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Investigation of Spatio-temporal Changes of Dust Storms and its Relation to Climatic Factors in Khuzestan Province, Iran

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ABSTRACT

Dust is one of the major crises in the Middle East. In recent years, the frequency and intensity of this crisis in the region has increased and this has increased the need to study this phenomenon. In this article, we have studied the temporal and spatial changes of the dust storm phenomenon in Iran, Khuzestan (south-west) in the period 2000 to 2018. For this purpose, ground dust data and horizontal visibility and (Aerosol Optical Depth) data of MODIS satellite have been used. The AOD Optical Visibility Index has been declining from 2003 to 2007 and then increasing again. In general, we can see a gradual but increasing trend in the AOD index in the study area, from an average of 0.35 at the beginning of the period to nearly 0.6 at the end of the period, which indicates the predominance of dust storms in the region. The relationship between dust and climatic parameters was also examined. In terms of external storms, precipitation had a significant (P <0.001) and negative effect. This means that on days when there is less rain, the horizontal visibility index decreases and more dust storms were formed. In terms of domestic storms, only the wind direction had a significant direct effect (P <0.05), which means that some directions had higher dust storm frequencies. Finally, it can be concluded that the trend of domestic and foreign dust storms is increasing. The frequency of their occurrence is also increasing and with the decrease of regional rainfall due to climate change, we should expect more severe storms in the near future. For this reason, it is necessary for the authorities to act as soon as possible in controlling the internal dust centers, and to provide the ground for controlling the regional centers through regional consultations.

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1. Introduction

With climate change and global warming, water resources in the middle latitudes have become more limited, leading to increased land vulnerability to wind erosion. Desertification in mid-latitudes, which is mainly caused by improper land management, has led to vegetation degradation and hence dust storm initiation. Water tension in the middles east, particularly with the introduction of dams on international rivers, has intensified land degradation and dust storm problems for the neighboring countries (Rashki & Middleton, 2021; Broomandi *et al*., 2017; Jafari *et al*., 2019; Tajiki *et al*., 2022; Sorkheh *et al*., 2022; Asgari *et al*., 2023; Deiravipour *et al*., 2022). One of the countries that has been affected by this phenomenon and has suffered more in recent years is Iran. Production of dust in neighboring countries such as Iraq, Kuwait, Syria, occupied Palestine, northern Egypt and Saudi Arabia and their transportation by wind to Iran has sharply decreased air quality in the western and southwestern regions and consequently the central regions of Iran has. In recent years, we have even witnessed the penetration of dust currents to the more inland regions of the country and even the northern regions of the country and the capital, and this shows the need for a closer look at this issue (Rashki & Middleton, 2021; Araghinejad *et al*., 2019). Since dust storms occur in large areas and managing these lands or surveying and monitoring them is very costly and time consuming, scientists and managers are looking for simpler, more accurate, up-to-date and accessible methods. Meanwhile, remote sensing methods, especially using free satellite data, which also have very good spatial and temporal coverage, stand out more than other options. One of the data that has been considered more than other satellites in the last decade has been the use of the MODIS satellite dust index. Modis with its very short time coverage and data interpolation capability has made it possible to have an almost up-to-date assessment of the dust phenomenon (Lee *et al*., 2011; Engel *et al*., 2004).

Many researches have examined the changes in the index AOD of Modis satellite in Khuzestan province and also observed that the changes in this index had a decreasing and then increasing trend and observed the highest amount of dust in the west to southwest (Namdari *et al*., 2016). Various algorithms have examined the use of MODIS satellite AOD index in the Middle East and concluded that combining thermal indices with AOD index can be useful in improving the accuracy of measurements (Jafari & Malekian, 2015). In a similar study, they concluded that algorithms based on the thermal spectrum of MODIS satellite with optimization models provide more accurate measurements than the separate application of the AOD index (Taghavi *et al*., 2017). They observed that the concentration of dust storms in Khuzestan province had an increasing trend and observed the highest amount of this concentration in 2008 and 2009. According to these researchers, the air vapor pressure vacuum in Iraq last month was one of the significant factors on the intensity of the dust storm in Khuzestan province (Javadian & Behrangi, 2019). Investigated the relationship between MODIS satellite AOD and measured PM10 values and observed that there is a high correlation coefficient between these two parameters. They also identified relative humidity as the most important factor influencing dust storms (Rangzan *et al*., 2019). Using machine learning methods and especially neural network method, they predicted PM10 values based on MODIS satellite AOD index and observed that the 476 nm band of this satellite was more successful in estimating 10-micron air particles than other bands (Hojati, 2017). Using the AOD index of Modis satellite, the changes of dust phenomenon in the period 2001 to 2017 in Khuzestan province were examined and values above 1 were considered as the threshold of severe storms. The results showed that this time period can be divided into three sub-periods 2001 to 2007, then 2008 to 2012, and finally 2012 to 2017. The results show a decrease, increase and decrease of dust concentration in Khuzestan province and Kuwait, Syria and Iraq are mentioned as the most important sources of dust production (Danial & Karimi, 2019).

