Integration of Satellite Observation and Dust Trajectory Modeling for Dust Transport and Dispersion Monitoring

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Abstract

Land use/cover change was distinguished as one of the most local environmental consequences and has an important role in increasing dust due to land degradation. The aim of study was to identify the local dust storm sources in Khuzestan province (southwestern Iran) due to land use/cover change and their dispersion and transport modeling from these sources by Lagrangian particle HYSPLIT model. In the first part of study, Landsat images for 1984, 1992, 2002, and 2017 were used in order to produce the land use/cover maps and post classification comparison was applied for land use/cover change detection from 1984 to 2017. The results of change detection showed that wetland areas (Horolazim wetland and Shadegan international wetland) experienced sever changes and converted to probable dust storm centers. Subsequently, HYSPLIT model was performed in dust trajectory modeling from the detected dust storm centers for 365 days of 2016 in three elevation level. Aerosol optical depth (AOD) product of MODIS and air quality monitoring(AQM) data were used for HYSPLIT performance assessment. The findings of modeling showed that storms originated from detected dust storm centers can be transferred to the transboundary of Khuzestan province, especially in hot season. Therefore, focusing on national programs could be as valuable as international cooperation for mitigation and controlling dust storms in southwestern Iran.

Introduction

Climate change phenomena result in more than just a change in the weather; a variation in climate can effect on some related aspects of reduced precipitation, drought occurrence followed by expansion of deserts, and drying of the earth (IPCC 2007). Dust is a key indicator of climate change (Shao et al. 2013) which could play an important role in past climate changes and may contribute to the future course of climate change (Harrison et al. 2001). Land use/cover change has been distinguished as one of the most local environmental consequences, but it is becoming a universal challenge (Foley et al 2005). It is beyond doubt that human activities such as land-use activities (Ning et al. 2018; Abbott et al. 2018; Qu et al. 2019; Khan et al. 2019; Claypool 2019) have modified the natural environment, significantly (Watson et al., 1996) and they have an important role in increasing dust (Sokolik and Toon 1996). It is predicted that about half of dust particles are deposited near the source area (30%) and re-distributed on a local scale (20%) and the other half of them are expected to be transferred to farther distances (Kim et al., 2003). The dust cycle includes two key physical processes: (i) a wind lifting process due to raising up of dust particles from bare land surfaces (ii) a large scale transportation process with a high spatial coherence (Guarnieri et al. 2011; Kok et al. 2014).

Understanding the role of dust in the earth's climate system has led to more development of dust transport and distribution models from the 1980s. Air quality models are applied methods and algorithms in order to study and find the relationship between source and receptor (Zannetti and Puckett 2004). The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model is an air quality modeler that can estimate air pollutant trajectory from a source center to another area (Draxler and Hess 1998; Perkauskas 2004; Anastassopoulos et al. 2004). HYSPLIT model is used in different researches,

including the emission of hazardous and poisonous gases (Zali et al. 2017), dust storm (Dong et al. 2018; Conceição et al. 2018; Yassin et al. 2018; Guan et al. 2019; Khalidy et al. 2019), volcanic ash events (Crawford et al. 2016; Chai et al. 2017) and air quality modeling such as visibility, haze, and ozone (Ni'Am et al. 2017; Langford et al. 2018; Salmabadi and Saeedi 2019).

The Middle East is famous for its arid and semi-arid ecosystems with frequent and intense dust/sand storms (Furman 2003). Historical reports of dust storms for Iran indicated that during the past decade, dust/sand storms have increased in intensity especially in its southwest parts (Esmaili et al. 2006). Experts believed that the dust in the southwest area of Iran originates from external and internal sources in a way that 5% of it has an internal origin and 95% of it has an external origin (Dargahian et al. 2017). Turkey, Iraq, and Syria have generated the largest amount of dust, and other countries such as Jordan, Saudi Arabia, and North African countries are also effective in the occurrence of this phenomenon (Ginoux et al. 2012; Bastan et al. 2013; Chudnovsky et al. 2017). Dust storms mainly occur in Khuzestan province particularly in the hot season (summer), while most intense and frequent dust storms are especially associated with eastern wind current (IRIMO Ahvaz 2008). About 60 dust storm days per year have arisen in different regions of Khuzestan province from 2007 to 2009, (Zarasvand 2009). More than half of the number of dust storm days in 2007–2009 had horizontal visibility of less than one kilometer (IRIMO Ahvaz 2008).

