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Effects of Climate Change on Dust Storm Occurrence in Kermanshah Province, Iran

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ABSTRACT

Aims: The climate change consequences are more severe in semi-arid regions in drought, desertification, and dust occurrence. This study aimed to investigate the effects of climatic changes on dust occurrence and sand mobility in Kermanshah Province, Iran.

Materials & Methods: The meteorological stations from 1992 to 2017 were selected within Kermanshah Province. The trend of climate change was analyzed by using the Mann-Kendall model. Furthermore, the dust storm index (DSI) method was used to study the frequency and severity of the dust phenomenon.

Findings: The results explored that the highest precipitation occurs in March and November in this province. DSI index was found higher value in Islamabad, Kermanshah, and Kangavar than that other station, mainly in the west of the province, occurring in 2008, and the lowest values were in 2010 and 2013. The mean wind speed was 4.6 ms^{-1}, while the highest winds with more than six ms^{-1} speed and dominant west and southwest directions have occurred in the western part of the province. Consequently, the annual dust rose was western. Furthermore, the highest amount of dust with 175 days occurred in Saprobe Zahab (west of the province), mostly related to the spring and summer seasons. Lancaster index explored that the sand mobility potential was prevalent in the southwestern (along to Iraq border)

Conclusion: The dust incidence is affected by climate change. Thus, maintaining vegetation and controlling land-use change is a fundamental management approach to adapting to climate change in this region.

Keywords: *Dust storm, Drought, Wind Speed, Lancaster Index, Sand Movement.*

CITATION LINKS

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Introduction

Climate change is the most fundamental human challenge which its consequences are more severe in the semi-arid regions in the form of drought, desertification, and dust occurrence. These impacts negatively affect soil, atmosphere, plants, and animals [1]. Constant winds and imperceptible movement of soil particles at the land surface cause land degradation and biological damage. This situation is the main factor affecting wind erosion and dust blown. It is estimated that about 44% of agricultural issues are impacted by wind erosion in the drylands [2]. However, unsustainable human activities constitute a significant challenge to accelerate climate change, particularly in sensitive and fragile ecosystems [3]. Drought, wind erosion, and dust incidence are induced by climate change, while improper anthropogenic factors such as land use/cover change and agricultural activities cause their severity. Wind erosion will cause degradation and reduction of vegetation to less than 16% [4]. There is more vulnerable, where wetland drying (converting to arable lands) and dam construction are significant [5, 6]. Climate change is more concerned due to its severe contribution to declining vegetation cover and soil moisture storage [7].

Akhzari and Haghighi [33], in their study, showed that drought as a natural parameter, overgrazing, dam construction, and high amount of water for crop production are human and policy factors causing dust storms to occur in the west of Iran. This situation is being the main challenge in the desert border ecosystem. A recent investigation revealed that dust days and wind speed had been increased in Iran's desert border and rangelands, which are boosted by heavy livestock grazing and trampling [8]. This trend in the central regions of Iran has led to the activation of sand dunes and their mobility [9]. Investigation of the trend of climate change and its consequences, including dust intensification using non-parametric Mann-Kendall and Sen's slope estimator statistical methods, indicate the intensification of this phenomenon in Iran [10, 11].

The study by Vali and Roustaei [12] indicates the intensification of wind erosion and dust storms index in the last 30 years (1985 to 2014) in Iran compared with last (1965 to 1985). There is more severe in the central and southern parts of Iran. The statistical analysis of 112 meteorological stations (1985-2005) revealed that the trend and the number of dusty days were correlated with evaporation, temperature, and precipitation [13]. This deficit in rainfall in Iran causes soil moisture deficit and subsequently more dust occurrence [14]. Furthermore, there are developed in semi-arid areas of Iran, particularly in the west, southwest, and northwest areas. Labor [34] studied the response of dust emission sources to climate change in current and future simulations for the southwest of Iran. Their results illustrate that the present dust emission sources are mainly driven by a combination of temperature, precipitation, and land-use management.

The results of these studies can help recognize the effect of climate fluctuations on the frequency of dust storms and inhibition of desertification in Iran. Based on a study of Pouyan et al. [15], the spatial distribution and classification of dust storm index (DSI) in 44 synoptic stations of the country using the linear torque method. Dust storm indexes were calculated using hourly dust data for each station. These results could be used in the spatial estimation and analysis of the dust index in many environmental studies, decision-making, and management processes of desertification and response programs.