As can be seen, most research acknowledges the accuracy and efficiency of the use of satellite imagery and products. But an important point that is not considered in most of these researches is the separation of phenomena of internal and external origin that can be better evaluated with the help of satellite data. Another issue that is less considered is the evaluation of the effect of wind parameters including direction and speed on the internal and external phenomenon of dust. In this study, we seek to evaluate the dust phenomenon in time and place, the relationship of this phenomenon with climatic parameters and the orientation of dust storms in Khuzestan province of Iran, which is a very suitable area for this research. The results of this study will be very useful in implementing future hurricane management projects, creating green belts and evaluating the effects.

2. Material and methods

2.1. Study Area

In this study, Khuzestan province in the southwest of the Iran with an area of 63,355 square kilometers between 30 degrees to 31.5 degrees north and 48 to 50.5 west was studied. This province is surrounded in the north by the high mountains of Chaharmahal and Bakhtiari province, in the west by the Arvand River and Karun rivers, in the south by the Persian Gulf and in the west by the mountainous areas of Kohgiluyeh and Boyer-Ahmad (Figure 1). The average rainfall in this province is 210 mm and the average annual temperature is 22 degrees. Most of the province is covered with Quaternary sediments and sometimes saline and rich in salts, which if the river dries up and reservoirs are good sources for dust production (MalAmiri *et al*., 2022).

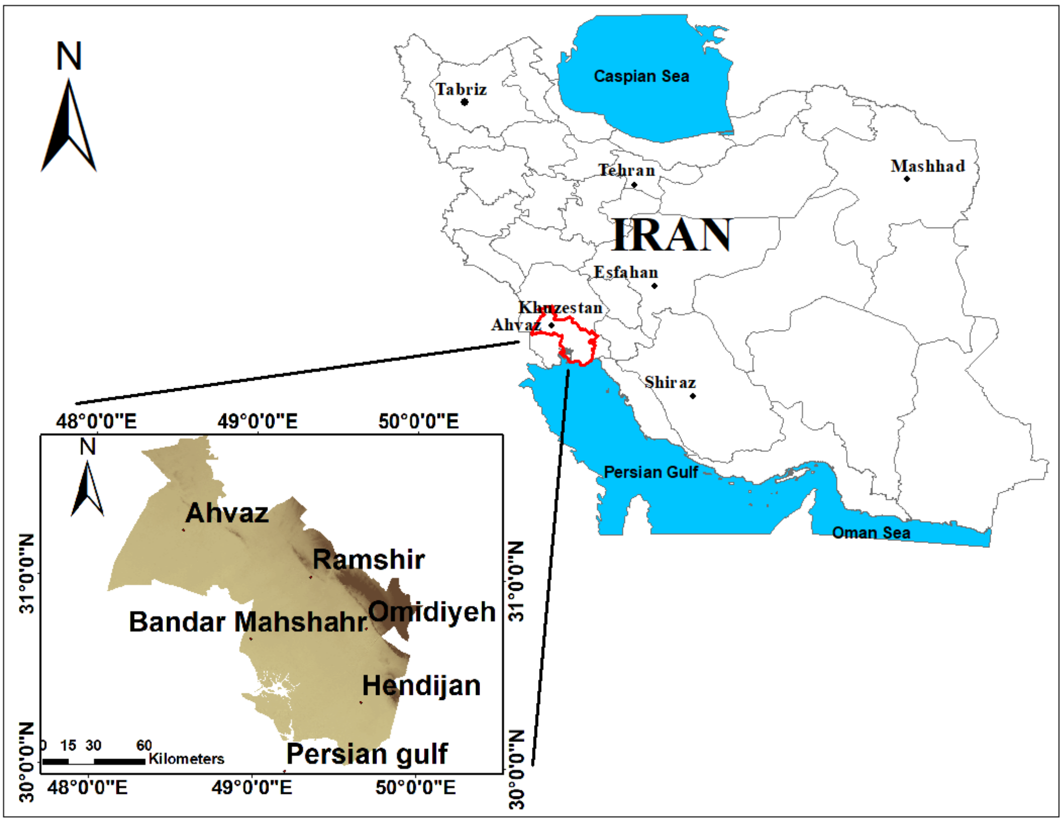

Fig. 1. The location of the study area in Khuzestan Province and Iran.