The long history of human occupation in Khuzestan plain in interaction with land cover has created patterns of native subsistence farming such as citriculture, dry farm, palm farm, and arable farming with an irregular geometry (Roozbahani et al. 2017). In recent decades, some extensive economic, political and social driving factors such as the land reforming law, expansion of urban areas and breakdown of sugarcane agro-industry companies and the occurrence of the eight-year war in the plain of Khuzestan have changed the structure and spatial patterns of land cover and land use (Roozbahani et al. 2017).

There are some researches in relation to dust events forecast that have used HYSPLIT model around the world (Dogan et al. 2018; Guan et al. 2018; Chauhan et al. 2018) and in Iran (Namdari et al. 2016; Zali et al. 2017; Goudarzi et al. 2019) as well as land use/cover change detection (Shahraki et al. 2011; Malmir et al. 2015). Also, the studies of land use have been reported in some urban areas, sub-basins, and wetlands in Khuzestan plain (Faraji et al. 2016), Bamdezh wetland (Scott and Crop 1972; Madadi and Ashrafzadeh 2010), Shadegan international wetland (Scott and Crop 1972; Savari et al. 2002) and Horolazim wetland (Cao et al. 2015; Ghobadi et al. 2015). For example, Roozbahani et al. (2017) used satellite images of Landsat 5 Thematic Mapper (TM) and 8 Operational Land Imager (OLI) for 25-year from 1991 to 2014 to model and monitor ecosystems changes in Khuzestan plain. Their results showed the increasing trend of degradation and fragmentation of natural land and area reduction in the natural ecosystems. Heidarian et al. (2018) used a hybrid approach of remote sensing, GIS, and sedimentology to identify dust sources in the year 2015. They used spatial data of soil, land use, climate, slope, and sedimentology as constraint layers. They distinguished that nine percent of Khuzestan plain area are as the origin of dust storm.

In Khuzestan, different studies have been carried out to determine external dust sources using backward HYSPLIT modeling (Ashrafi et al. 2014; Ahmadi and DadashiRoudbari 2017; Broomandi et al. 2017; Khalidy et al. 2019; Daniali and Karimi 2019). They identified Iraq and Syria's deserts as external dust hot spots in dust storm formation in the southwest of Iran.

International cooperation between Iraq, Syria, and Iran for future strategies in order to reduce dust storm with external origin and its impacts on region is costly and time consuming. Unfortunately, existing war and human conflict in Iraq and Syria have caused the dust storm and its impacts not to be the priority for their governments. Accordingly, focusing on national plans could be as valuable as international cooperation for mitigation and controlling dust storms in southwestern Iran, especially in Khuzestan province. According to the literature reviews, there is not any research that attempts to perform forward HYSPLIT Model for dust trajectory modeling from local dust sources in Khuzestan province. Therefore, in this research, besides the land cover/use change detection in a longer period than the previous researches for identifying the probable local dust sources due to land use/cover change, the dust forward transport and dispersion modeling was performed by the HYSPLIT model in seasonal formation (hot and cold seasons). Our objective is the recognition of dust trajectories that arise from local dust sources in order to control better the dust in Khuzestan and the other provinces in Iran.

Data

2.1 Study area

Khuzestan province is located in southwestern Iran (between 48° and 50° E longitudes and 30° and 32° N latitudes) and covers an area of about 63,210 km², which is 3.9% of the total area of Iran (Fig.1). The climate of Khuzestan is generally very hot and occasionally humid, particularly in the southern part, while its winter is relatively cold and dry, whereas the north of Khuzestan experiences cold weather. The annual mean of maximum and minimum temperatures are 50°C and 9°C, respectively. The annual mean of rainfall increases from south to north of Khuzestan gradually and the annual evaporation is 2000–4000 mm. Also, some studies showed that northwestern and western winds are the prevailing winds in this area. The wind speed in summer and autumn was lower than spring and summer (Farsani et al. 2018) (table 1).

