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Qualitative Analysis of Changing Procedure between Meteorological Parameters and Dust Occurrence in Kermanshah, Iran

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Background & Aims of the Study: Due to widespread dust-storms in the western regions of Iran and the significant role of meteorological parameters in formation and control of these storms, this study aimed to explore the correlation between meteorological parameters and dust-storm occurrences in the western part of Iran.

Materials & Methods: In this cross-sectional study, meteorological parameters of temperature, relative humidity, precipitation, prevailing wind velocity and direction were selected and their relationships with visibility below 1000 m as well the number of recorded dusty days in meteorological stations in monthly and annually scales were analyzed, using multivariate linear regression in Kermanshah province, Iran.

Results: Sarpol-e Zahab, Ravansar, Kermanshah and Eslamabad-e Gharb stations were characterized by 148, 111, 107 and 60 days with visibility below 1000 m, respectively. In the last decade, the highest and the lowest number of dusty days for all stations have occurred in spring and autumn with a total of 1548 and 216 days, respectively. Also, in all stations, the lowest precipitation (4.5 mm) was observed in summer.

Conclusions: According to the results, non-concurrence of season with stormy days (spring), with season with the lowest precipitation (summer), indicated most dust storms are from non-local sources among all stations. Due to large scale dust-storms and their non-local sources, providing a comprehensive long-term plan for identifying this phenomenon among all affected regions seems to be essential..

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Background

Climate Change and its numerous consequences, e.g., frequent drought conditions have led to a steady increase in frequency and intensity of dust and sand storms in various parts of the World. Increasing the severity of such storms is expected to continue over the coming years. Dust-and sand storms, which present environmental and health risks (such as desertification, respiratory diseases and others) and can influence the regional climate, have worsened also in the Middle East region over the last decade (1). Sand and dust storms (SDS) play an integral role in the Earth system but they also present a range of hazards to the environmental and economic sustainability of human society. These hazards are of considerable importance for residents of dry land environments and also affect people beyond drylands because wind erosion can occur in most environments and desert dust events often involve long-range transport over great distances (>1000 km)(2).

Dust is a mass of solid fine dust particles and sometimes smoke particles diffused in the atmosphere which limits horizontal visibility (3). According to the World Meteorological Organization (WMO), whenever in a station wind speed exceeds 15 m/s in and horizontal view reaches below 1000 m, a dust storm is reported. The sandstorms are winds that can move particles with a diameter of 0.15 to 0.20 mm up to a height of 15 m above ground surface. While, dust storms comprised very fine particles with a diameter of 0.05 to 0.1 mm move at much higher heights above ground surface and travel long distances in such a way that can cover and affect cities of a country or even countries of a continent (4). Currently, the incidence of dust storms has been increased regionally and globally. Several effects have been attributed to this natural disaster, which negatively or positively influence ecosystems. Studies carried out have divided the effects of these storms into two general groups, namely environmental and human effects (5). Among the environmental impacts are hardening of rocks, degradation of coral reefs, disruption in radiation energy, intensification of eastern waves, and absorption of nutrients by plants. Air pollution, animal insanity, asthma, business closure, machinery problems, and contamination of drinking water are among the most important effects of dust storms (6,7).

Dust mobilization at high latitudes is robustly affected by wind speeds, which are often quite strong in the presence of katabatic winds, sediment supply or dust availability, snow cover, freezing processes and vegetation(8). The combination of these factors is regularly led to create a strong seasonality in dust emission or dust storm frequency at high latitudes (9).