2.2. Data sources and analysis

In this research, dust code 6 and 7 data received from the Meteorological Organization were used to separate internal and external dust storm phenomena. In internal dust events, the values of horizontal visibility dust indices, AOD, climate indices and wind indices have been extracted. Climatic data have been extracted from distributed synoptic weather stations in the province (Figure 1). Storm intensity is determined based on horizontal visibility index and AOD. Horizontal visibility index means the maximum distance that the viewer can see and observe the object placed on the horizontal surface on which it is placed. This index decreases and increases with the decrease and increase of the amount of dust in the atmosphere and the amount of pollution, and it is possible to determine the occurrence of a storm and its intensity by classifying it (Eshghizadeh, 2021). In this research, three very extreme classes (horizontal visibility 0-50 meters), extreme (50-200) and moderate (200-1000) are used for two classes with external and internal sediment sources.

2.3. AOD index

Modis satellite has 36 discrete spectral bands with a wavelength range between 14.5-0.41 micrometers and covers a space of 1200 km by 1200 km with a spatial accuracy of 1 km. These features are well realized in MAIAC* algorithm. The algorithm that allowed this satellite to accurately retrieve the AOD index on land and sea. The AOD index or Aerosol Optical Depth is an index that monitors the thickness of the dust layer on land and sea (Araghinejad *et al*. 2022b). In this index, the size of particles on the sea and the type of particles on land can also be determined. To determine this index in Modis satellite, the Deep-Blue algorithm is used, which has recently been used to determine the optical thickness on the bright areas of the land. In recent MODIS satellite products, it has been possible to recover the amount of dust in the sea and on land, especially in desert lands, plains and dry areas, with high accuracy. In this paper, we have used the MCD 19A2 AOD daily index, which can be downloaded at https://ladsweb.modaps.eosdis.nasa.gov/search (Li *et al*., 2021). The AOD data used in this research covers the period of 2000-2018. Modis Terra satellite data with code MCD19A2_GRANULE were used in Google Earth Engine environment to determine AOD. Monthly data was also obtained by converting daily time series (average daily AOD index) to get the accuracy of monthly values as close as possible. The used values were also extracted by cutting the images for the study area. The code used to derive the data and the results will be made available upon a written request to the corresponding author.

2.4. Climatic indicators

Since dust storms (internal and external) are dependent on changes in meteorological and soil parameters, the effect of these parameters on dust storms has been determined separately. For this purpose, evaporation data (from the evaporation pan), wind direction, air pressure, soil temperature, precipitation, wind speed and daily air temperature have been used. Investigating the effect of these factors on dust storms has also been done by using Pearson's regression method and SPSS software environment. To determine the direction of dust storms, the distribution of AOD index in different wind directions has been investigated. North-East (0-90), East-South (90-180), South-West (180-270), and West-North (270-360) directions were classified and the average AOD index was obtained in each class. The distribution percentage of this index in different directions and in two groups of storms of internal and external origin indicates the prevailing direction of the storm and possible sources of dust. The impact of

* Multi-Angle Implementation of Atmospheric Correction (MAIAC)

different factors on dust storm was evaluated using the one-way ANOVA test.

3. Results

3.1. The general trend of changes in the AOD index

The values obtained for the AOD index of the Modis satellite in the study areas in the period 2000 to 2018 are shown in Figure 2. As the results show, the AOD optical range index has a decreasing trend in the period 2003 to 2007 and then shows an increasing trend again. In general, we can see a gradual but increasing trend in the AOD index in the study area, from an average of 0.35 at the beginning of the period to nearly 0.6 at the end of the period, which indicates the predominance of dust storms in the region.