Desertification is a main environmental problem in Khuzestan province, where sandy land covers more than 20.2% (about 13,000 km²) of the study area (Hashemimanesh and Matinfar 2012). Wetlands, dams, floodplains, and rivers are some examples of water bodies that can be observed as natural and human-made water bodies in Khuzestan plain. Major land cover classes in Khuzestan province include cropland, rangeland, water body, built-up areas, sand, and wetland.

2.2. Remotely sensed data

For this study, Landsat image of Multi Spectral Scanner (MSS), (TM), Enhanced Thematic Mapper plus (ETM+) and (OLI) for the years 1984, 1992, 2002 and 2017 were obtained from United States Geological

Survey Earth Explorer website (<http://www.earthexplorer.usgs.gov>) (table 2). Each set of Landsat data included three adjacent paths (path/row: 164/37, 38; 165/37, 38, 39 and 166/37, 38, 39). Eight satellite images were mosaiced to each other and subsequently extracted by the study area boundary. For showing dust emission and its expansion in the southwest of Iran, MODIS color composites images and Aerosol Optical Depth (AOD) product with resolution of 250 m and 1 km respectively, were obtained via <http://rapidfire.sci.gsfc.nasa.gov/realtime>.

Methods

3.1. Image pre-processing and classification

In this study, Fast Line of sight Atmospheric Analysis of Hypercubes (FLAASH) atmospheric correction model that can accurately compensate for atmospheric effects was used (Anderson et al. 1999; Cooley et al. 2002). The maximum likelihood classifier (MLC) quantitatively calculates both the variance and covariance of the spectral response patterns for each class when classifying an unknown pixel, so that it is considered to be one of the most precise classifiers since it is based on statistical characteristics. For more details please refer to Richards, 1986.

The area was classified into ten main land cover classes including salt, urban, water body, forest, rangeland, rock, swamp, wetland, cropland, and aquaculture. The explanation of different land use/cover classes are expressed in table 3. Kappa coefficient is the most popular multi-variate technique for accuracy assessment (Congalton and Mead 1983; Stehman 1996). In this research after calculating the error matrix, the overall accuracy and Kappa coefficient were expressed as accuracy assessment.

3.2. Land use/cover change detection

In this study, the post-classification comparison method was applied for land use/cover change detection. It is the most popular method of land cover change detection, which compares independent thematic maps (Shalaby and Tateishi, 2007).

3.3. HYSPLIT model

In this research, the HYSPLIT model was used, which is a shared research program of the U.S. National Oceanic and Atmospheric Administration (NOAA) and Australia's Bureau of Meteorology (ABOM). HYSPLIT is used in dust storm forward/backward trajectory simulations. The model has been widely used to distinguish the aerosol sources and sinking processes (Rana et al. 2009). Forward trajectory simulation is a perfect instrument for investigating transport pathways of air pollutants and representing their potentially affected regions. Different researches performed this model to represent areas affected by different dust storm sources (Rashki et al. 2015; Ge et al. 2016; Rashki et al. 2017). HYSPLIT model is the spread of the Eulerian and Lagrangian hybrid models which captures transfer, diffusion, and settling processes. The archive data with 3-hour interval at 1 degree (latitude and longitude) spatial resolution, GDAS, from the National Centers for Environmental Prediction (NCEP) was applied to perform the model

(Yan et al. 2015). GDAS0.5 is a daily metrological dataset from November 2007 with a 0.5° spatial resolution. It provides data at 55 vertical levels from 1000 to 13 hPa (approximately 31 km) (ARL 2018).