Dust storms occur when the total annual precipitation is significantly lower than long-term mean annual precipitation. With increasing the temperature in late winter and early spring, the temperature of air adjacent to soil surface increases, causing the turbulence and wind blowing in lower layers of atmosphere. If the wind velocity exceeds the erosion threshold, considerable quantities of soil particles are separated from bed and enter into the atmosphere as dust (10). The occurrence of dust storms is closely related to local climatic conditions such as rainfall, temperature, and also ground surface features such as vegetation, snow cover and soil texture. Researchers believe that in some regions, such as East Asia, there is a significant correlation between occurrence of dust storms and wind speed near ground surface. While in some researches, due to local origin of dust storms, there is no significant correlation between wind speed and frequency of occurrence of dust storms (11). Some researchers state that regional climate change plays an important role in dust storms. These researchers have shown that high air temperatures, low rainfall, poor vegetation cover and high wind speed provide favorable conditions for formation of dust storms (12). In another study, it was shown that the number of days with a dust storm was less than the number of wind days in Mongolia (China), which reveals that the incidence and severity of these storms, in addition to being affected by climatic conditions, such as wind speed, is affected by surface characteristics, e.g., vegetation cover, soil moisture content, and so on (13). The researchers have studied the effects of dust storms and land surface characteristics using NOAA satellite (Normalized Differences Vegetation Index) (NDVI), National Oceanic and Atmospheric Administration, along with meteorological station data (14), and a considerable relationship was diagnosed between dust storms and other atmospheric parameters such as rainfall and temperature, so that ground cover characteristics (vegetation, snowfall and soil texture) was found to be effective in the occurrence of dust storm events. It was also found that precipitation in form of hail directly affects such events. In another study, the correlation between parameters such as relative humidity, temperature, wind speed and precipitation, with the occurrence of dust storms in Zahedan province was investigated, and it was observed that among the parameters studied, wind speed and relative humidity showed the highest and the lowest significant correlations (4). In studying the relationship between climatic parameters and occurrence of dust storms in Khuzestan province, Mehrabi et al. (1394) showed that in some stations, season with the highest number of days with storm (spring), did not co-occur with season with the lowest rainfall (summer) and attributed it to the difference between the climatic characteristics of deposition area and source region (15). Kermanshah et al. (2016) evaluated the effect of Middle East meteorological parameters on dust storm activities in western Iran using satellite and ground data and concluded that the rainfall parameter was negatively correlated with dust pollution index, while wind speed was strongly and positively correlated with this index in selected stations (16). Kermanshah province is frequently exposed to intense dust storms due to being close to the vast desert areas of neighboring countries such as Iraq, Syria, northern Saudi Arabia and Northern Saharan in Africa which creates critical biological conditions in this province.

Aims of the study:

Considering the negative and destructive effects of dust phenomena as well as lack of sufficient studies in Kermanshah province, the present study was aimed at investigate the trend in meteorological parameters and the occurrence of dust storms in this province.

Materials & Methods

Geographical location of the study area

The study was cross-sectional. This research was carried out in Kermanshah province and in Kermanshah, Sarpol-e Zahab, Kangavar, Ravansar, and Eslamabad-e Gharb Counties. Meteorological data of five synoptic stations were collected aiming to determining the correlation between climatic parameters of temperature, relative humidity, rainfall, wind speed and direction, as well as visibility, because of having the highest role in creating dust storms, over a 10-years period (years 2005 to 2015). The characteristics of the studied stations are presented in Table (1). The stations were selected in such ways that cover the entire province.

Table 1) Geographical characteristics of the studied stations

Station	Latitude	Longitude	Elevation above sea level (m)
Kermanshah	34° 23′	47° 00 ′	1318
Eslam abad	34° 6′	46° 31′	1335
Kangavar	34° 30′	47° 57′	1500
Sarpol	34° 28′	45° 51′	550
Ravansar	34° 43′	46° 40′	1336

Analysis of climatic data

Because highly susceptible conditions for raising dust particles are dry soils (decreased precipitation and subsequently decreased humidity and increased temperature), and wind speeds higher than threshold, we evaluated the annual and seasonal trends as well as the relationship between number of days with dust storms and five parameters of temperature, relative humidity, rainfall, wind velocity and direction.

After collecting the meteorological data of synoptic stations of the province from Meteorological Organization, the relationship between climatic parameters and the occurrence of dust storms in the province during a 10-years period (2005 to 2015) was studied using SPSS V.21 software and the correlation between meteorological factors and dust storms was investigated using multivariate regression.

To do this, an average of values for 2, 3 and 5 days before and after the dust storm occurrence was separately calculated and analyzed for each climatic parameter. Ultimately, final models were presented for calculating visibility using multivariate linear regression methods.

Results

Number of days with dust storms in the studied stations:

Figure (1) showed the number of days with dust storms for in Kermanshah, Sarpol-e Zahab, Kangavar, Ravansar, and Eslamabad-e Gharb stations during a 10-year period (from 2005 to 2015).