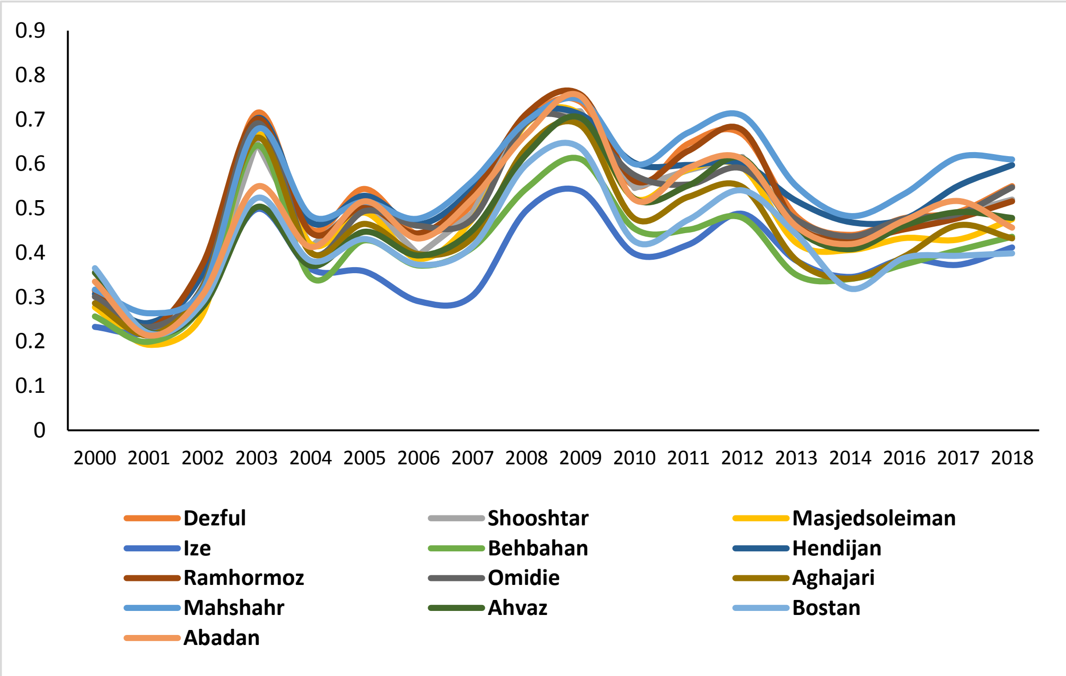

Fig. 2. Values obtained for the AOD index of Modis satellite in study areas in the period 2000 to 2018

3.2. Monthly changes of AOD index

The monthly changes of AOD index in selected stations of Khuzestan province are shown in Figure 3. The results show that the relevant index in all stations has an increasing and then decreasing trend throughout the year. As this index has increased from January to July, it has reached its peak and has a decreasing trend until January. The results show that July and Ramhormoz station have the most unfavorable conditions among all stations in the province. Then Dezful, Masjed Soleiman and Abadan had the worst conditions and Izeh station, which is closer to the heights of Chaharmahal and Bakhtiari province, had the lowest index among all stations.

3.3. Frequency distribution of dust storms in the stations of the province

Frequency distribution of dust storms in selected stations of Khuzestan province in three classes very severe (horizontal visibility 0-50 m), severe (50-200) and moderate (200-1000) for two classes with external sediment sources (Table 1) (Rajaei *et al*., 2022). And internal sediment (Table 2) is presented. According to the results obtained for foreign sources, Abadan, Ahvaz, Mahshahr, Shooshtar and Masjedsoleiman stations have received the most impact. According to the results presented for dust storms with internal sources, the most damage was received by Omidieh, Ahvaz, Abadan and Hindijan stations and no stations were in the very severe storm class.