In this study, we applied GDAS 0.5 meteorological data provided by NOAA. Forward trajectory simulations were used for motion direction of dust storms over Khuzestan for 365 days of 2016. The start point for forward trajectories is Shadegan (30.93 °N, 48.78 °E) and Horolazim (31.30 °N, 47.74 °E) at the time of dust storm formation. The start time was considered from 20 June at 00:00 UTC to 21 June at 00:00 UTC and total run time of 48 hr for start height of 500 m AGL. A horizontal domain of 30°×30° with a resolution of 0.05°×0.05° and a vertical level of 100 meters above ground level is considered in the dispersion model.

For the HYSPLIT trajectory setting, three trajectory tracking levels including 500, 1000, and 1500 m considered. To determine the impacts of dust storms on Khuzestan and their possible transmission paths, and considering the movement of dust particles below the height of 1500 m (Huang et al. 2015), the simulation was considered in different heights (500 m, 1000 m, 1500 m). The 500-meter elevation above the surface as half of the mean boundary height was considered as the receptor height since it guarantees the transition and ending of dust particle paths in the boundary layer (Karaca et al. 2009; Ma et al. 2015) and it was almost allocated as the ending height above receptors area in different researches (Fedkin et al. 2019; Jiang et al. 2019).

3.4. HYSPLIT Assessment

Moderate Resolution Imaging [Spectroradiometer](#) (MODIS) Aerosol Optical Depth (AOD) product and Air Quality Monitoring stations (AQM) data have been used for accuracy assessment. MODIS AOD plays an important role in earth observations of particle matter and dust events which can identify dust storms using optical satellite images based on the radiation and scattering characteristics of particles (Namdari et al. 2018).

Results And Discussion

4.1. Land use/cover change detection

Land use/cover change detection requires valid identification of the terrain phenomenon and classification methods (Yang and Lo 2002). After image classification and producing the land use/cover maps for the years 1984, 1992, 2002, and 2017 (Fig. 2), overall accuracy and Kappa coefficient were calculated using the error matrix (Table 4). Finally, land cover maps of the years 1984 and 2017 were compared by post-classification comparison.

One of the most considerable changes is the increase in cropland up to 12.38% (799918.02 ha) from 1984 to 2017 (Table 5), while rangeland decreased up to 14.29% (923570.46 ha) during the same period. It shows that rangeland class has responded to the needs of the community based on land use planning and was converted to cropland and urban classes during this period. The results of some studies have

shown that sugarcane monoculture, in large scale, leads to soil degradation in tropical regions, whilst a wide area of Khuzestan plain is allocated to it (Behravan et al. 2013; Pourkeihan et al. 2018)

Results showed an increasing trend of cropland expansion in Khuzestan plain in three past decades (Fig 3), which are similar to the results of the studies of Madadi and Ashrafzadeh (2010), Faraji et al. (2016), and Roozbahani et al. (2017).

Two other significant changes happened in salty land and swampland with the decrease of about 3.89 % (251528.22 ha) and 1.44 % (93032.28 ha), respectively (Table 5).

Over the recent decades, urbanization has made significant land use/cover changes, such as decreased rural areas and increased built-up or urban areas (Mundia and Aniya 2005; Dewan and Yamaguchi 2009;). According to the results (Table 5), the built-up area had increased by up to 0.43% (27620.46 ha) from 1984 to 2017. The highest rate of urban expansion and cropland growth was observed from 1992 to 2002 in Khuzestan (Fig 3). Dam construction across Karkheh River in 1998 caused urban sprawl, population growth and agriculture flourishing in this period. Unfortunately, the urbanization growth and high pressure on land, in order to be inhabited, and the creation of other necessary structures such as dam construction has led to the destruction of natural resources. Results of Fig.4 showed that the main reason for Horelazim wetland reduction from 1992 to 2002 is the decreasing of water volume that enters into the pond because of Karkheh dam construction. Similar results were represented by Makrouni et al. in 2016. Karkheh River is one of the largest water sources that determines the water of Horolazim wetland (Fuladavand and Sayyad 2015). Also, the studies by Jones et al. (2005) showed that the Karkheh dam construction has caused severe reduction in Horolazim area. Zarasvandi et al. (2012) also indicated that 72% reduction in area of Horolazim wetland was induced by the increasing agricultural demands for water and human interferences.