Therefore, the dust and wind erosion

phenomena are one of the significant consequences of climate change in semi-arid regions which the process analysis can be done using non-parametric methods such as Mann-Kendall and Sen's slope estimator for DSI. These methods have excellent scientific support that could be used in the present study for Kermanshah Province. The purpose of this study was to investigate the trend of changes in climatic factors on the occurrence of dust and mobility of sand fractions in Kermanshah Province, which was done by the analysis of meteorological data in this Province in 2017-2020.

Materials & Methods

Study area

The study area is Kermanshah Province, located west of Iran with 2.5 million ha (about 1.5% of Iran areas). It is lies between 33˚40´ to 35˚10´ N latitudes and 45˚30´ to 48˚20´ E longitudes (Figure 1). This Province comprises plains, hilly and mountainous areas with forests, rangelands, and agricultural lands. The mean annual precipitation and temperature are 480mm and 17.7˚C, respectively. The minimum and maximum altitudes above the sea level are 270 and 3350 m. This Province is located between the plateau of Iran and the Mesopotamian plain. Most parts of this Province are occupied by Zagros mountain chains approximately with the same climatic condition of the Mediterranean region.

The mean precipitation in different parts of the Province varies between 300 to 800 mm, and in general, the mean precipitation in the Province can be considered 450 mm. West parts of Kermanshah Province along to Iraq border are characterized by low altitude (less than 400 m) and more extended dry season and influenced by the deserts of Iraq and Saudi Arabia. Thus, these areas are more vulnerable to desertification and other climate change impacts. Dense and problematic atmospheric dust, as one of the natural hazards of the Province, and the occurrence of absolute maximum

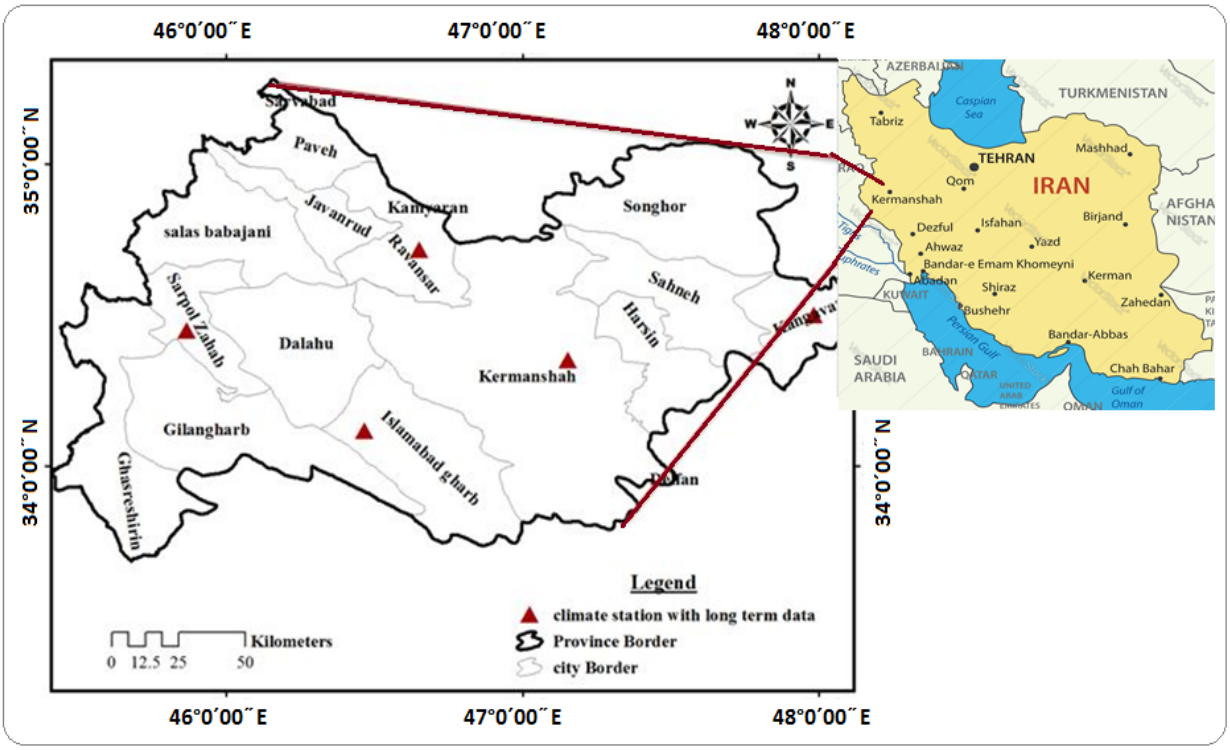

Figure 1) The study area map (the climate stations situation within Kermanshah province).