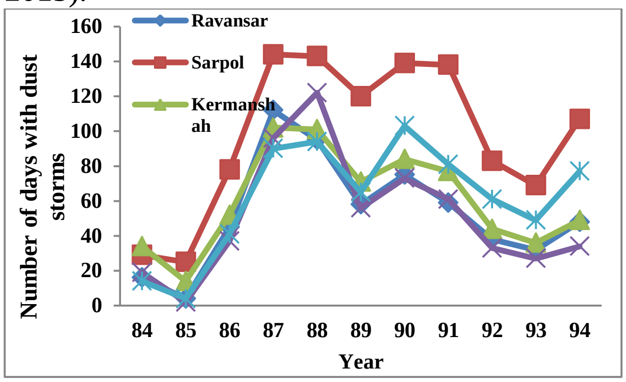

Figure 1) Number of days with dust storms in a 10-years period (from 2005 to 2015)

In all stations, the number of days with the dust storm followed a decreasing trend in the years 2005 and 2006, so that the lowest number of days with dust storm occurred in the year 2006. In 2007, this trend was increasing in all studied stations, so that the highest number of stormy days was recorded in the province in the years 2008 and 2009. In the year 2010, the trend was decreasing, and a gradual increasing trend in storms was observed in the years 2011 and 2012. In the years 2013 and 2014, the trend was decreasing, while a gradual increasing trend was found in 2015.

Mean annual relative humidity, temperature and rainfall:

Figure 2 (a, b, c, d and e) represents the mean annual of five climatic parameters of rainfall, temperature, relative humidity, prevailing wind velocity, and direction for five stations in Sarpol-e Zahab, Kermanshah, Eslamabad-e Gharb, , Ravansar and Kangavar in a 10-years period (2005-2015). As can be seen, the temperature parameter follows the same trend in all stations. Relative humidity during the last ten years at all stations tends to follow a particular trend with very low fluctuations, contrary to the extreme fluctuations observed in the number of days with dust storm.

In terms of precipitation, it can be said that this parameter is of relatively higher fluctuations compared to the two previous parameters.

According to the statistics, the mean prevailing wind direction for the Sarpol-e Zahab, Kermanshah, Eslamabad-e Gharb, Ravansar and Kangavar stations was 182, 205, 220, 127 and 241 degrees, respectively, with the mean prevailing wind direction between 180 and 270 degrees.

On average, the maximum wind speed were 14.8, 12.8, 13.6, 13.6, and 16 m/s for Sarpol-e Zahab, Kermanshah, Eslamabad-e Gharb, Ravansar and Kangavar Counties, respectively