In 1984 the wetland class had covered about 3.36% of the whole Khuzestan (216908.55 ha), but due to the anthropogenic forces, the amount of the wetland area decreased to 2.32% in 2017 (149809.5 ha) (Fig. 4). Unfortunately, the decreasing trend of the wetland area was observed from 1992 to 2002 (about 59878.8 ha). Cao et al. (2015) reported that Horolazim marshes are now subjecting to rapid land degradation due to natural and anthropogenic factors and might totally dry in the future. Land use and cover changes and intensive wetland desiccation occurred due to cropland expansion, high demand of water for irrigation systems, and dam and large projects construction (Ghobadi et al. 2015). Pourkhabbaz et al. 2015 showed that Shadegan international wetland area has decreased by 8.5% over the past two decades.

The decrease of 0.4% (25730.91ha) of water bodies is due to the increasing in water consumption and lengthening of dry periods. The discharge of Marun, Karun, and Karkheh rivers has been decreased by 40, 37, and 149 percent, respectively in 2000-2001 compared with the mean of the past 32 years in Khuzestan province (Mousavi 2005). Karkheh River basin (approximately 51,000 km²) stretches from the Zagros Mountains to the Horolazim swamp, which is a trans-boundary wetland located at the Iran-Iraq

border. Karkheh river basin is one of the most productive cropland in Iran (Ashraf Vaghefi et al. 2014). The impacts of land-use change in river basins have been shown in previous studies (Masih et al. 2010; Tabari et al. 2011; Salajegheh et al. 2011). These changes indicate that the situation will get worse in the future.

4.2. Main local dust sources due to land use/cover change

According to the remotely sensed data classification results during the 35 year period (1984-2017), we assumed two main local zones were as dust sources in Khuzestan province, because of significant land use change. The southern part of the Horolazim wetland and the northern area of Shadegan wetland have been converted to dust storm sources as the result of converting the wetlands to low-density rangeland and sand with the area of approximately 29387.99 ha (Fig. 4). The dried areas of wetlands are sources of the dust storms formation, affecting on the surrounding areas (Heidarian et al. 2018; Rashki et al. 2021). Heidarian et al. (2018) reported that nine percent of Khuzestan province, equivalent to 349254 ha, are dust-generating sources. Human activities such as land use/cover change have been identified as dust centers in globale scale (Ginoux et al., 2012).

It is important to mention that the soil type of the western, southern, and southeastern of Khuzestan province is clay (Hamidi et al. 2017). Abyat et al. (2019) in their research showed that dust particles type was clay as well. Clay particles are light and can extend the distance of the dust movement. High ability of clay particles to attract organic and inorganic chemicals and their fine texture makes them more susceptible to be dangerous (Keramat et al. 2011).

Cao et al. (215) indicated that the shrinkage of Horolazim wetland, especially in the southern and southwest parts of the wetland areas is the result of phenomena such as climate change, low-water periods, as well as negative effects of human activities that a conclusion supported by Javadian et al. (2019) who found these wetlands to be one of the three most important dust centers affecting the other cities of Iran. Anthropogenic activities include extreme harvesting of water from wetland resources, wetland drying and converting into cropland, dams construction on the rivers, increasing human access to a wetland through construction roads inside wetland, an oil company drilling and undeniable impacts of Iran-Iraq war that have undesirable effect on the wetlands (Gerivani et al. 2011). Arkian (2017) highlights the impact of oil extraction around the Horolazim, one of the most important wetlands in southwestern Iran, as the primary reason for its declining water levels in recent decades. Cao et al. (2015) expressed that the dried area of Horolazim wetland that still keeps expanding is the main dust storm source in Iran, and have had a great effect to increase dust storm in the southwest part of Iran.

The results of Broomandi et al. (2020) indicated that Horolazim area acts as a source in the region. The susceptibility of southern area of Horolazim wetland to turn into a persistent dust centers has been mentioned in other studies (Broomandi et al., 2017; Cao et al., 2015; Heidarian et al., 2018).