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temperatures of +50 degrees, are unusual phenomena in western parts such as Qasr-Shirin and Sarpole Zahab. In Kermanshah Province, the year can be divided into hot and cold main seasons. The transitional seasons of autumn and spring are very short and fleeting [16].

Research method

The meteorological stations

Although there are 32 meteorological stations in Kermanshah Province, five meteorological stations (Kermanshah, Kangavar, Ravansar, Islamabad Gharb, and Sarpol-e Zahab) have long-term statistics with suitable distributions during the period 1992 to 2017. These stations were selected for this study (Figure 1).

The changes in climatic variables

The trend in change of climate variables, including temperature, rainfall, evaporation, and wind, were analyzed using Eq. (1). Mann-Kendall [17] and Sen›s slope estimator [17] statistical tests were used to examine the trend of change of the studied variables. The Mann-Kendall test is a non-parametric test to examine the trend of change. In this method, hypothesis H_0 shows the data are independent of the series and have the same distribution. The Mann-Kendall test is calculated based on the following Eq. [16]:

$$s=\sum_{i=1}^{n-1}\sum_{i=1+1}^{n}\operatorname{sgn}(X_j-X_i), where \operatorname{sgn}(x) \qquad \text{Eq. (1)}$$

$$=\begin{cases}+1, x>o\\ 0, x>=o\\ -1, x<o\end{cases}$$

Where x_i and x_j are consecutive data, N is the time series length. The sgn was calculated based on many sequences (t) depending on time series number (N) using Eqs. (2) and (3).

$$\sigma_s^2=\frac{1}{18}\left[N(N-1)(2N+5)-\sum_{i=1}^{m}t_i(t_i-1)(2t+5)\right] \qquad \text{Eq. (2)}$$

The trend line slope (Qt) and constant value (B) were calculated using Eqs. (3) and (4).

$$f(t)=Qt+B \qquad \text{Eq. (3)}$$

$$Q_i=\frac{x_j-x_k}{j-k} \qquad \text{Eq. (4)}$$

Qi is the slope between observational data at times j and k, where j> k. Based on Eq. (5), n numbers of xj in the time series, the estimated slope was calculated using Eq. (6). A slope is obtained for each pair of observational data. Using these slopes, Q_i can be calculated based on Eq. (7). Therefore, the positive trend line indicates that the trend is upward.

$$N = n(n-2/1) \qquad \text{Eq. (5)}$$

$$Q=Q_{\left[\frac{N+2}{2}\right]} \qquad \text{Eq. (6)}$$

$$Q=\frac{1}{2}\left[Q\frac{N}{2}+Q_{\left[\frac{N+2}{2}\right]}\right] \qquad \text{Eq. (7)}$$

Wind regime of the area

In order to investigate the wind characteristics with dust incidence, the wind direction and speed data in synoptic stations were selected for time and date regarding standard dust codes (6, 7, 8, 9, 30, 31, 32, 33, 34, and 35). Next, the monthly, seasonal, and annual winds were analyzed by Wrplot 7 software in 8 directions with 45-degree intervals and nine-speed classes.

Climate change effects on sand particles movement

The particle mobility (M) was calculated based on wind speed (W) higher than the erosion threshold (%), annual precipitation in mm (P), and evapotranspiration (PET), using Eq. (8) as outlined by Chapel et al. [20]. That is considered for the Lancaster Sand Dunes Mobility Index [18].

$$M=W/(P/PET) \qquad \text{Eq. (8)}$$

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Geologists and geomorphologists widely use this Lancaster index to determine active or stabilized sand dunes. The experimental value obtained from the index (M) is:

- < 50: inactive sand dunes and sand surfaces stabilized by vegetation;
- 100: active only in sand dune canopy areas;
- 100-200: sand dunes are active, but their surrounding is stabilized by vegetation; and
- > 200: fully active sand dunes.