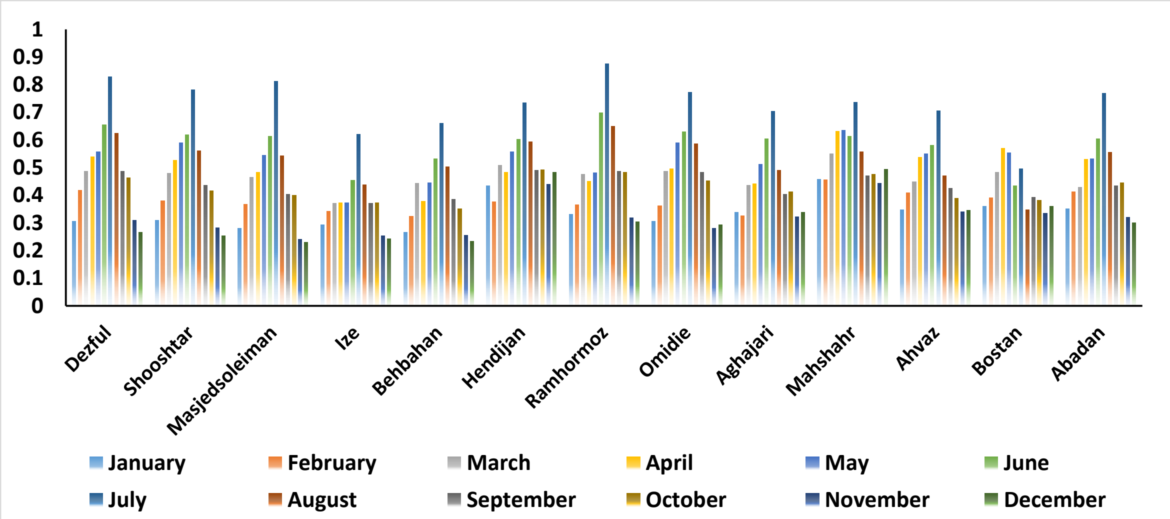

Fig. 3. Monthly changes of AOD index in selected stations of Khuzestan province

Table 1. Frequency of horizontal vision classes in different stations of Khuzestan province for code 6 (numbers provided in parenthesis are relative frequency values)

Station name	0-50	50-200	200-1000
Abadan	(1/1) 2	(2/5) 9	(7/93) 163
Aghajari	0		(100) 4
Ahwaz	(9/2) 5	(9/2) 4	(2/94) 162
Mahshahr		(6/1) 2	(4/98) 126
Behbahan	(9/1) 1	(9/1) 1	(2/96) 51
Bostan	(9/0) 1	(9/0) 1	(2/98) 106
Dehdez	(25) 2		(75) 6
Dezful		(8/4) 5	(2/95) 99
Hendijan		(3/5) 1	(7/94) 18
Ize	(5/4) 2	(8/6) 3	(7/88) 39
MasjedSuleiman	(1/3) 4	(8/0) 1	(1/96) 123
Omidiyeh (Aghajari)		(4/3) 1	(6/96) 56
Omidieh (air base)		(8/1) 2	(2/98) 112
Ramhormoz			(100) 30
Shushtar	(6/0) 1	(2/1) 2	(2/98) 163

Table 2. Frequency of horizontal vision classes in different stations of Khuzestan province for code 7

Station name	0-50	50-200	200-1000
Abadan		(1) 2	(99) 20
Ahwaz		(7) 3	(93) 28
Mahshahr			(100) 15
Behbahan		(50) 1	(50) 2
Bostan			(100) 16
Dezful			(100) 9
Hendijan		(8.3) 2	(91.7) 22
Ize			(100) 2
MasjedSuleiman			(100) 3
Omidieh (air base)		(1.1) 1	(98.9) 86
Ramhormoz			(100) 3
Shushtar		(14.3) 1	(85.7) 6

3.4. Influence of climatic parameters on dust storm

The results of correlation evaluation of AOD index and climatic parameters are presented in Table 3 (ANOVA test). In terms of external source storms, precipitation had a significant (P <0.001) and negative effect on dust storms. This means that on days when there is less rain, the horizontal visibility index decreases and more dust storms are formed. In terms of domestic storms, only the wind direction had a significant direct effect (P <0.05) on the horizontal visibility index and dust storm, which means that some aspects of the storm had more dust. Other parameters did not have a significant effect on dust storm. Interestingly, in both storms, none of the parameters had a significant relationship with the AOD with the internal and external source. The main reason for this is the mismatch of measurement hours on satellites and synoptic stations.

Table 3. Correlation between soil and climatic parameters with dust storm phenomenon in Khuzestan province

Source	Air temperature	Wind speed	Precipitation	Soil temperature	Atmospheric pressure	Wind direction	Evaporation	Parameter
Code 6	0/21	0/17	**-0.55	0/15	0/31	0/21	0/22	visibility
Code 7	-/46	0/09	0/07	0/06	0/18	*0/48	0/26	visibility

** Significant at 99% level * Significant at 95% level

Figure 4 shows the distribution of storm intensity in different wind directions in Khuzestan province. Accordingly, the south-west and west-north directions had the highest intensity of the dust storm. Major local storms with west to north and south to west directions and major storms with external sources had west to north directions (mainly northwest).