The degradation process of Shadegan international wetland goes more quickly. When the population in the surrounding of wetland increases, it lead to demand for economic activities and development. Most

of the economic activities and the development plans around the wetland have adverse effects on wetland due to the lack of environmental assessment of development plans.

The results indicated a decrease in the area of Shadegan international wetland, especially in the northern part of the wetland called the freshwater wetland. Most of the threats in this area can be caused by increased access to the wetland (road construction). Also, water-fed wetlands through streams in this area, are entered into the wetland and strongly effect on the salt, sediment, and water quality of the wetland. The cumulative effects of the threats have a high risk on this part of the wetland. Due to the construction of several dams and the implementation of irrigation network development projects in recent years, the drought has led to changes in the vegetation cover of these wetlands, which was identified as a source of dust (Javadian et al. 2019). Rahimi Blouchi and Malekmohammadi (2013) showed that instead of the change in natural habitats, change in hydrological patterns due to dam construction and also water pollution has been identified as the most important risks of the Shadegan international wetland.

4.3. Transport and dispersion modeling

After the detection of dust storm sources based on land use/cover change in Khuzestan province, HYSPLIT forward trajectory model was performed to find the possible paths of dust storm and their dispersion scale. This modeling was performed for the south of Horolazim (center 1) and north of Shadegan international wetland (center 2) in three elevation levels of 500, 1000, and 1500 meters for 365 days in 2016.

According to the HYSPLIT model results, dust particles in the hot period (spring and summer) of the year 2016, had tracks to the southwestern Khuzestan, southern Bushehr, Hormozgan, Persian Gulf, and even some days to Saudi Arabia (Fig. 5). Abdi Vishkaee et al., (2011 and 2012) mentioned that Shamal wind in summer is especially more severe than winter in Khuzestan province.

During the cold period of the year, western winds have a significant role in the occurrence of dust storm and its dispersion in Khuzestan province (local scale). According to the results, during the cold seasons (autumn and winter), dust storms moved to northeastern of Khuzestan province such as Chaharmahal and Bakhtiari, Isfahan, and southern Khorasan provinces in Iran and rarely to Iran's neighbors such as Turkmenistan. The main factors in the formation and occurrence of dust storms in Khuzestan are migratory systems of westerlies (west winds) and polar front jet stream (PFJ) (Tavoosi et al. 2010; Raispour et al. 2016). It is important to mention that dust storms in Khuzestan occur mainly in the late spring (May) (Shahsavani et al. 2012) and in the summer (June-July) although some dust events in Khuzestan occur in the winter (Modarres and Sadeghi, 2018; Kamal et al. 2020). According to the results of forward Hysplit trajectory modeling from internal dust storm (center 1 and center 2), most neighbor provinces of Khuzestan subjected to dust storm with internal origine in cold season.

According to Figure 6, the MODIS color composite image was similar to MODIS AOD product of July 19th and 20th 2016. Analysis of the visibility data of AQM stations indicated that there were 30 dust-storm days in July 2016 (visibility <1 km) in Khuzestan. Figure 7 shows that the visibility value during the

studied days has decreased in Khuzestan, Ilam, and Lorestan's AQM stations. Based on the true color composite of MODIS sensor, dust storm in 17 July 2016 after passing through deserts of the north of Saudi Arabia and south of Iraq would extend to Khuzestan, Ilam, Hormozgan, and Bushehr located in the south and southwest of Iran. AOD product recorded a high value of particles in Khuzestan province (Fig 6). Khuzestan Province is the area that is heavily influenced by deserts of the north of Saudi Arabia and south of Iraq. The images clearly show that about 61% area of Khuzestan province covered with desert ecosystems (having low density vegetation) and western provinces are engaged with dust storm, except some of the northern and eastern mountainous areas. Rajaei et al. (2020) and Borna et al. (2021) used MODIS color composite image and AOD product for HYSPLIT modeling assessment.