This index seems to be a good indicator of climatic variables and geomorphic environments in sand activity.

Dust Storm Index

The Dust Storm Index (DSI) [22] was calculated using Eq. (9) and classified based on the sum of observations of dust codes as categorized in Table 1.

$$DSI= \sum_{i=1}^{n}[(5 \times SD) + MD + (0.05 \times LD \qquad \text{Eq. (9)}$$

where n indicates the number of stations.

Findings

The studied climate stations

The annual mean precipitation, evaporation, temperature, and relative humidity are shown in Table 2. Accordingly, the highest and the lowest mean annual precipitation of these stations are related to Ravansar (492 mm) and Kangavar (376 mm), respectively. In terms of the monthly distribution of precipitation, the highest rainfall occurred in March and November in Kermanshah Province. In general, in most stations, 1993 and 1994 were the rainiest years of the period, and 2007 and 2008 were the least rainy years. Also, the northern parts of the Province have the highest amount of rainfall, followed by the central and eastern regions. The lowest rainfall was recorded in the southwest of the Province and Somar. In terms of evaporation, the highest and the lowest annual evaporation occurred at Sarpole Zahab station with 1466 mm and the lowest at 1158 mm at Kangavar station, respectively. The station survey showed that the rate of evaporation increases from east to west of the Province, and evaporation has the highest amount in October and September.

Evaluation of wind conditions in the area

The result revealed that the mean wind speed was 4.6 m.s^{-1}, the highest in March and April (at Ravansar station at 5.51 m.s^{-1}) and the lowest in December and January at Kangavar station (5.11 m.s^{-1}) (Figure 2).

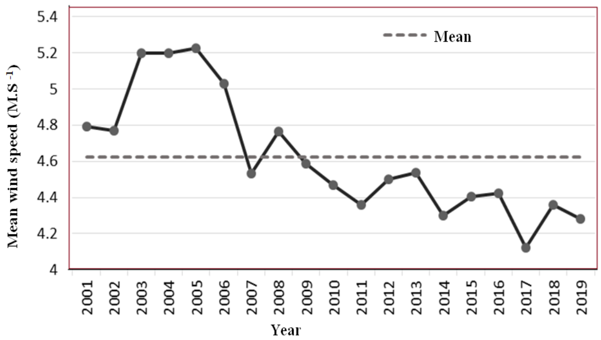

Figure 2) Mean periodic wind speed (2001-2019) in Kermanshah Province.

The erosive wind map (Figure 3a) showed that the highest winds speed of more than six ms^{-1} was occurred in the southwestern (Gilangharb and Somar), prevailing (%19.4) of total winds in these areas. The annual dust rose study showed that except in Gilan-e-Gharb station, most of the stations in the Province were in the direction of the prevailing annual dust rose. Summer dust rising off the Province indicates the formation of erosive winds with high speed from the west of the Province, which can factor in the transfer of dust from neighboring countries to the Province in this season (Figure 3b).

Number of days with dust incidence

Table 3 shows the correlation coefficient for wind and dust variables, including dusty days (local origins) with precipitation, temperature, relative humidity, and wind

Table 1) Different meteorological codes for different types of dust phenomenon [22]

Meteorological code	description
6	Suspended dust
7	Dust
8	Tornado
9	Storm
30	Dust storm with light sand
31	Dust storm with light sand
32	Dust storm with light sand
33	Dust storm with heavy sand
34	Dust storm with heavy sand
35	Dust storm with heavy sand

Table 2) Some statistical characteristics of the studied variables in meteorological stations on a monthly time scale (1991 to 2017).