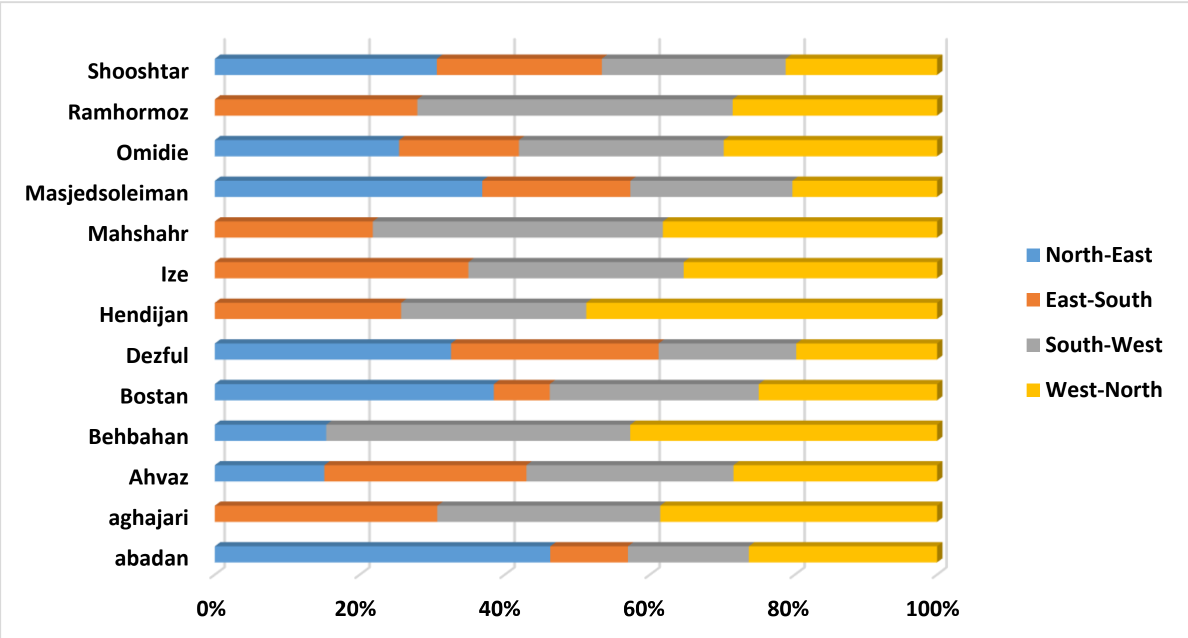

Fig. 4. Distribution of dust storm intensity in different wind directions in Khuzestan province

Fig 5 shows the distribution of the AOD parameter, the average wind speed and horizontal visibility in internal and external storms, but the logarithm of this factor is used to better represent the visibility parameter. The results show that the visibility interval in both internal and external storms is more or less the same. But in terms of average wind speed, storms of domestic origin had higher wind speeds than foreign storms. On the other hand, both storms are almost the same in terms of average AOD index.