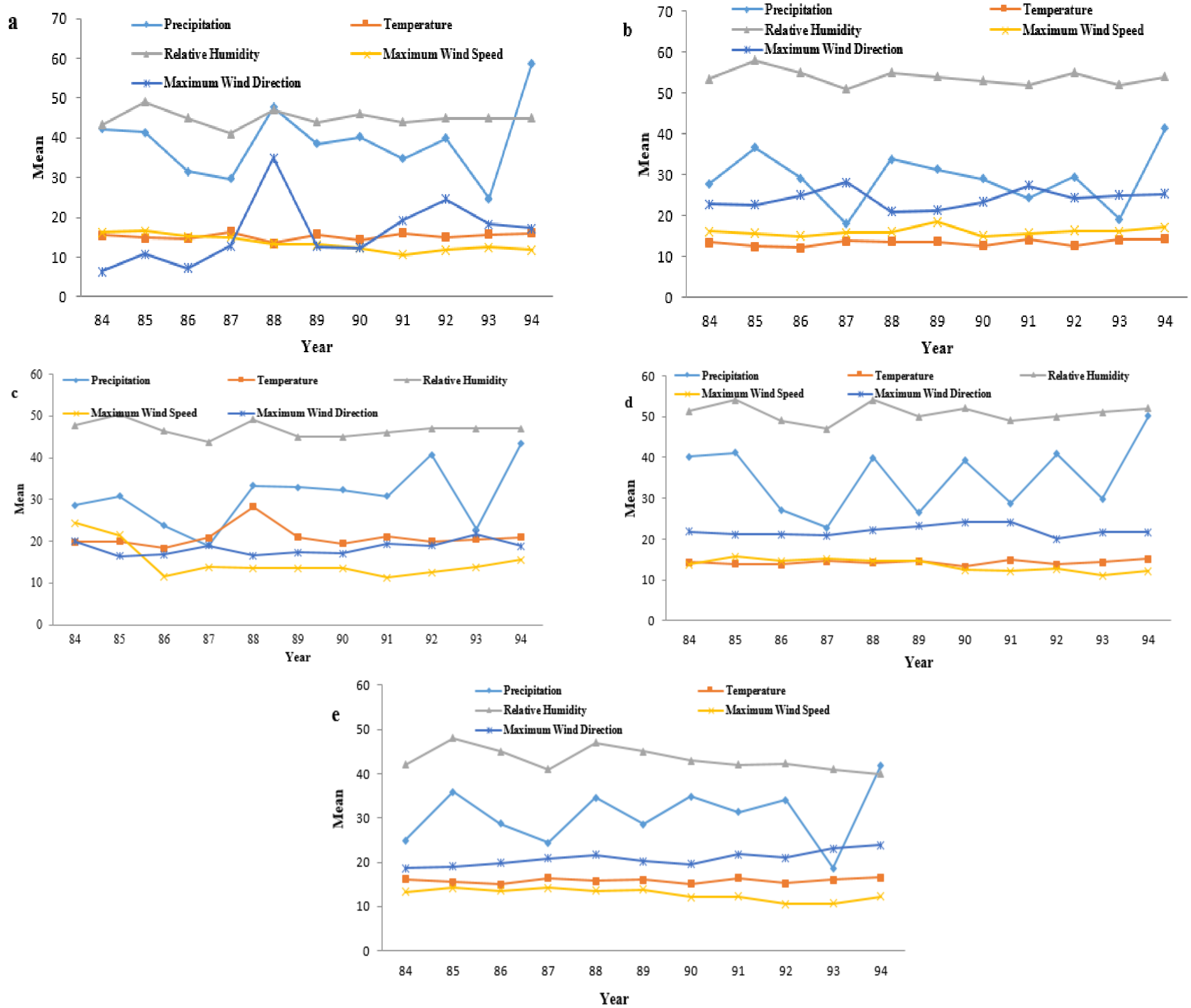

Figure 2) mean annual rainfall, temperature, relative humidity, prevailing wind speed and direction in five stations; a) Sarpol-e Zahab; b) Kermanshah; c) Eslamabad-e Gharb; d) Ravansar; e) Kangavar.

Table 2) Seasonal means of climatic parameters in the studied stations

Station	Meteorological	spring	summer	fall	winter
Sarpol-e Zahab	Temperature (ºC)	23	32	17	10
	Relative humidity (%)	44	26	52	63
	Cumulative rainfall (mm)	842	10	1574	1632
	Wind speed (m/s)	15	13	14	17
	Wind direction	17	22	17	16
Kermanshah	Temperature (ºC)	17	27	15	5
	(%) Relative humidity	43	19	49	60
	Cumulative rainfall (mm)	1014	35	1495	1505
	Wind speed (m/s)	14	11	11	13
	Wind direction	23	22	20	16
Eslamabad-e	Temperature (ºC)	16	26	10	3
	(%) Relative humidity	50	29	55	66

Gharb	Cumulative rainfall (mm)	953	54	1682	1906
	Wind speed (m/s)	14	13	13	13
	Wind direction	23	26	18	18
Ravansar	Temperature (ºC)	16	27	12	4
	(%) Relative humidity	44	21	50	63
	Cumulative rainfall (mm)	1206	24	1848	2069
	Wind speed (m/s)	13	13	13	14
	Wind direction	16	12	13	10
Kangavar	Temperature (ºC)	15	25	9	2
	(%) Relative humidity	53	36	58	66
	Cumulative rainfall (mm)	1042	25	1526	1247
	Wind speed (m/s)	17	15	14	16
	Wind direction	24	27	23	21

Number of days with dust storms (per season):