Station	Precipitation (mm)	Maximum temperature (C°)	Minimum temperature (C°)	Mean temperature (C°)	Maximum relative humidity (%)	Minimum relative humidity (%)	Mean relative humidity (%)	Evaporation (mm)
Islam Abad	28.6	22.4	5.3	14.1	70.7	30.5	50.3	100
Kangavar	22.2	21.7	4.5	13.4	75.8	30.2	51.4	96.5
Kermanshah	23.3	23.6	7	15.5	63.1	24.9	43.2	102.3
Ravansar	31.6	21.8	8.4	15.2	61.4	28.25	44.3	103.2
Carol-e-Zahab	26.3	28.3	12.3	20.4	66.6	27	46.6	122.2

speed. The high impact of the Province on dust along with the neighboring areas with Iraq (west and southeast of the Province). The highest recorded foreign dust was related to the Sarpole Zahab station in the west of the Province, with 175 days of dust occurrence. Among all the studied parameters, the dusty day and the dust phenomenon in Kermanshah station showed the highest correlation with the mean and maximum wind speed. After that, the mean minimum and maximum temperatures showed the highest correlation with dust. Furthermore, the highest number of days with dust incidence was found in spring, while there was lowest in winter (Figure 4a). There was a significant relationship between precipitation and dust frequency for the Islamabad Gharb station.

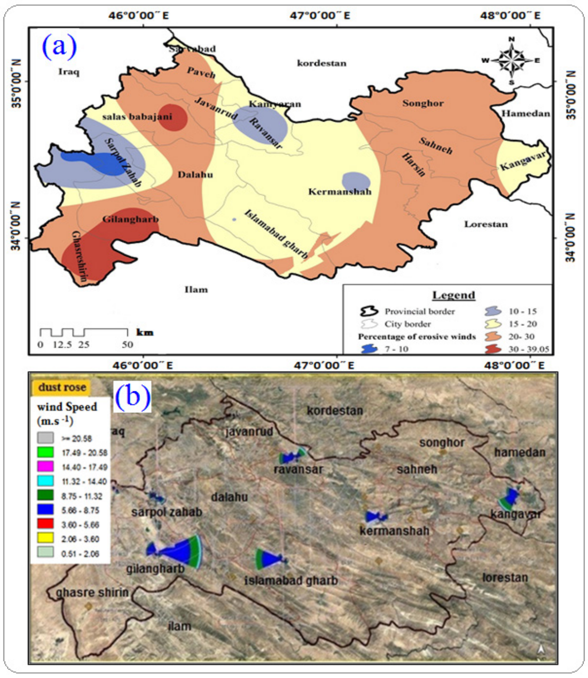

Figure 3) Zoning map of erosive wind (a) and dust rose (B) in Kermanshah Province.

Dust storm index (DSI)

The results of the DSI index in Islamabad, Kermanshah, and Kangavar stations (east of the Province) were higher than the west of the Province. There was the highest value in 2008 and the lowest in 2010 and 2013 (Figure 4 a, b).

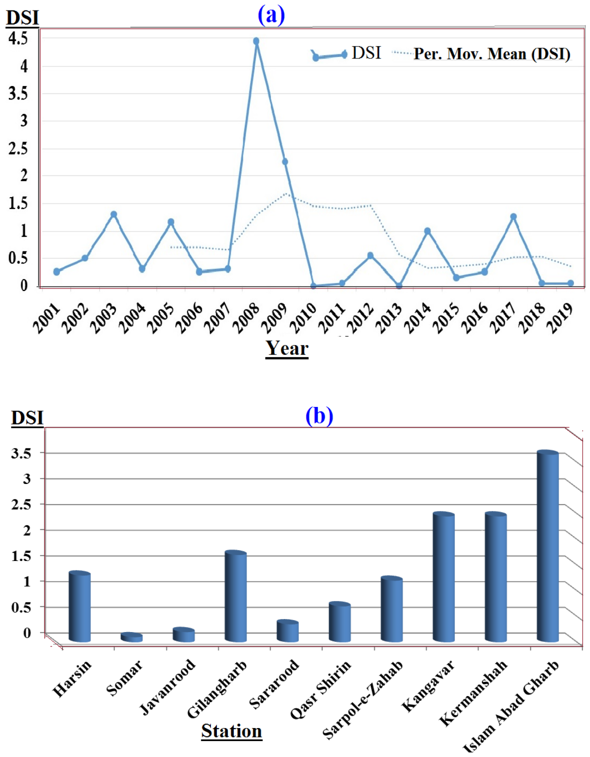

Figure 4) Changes in DSI during the period 2001-2019 (a) and on the climatic stations (b).