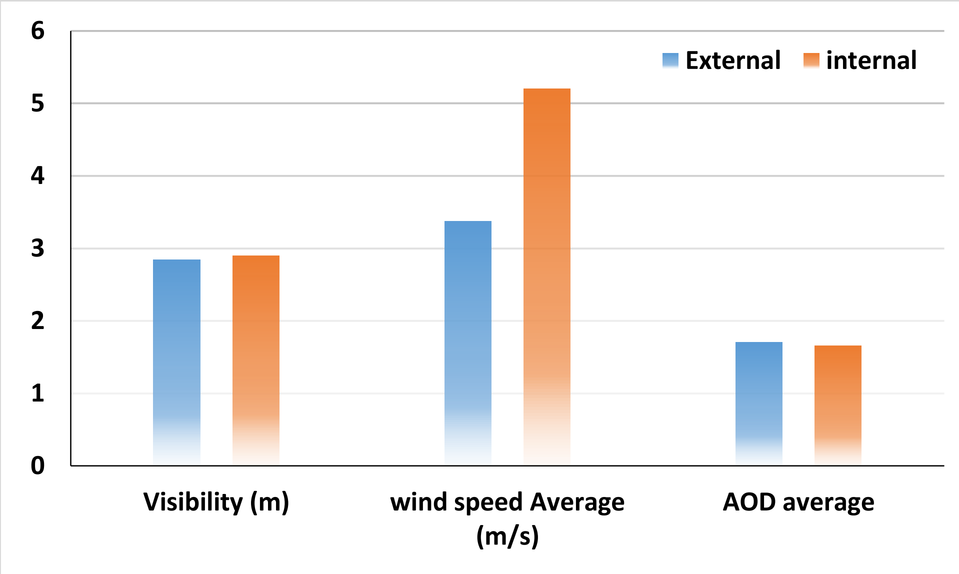

Fig. 5. Distribution of AOD parameter, average wind speed and horizontal visibility (logarithm) in indoor and external storms

4. Discussion and Conclusion

In this article, we have studied the temporal and spatial changes of the dust phenomenon in Khuzestan province in the period 2000 to 2018. For this purpose, ground view horizontal data and AOD satellite data of Modis satellite have been used. The trend of long-term changes in the data showed that the changes in dust in the region are more frequent and intense, so that the AOD index with a growth of 0.25 units from 0.35 at the beginning of the period to 0.6 at the end of the period. The same results have been observed by (Dadashi & Ahmadi 2020; Mohammadpour & Rashki 2022; Crosbie *et al*., 2014).

Between January and August, there is an increasing trend (half of the year) and from August to January (the other half of the year) there is a decreasing trend. The worst dust conditions occur in the summer months, including July and August, when the region is in its driest and hottest condition. Dust index to the south and west shows an increasing trend and moving to mountainous areas reduces the amount of dust storm. The main reason for this is the barrier role of mountainous areas against dust and the favorableness of more southern areas both in terms of local dust source and the absence of barriers to the entry of dust of foreign origin (Washington *et al*., 2003; Middleton 1991; Zhang *et al*., 2008).

The horizontal visibility index class for hurricanes of internal and external origin shows that the frequency of extreme storms is higher in external hurricanes and internal dust storms are less in terms of both intensity and extent. However, changes in recent years show that due to severe droughts, local dust sources have become more active and play a more prominent role in dust production (Rangzan *et al*., 2014; Geravandi *et al*., 2018; Soleimani *et al*., 2020).

Since dust is logically related to climatic parameters, the correlation between dust storms and a range of these parameters is evaluate. In external storms, rainfall had a significant effect. The main reason for this is the prominent role of precipitation in the adhesion of soil particles and preventing the formation of dust hotspots in a way that by reducing 24-hour rainfall, the frequency of dust has increased (Liu *et al*., 2004; Dar *et al*., 2022). Since the rainfall conditions in Iran and neighboring countries in the Middle East and North Africa are more or less the same, we assumed that the lack of 24-hour rainfall in Iran occurred simultaneously with neighboring countries and regional drought had a significant impact on the occurrence of dust storms. In terms of internal storms, we observed that the west to north and south to west directions were more frequent in terms of hurricanes. In general, no significant correlation was observed with AOD. The main reason for this, according to the authors, is that the time of measurement of climatic parameters in synoptic stations does not correspond to the time of measurement of dust index in the satellite, and mainly when the storm subsides or intensifies, satellite measurements coincide with terrestrial data. Have not been consistent with the results (Liu *et al*., 2009; Hummrich *et al*., 2005).

Another interesting point is that the visibility interval was not different in both internal and external storms, but the average wind speed in internal storms was higher than external storms. This means that dust particles carried in domestic storms are coarser and foreign transported particles are finer and have more destructive effects (Sissakian *et al*., 2013). Because the results showed that in severe internal storms, very severe storms did not occur, which means that the particles carried by the wind settled quickly and the storm did not reach the critical stage (Hoffman *et al*., 2008).

Finally, it can be concluded that the trend of domestic and foreign dust storms is increasing. The frequency of their occurrence is also increasing and with the decrease of regional rainfall due to climate change, we should expect more severe storms in the near future. These dust storms will not only have severe environmental effects, but also severe economic and health effects on the border community of the country and the western provinces. Similar results have been reported by Shi *et al*., (2007) and Lababpour (2020). For this reason, it is necessary for the authorities to act as soon as possible in controlling the internal dust crisis centers, and provide situation for controlling the regional centers through regional consultations. Managing natural areas, providing wetlands, regional consultations on crisis centers, preventing soil degradation and creating new centers for dust production are the most important crisis management strategies in the region.

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