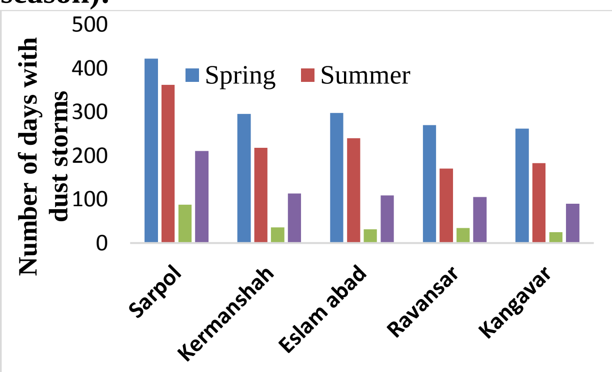

Figure 3) Number of days with dust storms in different seasons of the year in a 10-years period (from 2005 to 2015)

As seen, in all studied stations, the highest frequency of dust storms is related to spring season, which co-occur with air dryness, decreased soil moisture and higher rising of particles and higher wind speeds. Generally, in the last decade, the highest and the lowest number of days associated with dust storms for all stations was related to spring and fall seasons, respectively.

Mean seasonal temperature, relative humidity, rainfall, prevailing wind speed and direction

Table 2 shows the seasonal means of climatic parameters of relative humidity, temperature, rainfall, prevailing wind speed and direction for Kermanshah, Sarpol-e Zahab, Kangavar, Ravansar, and Eslamabad-e Gharb stations during a 10-year period (from 2005 to 2015).

As can be seen in table 2, in all stations, the highest relative humidity was observed in winter. Also, in all stations, the lowest rainfall was related to summer season. in all stations, the highest number of days associated with dust storms was observed in spring season. The seasonal mean of prevailing wind speed in Sarpul-e-Zahab, Kermanshah, Eslamabad-e Gharb, Ravansar and Kangavar stations was 14.9, 12.7, 13.5, 13.5, and 16.1 m/s, respectively.

Table 3) Number of days with visibility below 1000 m in the studied stations

Station	Number of days with visibility below 1000 m
Kangavar	195
Sarpol-e Zahab	148
Ravansar	111
Kermanshah	107
Eslamabad-e Gharb	60

According to table (3), among the stations under study, the Kangavar station, with 195 days, had the highest number of days with visibility below 1000 m.

There were 148, 111, 107, and 60 days with visibility below 1000 m in Sarpul-e-Zahab, Kermanshah, Eslamabad-e Gharb, and Ravansar stations, respectively.

Investigating the relationship between visibility and meteorological parameters using multivariate linear regression

In order to prepare the best model for each station, the relationship between the visibility below 1000 m and other daily parameters including mean temperature, relative humidity, rainfall and wind speed at each station were investigated during a 10-years period of 2005 to 2015. Then for each of the above parameters, a mean value of 2, 3, 5 days before and after the occurrence of dust storms was separately recorded. The data of visibility below 1000 m parameter in days with dust storms was used as the dependent variable and the mean of 2.3 and 5 days before and after occurrence of dust storms was selected as an independent variable to select the best model. Different combinations of these parameters were investigated to be entered into the regression model using stepwise method. Based on the multivariate linear regression method (Backward), all models would be analyzed and then the model with the smallest value compared to the t statistic will be excluded. This trend will continue until the highest values remain compared to the t statistic.

Table 4) Correlation between meteorological parameters with visibility below 1000 m in studied stations