Sands particle movement (Lancaster index)

The study of the Lancaster index in the 2001-2017 periods revealed that in the Somar and northern part of Qasr Shirin (western and southwestern parts of the Province), sand fraction movement with active and fully active degrees occurred. This index was found in the low class, reflecting inactive sand movement phenomenon by wind-blown (Figure 6).

Warmer temperatures without a change in precipitation or even an increase in precipitation can potentially increase the mobility of sand particles, depending upon the change in annual and seasonal rainfall, which affects adequate precipitation (EP). The highest precipitation (P) to EP ratio (P/EP) value occurs when significant precipitation is received during the cold months of the year because of a lower level of evaporation. Warmer winters reduce P/PE and extend the time that dunes can move. Therefore, by decreasing the P/PE value, we can expect the dunes to become more active in the future (Figure 5a).

The sand particle mobility index is more sensitive to changes in the simultaneous increase of evaporation and wind than the simultaneous decrease of these two parameters. It means that if evaporation and wind, which are entirely interdependent, increase by 30%, the mobility of the sand will increase by about 86% (Figure 5b).

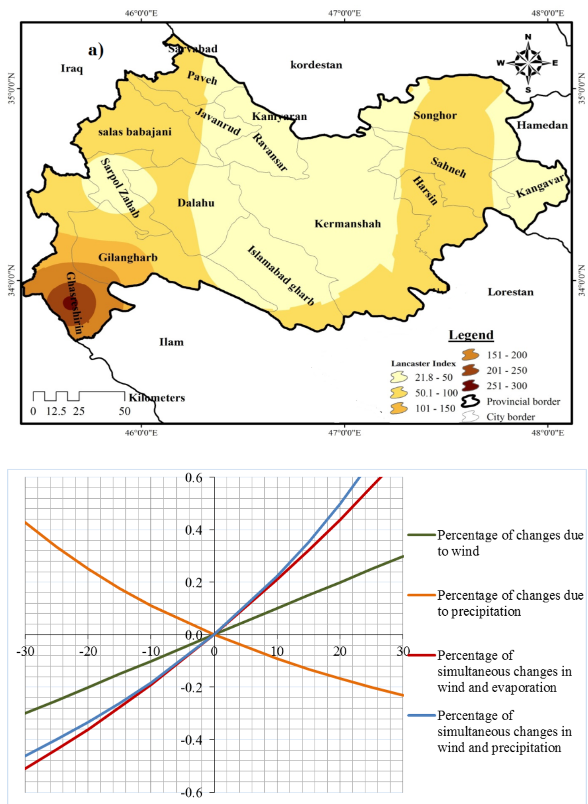

Figure 5) Lancaster index zoning map (2008-2017) in Kermanshah Province (a) and Lancaster index of erosive wind threshold at Sarpol-e-Zahab station (b).

Discussion

The research explored that climate change is a driving factor increasing the dust incidence in Kermanshah Province, Iran. Climate characteristics, mainly temperature, wind speed, and rainfall, have the highest impact on the occurrence of dust. The highest increase in dust occurred in the southwestern areas of the Province, including the cities of Somar and Qasr Shirin. According to the results of most recent studies, climate change based on the characteristics of wind, humidity, evapotranspiration, temperature, and precipitation causes the occurrence and intensification of dust phenomenon and mobility of sand particles. Thus, the dust storm index (DSI) is increased [22]. In Kangavar and Kermanshah stations indicate drought signs based on the deficit in annual precipitation and adversely increasing evaporation indices. Although the wind speed significantly increased in these areas, there was no sand particle movement index. The study of drought trends based on the standardized precipitation-evapotranspiration index indicates climate change in Iran, which has tended to drier periods spreading drought signs in winter [23]. According to various studies, Iran is one of the countries suffering from drought incidence based on the SPI index in most parts of west Iran (including Kermanshah Province. Thus, proper management of natural resources and agriculture should be seriously considered [24]. Moreover, drought trend analysis based on the Mann-Kendall test indicates a decrease in crop yield mainly related to the drought phenomenon [25].

It is mainly due to a reduction in the adequate daily rainfall, which results in increased evaporation and insufficient moisture storage in soil depth for plants uptake. In the Zagros region, the number of days with adequate rainfall has decreased [25, 26]. In some areas, an increase of one degree (°C) temperature causes significant water demands for crops productions and consequently imposes additional costs and exacerbates lung, heart, and mental debases due to pollution hazards of dust fractions [27].

