In addition, local instabilities reach the maximum level in the spring, while frequency of dust events minimizes in the winter owing to settling high-pressure systems and their constancy in the area. The results demonstrated that drought was related to dust events, and an increase in drought intensity in the station increased dust events, so that most

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