Station	The correlation type between meteorological parameters with visibility below 1000 m in each station
Sarpol-e Zahab	There is a inverse correlation between the parameters of average temperature 3 days after the storm, average rainfall 2 days before the storm, average temperature of 5 days before the storm and average relative humidity 3 days before the storm with visibility below 1000 m in this station, as the parameter of average rainfall 2 days before the storm showed the highest reverse correlation with visibility below 1000 m. the final model of this station is: $V=5.3_{t3a}-13.32_{p2b}-6.64_{t5b}-5.81_{r3b}+934$
Kermanshah	There is a positive correlation between the parameter of average rainfall 3 days after the storm, with visibility below 1000 m in Kermanshah station and the final model of this station is: $V=19.88_{p3a}+373$
Kangavar	The inverse correlation was observed between the parameters of temperature 5 days before the storm and the relative humidity 3 days after the storm with visibility below 1000 m in Kangavar station and the final model of this station is: $V=2.47_{r3a}-7.39_{t5b}+471$
Ravansar	There was a positive correlation between parameters of rainfall 5 days before the storm, temperature of 3 days after the storm, the relative humidity of 5 days the storm and temperature of 3 days before the storm with visibility below 1000 m in Ravansar station, so that the highest positive correlation was related to the rainfall parameter 5 days before the storm and followed by the parameter of temperature 3 days before the storm visibility below 1000 m. The parameter of relative humidity 2 days after the dust storm also was negatively correlated with visibility below 1000 m. Final model of this station is: $V=17.64_{p5b}-2.86_{r2a}+9.59+3.67_{r5a}+11.82_{t3b}+164$
Eslamabad-e Gharb	The parameter of visibility below 1000 m was positively correlated with wind speed 5 days after the storm, wind speed 3 days after the storm , wind speed 5 days before the storm, wind speed 2 days before the storm , precipitation 3 days after the storm , rainfall 2 days before the storm , relative humidity 3 days after the storm, relative humidity 2 days after the storm, relative humidity 5 days before the storm , relative humidity 2 days before the storm , temperature 5 days after the storm, temperature 2 days after the storm , temperature 5 days before the storm and temperature 2 days before the storm. the parameters of wind speed 2 days after the storm, the wind speed 3 days before the storm, precipitation 5 days after the storm, precipitation 2 days after the storm, precipitation 5 days before the storm, precipitation 3 days before the storm, relative humidity 3 days after the storm, relative humidity 3 days before the storm, temperature 3 days after the storm, and temperature 3 days before the storm had a

positive correlation with visibility below 1000 m. The parameters of wind speed 5 days after the storm, rainfall 3 days after the storm and temperature 2 days before the storm had the highest negative correlation and the parameters of wind speed 2 days after the storm, rainfall 5 days after the storm, rainfall 2 days after the storm, and temperature 3 days before the storm had the highest positive correlation with visibility below 1000. Final model for Eslamabad-e Gharb station is:

$$V=-49_{s5a}-4_{s3a}+129_{s2a}-7_{s5b}-6_{s2b}+25_{p5a}-17_{p3a}+20_{p2a}+1_{p5b}+7_{p3b}-2_{p2b}-3_{r5a}+3_{r3a}-3r2a-2_{r5b}+4_{r3b}-9r2b-2_{t5a}+5_{t3a}-4_{t2a}-1t5b+18_{t3b}-15_{t2b}-15_{t2b}+890$$

Discussion

In the period from 2003 to 2010, the dust storm occurrence trend was increasing with a decreasing trend in precipitation. Among the stations studied in the province, kangavar County had experienced he lowest number of days with dust storm due to being far distant from the dust source, and while in the stations of Sarpol-e Zahab, Eslamabad-e Gharb and Kermanshah showed the highest number of days with dust storms because of proximity to the deserts of Iraq and Arabic countries. The results of Shamshiri et al. (2014) also authenticate the observed results (18). According to the results of Shahsouni et al. (2012), Kermanshah province has experienced The most intense dust storms in viewpoint of concentration (with an average of 2634 micrograms/m^2) among the province under the effect of dust storm during the years 2008-2010, so that the mean concentration of total maximum suspended particles in Kermanshah province during the years 2008-2010 reached 2301 micrograms/m^2 (17).

In fact, severe fluctuations in the number of days with dust storm show no significant effect on the temperature and relative humidity during 10-years period. Due to the fact that during the occurrence of these storms, the relative humidity decreases by 20 to 40%, the significant decreased relative humidity in the years with the highest frequency of dust storms can be due to the non-local source of most dust storms. In most of the stations, the lowest rainfall is due to the year when the number of stormy days was significant. Therefore, one can say that the highest number of days with dust storms in Kermanshah province has co-occurred with years of the lowest rainfall during the decade. In this regard, the results of this study are confirms the findings Abdovis et al. (2011) and Mehrabi et al. (2015), who showed that the years with the highest number of days with dust storms were correlated to the years with the lowest rainfall amount (15,19). In 2008, when a severe dust storm occurred, the mean prevailing wind direction in the province was 203 degrees, indicating Iraq and Saudi Arabia countries as the dust storm source. On average, the maximum wind speed was 14.8, 12.8, 13.6, 13.6, and 16 m/s for Sarpol-e Zahab, Kermanshah, Eslamabad-e Gharb, Ravansar and Kangavar Counties, respectively, and all of these averages were at the storm threshold. in 2008, mean wind speeds in Sarpul-e-Zahab, Kermanshah, Eslamabad-e Gharb, Ravansar, and Kangavar stations were 13.75, 14.25, 15.16, 15.08, 15.91 m/s, respectively, which most of the stations were at higher than the threshold of the storm beginning.