More sensitive areas to dust and sand movements were found in degraded lands, where soil quality and vegetation density were negatively impacted by improper agricultural activities, overgrazing, over-up-taking of groundwater, and land use/cover change. There is more severe in western parts of Kermanshah Province due to severe and more extended periods of higher temperature than in other parts of the Province. Furthermore, this situation increases soil moisture loss and water deficit through evaporation.

Most parts of these areas are winter rangelands and irrigated agricultural lands. Therefore, grazing management and proper irrigation are essential solutions for dust occurrence and sand particle movement. In these areas, grazing management and some rangelands measures such as pitting, farrowing, seeding, and grazing enclosure significantly cause carbon sequestration, soil moisture storage, and enhancement of vegetation cover [28]. Such measures also play an essential role in maintaining the livelihood of farmers [29].

Moreover, due to the decreasing trend of precipitation and increasing temperature in recent years, the necessary programs and measures should be adopted to prevent the increasing expansion of these areas. Increasing public awareness and paying attention to the concerns of the exploiting community is also a great help in this regard. There is a causal relationship between the perception of the symptoms of climate change and people's livelihood changes so that by increasing their awareness of the symptoms of climate change, their livelihood has changed more [29]. Because villagers and nomads are more vulnerable to climate change, especially drought, planning a participatory approach empowers them and adapts to such conditions [30]. In such

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circumstances, it is necessary to reform the management method and adopt correct and optimal policies to preserve water resources and increase water productivity in various environmental, economic and social sectors [31].

In Kermanshah Province, there is no sand dune feature. Furthermore, the Lancaster index explored that the sand mobility potentially is related to increased evaporation and wind-blown that was only prevalent in the neighboring southwestern areas to the Iraq border (mainly Somar) while there was no sand mobility potential in most parts of Kermanshah Province. Lancaster index analysis also showed that rainfall and winds that have blown greater than the erosion threshold contribute to the mobility of sands particles. This situation is related to effective rainfall occurrence that adversely causes the mobility potential of sand particles. Accordingly, the effective rainfall is higher in most parts of the Province (except the Somar areas). Effective rainfall contributes to strengthening vegetation and increasing soil moisture and organic matter.

Conclusion

In general, this study highlighted the effects of climatic changes on the occurrence of dust and sand mobility at the local scale. The result has illustrated that the dust incident and sand movement are affected by climate change. According to this, among all the studied climatic factors, the dusty day and the dust phenomenon in Stations of Kermanshah Province showed the highest correlation with the mean and maximum wind speed. After that, the mean minimum and maximum temperatures and precipitation showed the highest correlation with dust. According to global research, the frequency, intensity, and range of temperature and precipitation events (as the main components of climate change in arid and semi-arid regions) are significant and have caused severe damage to the livelihoods of local communities and empowerment of households. Small-scale exploitation is an essential priority for adapting to climate change and maintaining food security [32]. Therefore, climate change and its consequences in the western regions of Iran and Iraq, particularly in Qasr Shirin, Somar, and Naftshahr, are more severe, and its neglect will cause considerable environmental challenges.

This study showed that dust is not affected by one factor, while the set of temperature, rainfall, drought events, and other parameters and climatic indicators and human factors in the form of lack of proper management leads to destructive dust storms. If we ignore integrated management in controlling dust storms, this phenomenon will become more pervasive and severe as a significant challenge due to the upcoming climate conditions.

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Ethical permissions: The authors of this study approve to send it to ECOPERSIA journal and declare that this study is not under revision in any other scholarly journals at the time of submission to the journal and will not be sent to any other scholarly journal during the revision at the journal until the definite answer about it. The authors choose Dr. Khosro Shahbazi (first author) as the corresponding author and delegate all the responsibility of the article to her regarding following the relation with ECOPERSIA.

Conflict of Interest: The authors declare

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that there is no conflict of interest regarding the publication of this study.

Authors' Contribution: Khosro Shahbazi (First author), Introduction author/Methodologist/ Original researcher/Discussion author (45%); Mosayeb heshmati (Second author), Introduction author/Methodologist/Discussion author (35%); Zahra Saieedifar (Third author), Introduction/ data analysis and writing Methodologist (20%).

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