The seasonal total number of days with dust storms in Sarpul-e-Zahab, Kermanshah, Eslamabad-e Gharb, Ravansar and Kangavar Counties. Similar results have been obtained in other studies. Nastagdori et al. (2002) by studying and analyzing dust storms from 1937 to 1997 in Mongolia, concluded that 61% of the storms occurred in the spring season (20). Chia et al. (2004) showed that spring season had the highest value of dust pollution index (21). Zolfaghari and Abedzadeh (2005) reported the highest frequency of dust occurrence in the late

spring and early summer (22). Kermanshah et al. (2016) also reported May, June and July as the months with the highest values of dust (16).
In all stations, the highest relative humidity was observed in winter, indicating non-co-occurrence of the season with the highest relative humidity with the season with the highest number of days of dust storms in the province. This conclusion was consistent to results of Mehrabi et al., (2015) (15) which can confirm the non-local source of most of the dust storms.
On the other hand, the highest temperatures in all stations were found in summer. In summer, wet deposition of particles decreases due to decreased rainfall, so the particles, are easily and individually removed from the soil and the probability of storm formation increases. However, in all studied stations, the highest number of days associated with dust storms was related to the spring season. This non-co-occurrence also indicates the non-local source of most storms in this province, confirming the results of Mehrabi et al. (2015) (15). In the summer, increasing the temperature is related to decrease in mean rainfall. A potent positive relationship between temperature and dust index indicates higher possibility of dust occurrence of in this season. While in all stations, the highest number of days associated with dust storms was observed in spring season. Therefore, it can be said that in all stations, most dust storms are identified by non-local source. In case of Sarpul-e-Zahab, Eslamabad-e Gharb and Ravansar stations, it is noteworthy that the prevailing wind speed was observed in the winter season and the highest frequency of days with dust storms occurred in spring season. Farajzadeh et al. (2011) revealed that, in most stations, there is no significant relationship between mean wind speed and the frequency of storms occurrence; so that stations with high frequency of dust storms do not necessarily have a high mean wind speed (23). Indeed, this can describe the non-local source of dust storms in these counties. While in Kermanshah and Kangavar stations, the highest wind speed was related to spring season and the highest frequency of days with dust storms was also observed in spring, and this co-occurrence partially indicates the local source of dust storms in the two counties. Moreover, Kermanshah et al. (2016) reported a direct link between wind speed parameter and dust pollution index (16).
Among the stations under study, the highest number of days (195 days) with visibility below 1000 m was observed in Kangavar station, while this station was at a greater distance than the source of dust. It can be due to the existence of numerous brick-burning furnaces in this county, in fact, most of the dust in this station is of local source. The results of studying of the climatic data showed that there were 148, 111, 107, and 60 days with visibility below 1000 m in Sarpul-e-Zahab, Kermanshah, Eslamabad-e Gharb, and Ravansar stations, respectively. Sarpul-e-Zahab, Kermanshah and Ravansar counties showed the highest number of days with dust storm due to their close proximity to the deserts of Iraq and the Arabic countries.

Conclusion

By determination of the effective parameters, e.g., rainfall, humidity, temperature and wind speed, the determination of visibility, an indicator of storm intensity, is possible. On the other hand, because of the correlation between the above parameters and the frequency of dust storms, the higher number of parameters closely correlated with visibility in a meteorological station indicates a closer dust storm source. Lower number of parameters with significant correlation shows that source region is far distant from deposition area.

Footnotes

Acknowledgments:
This study was extracted from the PhD thesis Neda Sekhavati from Faculty of Natural Resources, University of Tehran, Iran.

Conflict of Interest:

The authors declared no conflict of interest.

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