Conclusion

The purpose of this study was the identification of the probable internal or local dust centers due to land use/cover change in Khuzestan province. In order to study the role of land use/cover change as one of the effective factors in the formation of the dust storm, land use/cover change detection was done during 1984-2017. The results represented that the southern regions of the Horolazim wetland and the northern area of Shadegan international wetland were as the local sources of dust storms. Reduced vegetation cover and soil disturbance can make more sediment available for emission in dust storms. It is worth mentioning that the sugarcane industry is playing a significant role in the Khuzestan economy and native and non-native people occupation and has direct or indirect negative environmental impacts on croplands and Shadegan international wetland. Unfortunately, Iranian authorities have not considered sustainable development for industrial growth such as sugarcane cultivation and industry in Khuzestan province. Unsustainable developments in this province has caused the formation of new dust storm centers due to land use/cover conversion that had negative environmental impacts on the human and natural areas inside and outside of Khuzestan.

The HYSPLIT model results showed that more than 90 percent of Khuzestan province area, southern of Lorestan province, Ilam, Fars and Bushehr provinces, southwest of Hormozgan province and parts of the Kohgiluyeh and Boyer Ahmad province will be subjected to the transport and dispersion of dust originated from these two centers specially in cold periods. The dust path trajectory modeling in warm period indicated the majority of dust path are leaded to south of Khuzestan and Persian Gulf and effected mariane ecosytme. Although the share of internal/local dust center is lower than external/regional hotspots, the severe land degradation especially cropland, wetlands, and rangelands conversion to deserts as important local dust storm centers and transfer of dust particles to other cities of Iran as internal management programs should be followed, seriously. Planting of endemic vegetation in the region, especially saline grasses or bushes in accordance with the ecological conditions of Khuzestan and avoiding water transfer projects can be useful for dust storm mitigation in the future.

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Faezeh Alizadeh: Doing this research for her Master of Science, writing original draft

Afsaneh Afzali: Advisor of this research in HYSPLIT model)

Additional declarations for articles in life science journals that report the results of studies involving humans and/or animals

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Tables

Table 1. Wind speed and wind direction in Ahvaz station

	Autumn	Winter	Spring	Summer
Prevailing wind direction	west	west	west	west
Strong wind speed (m/s)	11.6	12	12.3	8.6

Table 2. Satellite images characteristics

Satellite data	Spatial Resolution	Spectral Bands	Swath Width	Date
Landsat-MSS	60 meters	4 multispectral	185 km	28 July 1984
Landsat-TM	30 meters	7 multispectral	185 km	18 July 1992
Landsat-ETM ⁺	30 meters	7 multispectral	185 km	12 August 2002
Landsat OLI	30 meters	8 multispectral	185 km	23 June 2017
MOD08	1 ×1 km	—	—	20 June 2016

Table 3. Explanation of different land cover classes of the study area

class	Description
Salt	Includes lands that have bare and salty soil.
Urban	Includes lands with human facilities (residential, sports, commercial, industrial, etc.).
Water	Includes the Karoon River, Dez, Hendijan, and Manhattan dams.
Forest	Includes lands with Oak coverings in the west, located at altitudes above 1900 m.
Rangeland	Includes lands with vegetation cover, bush and grass meadows, or active state, as well as bare soil or ground.
Rock	It Includes lands located at high elevations with rocky outcrops.
Wetland	Includes wetlands, vegetation, and forests in wetlands.
Cropland	Includes agricultural lands and gardens.
Swamp	Includes aquatic vegetation, or vegetation that tolerates periodic inundation or soil saturation.
Aquaculture	Includes aquaculture farms.

Table 4. Accuracy assessment for produced land cover maps

Class name	Kappa statistic	Overall Accuracy
1984	0.735	79.34
1992	0.84	89.46
2002	0.86	88.24
2017	0.925	85.40

Table 5. Land use/cover change area from 1984 to 2017

Land use/cover	1984		2017		Change in 1984-2017 (%)	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Rangeland	4172368.86	64.57	3248798.4	50.28	-923570.46	-14.29
Forest	636615.05	9.85	636316.59	9.86	301.5	0
Salt	28289.97	0.44	279818.19	4.33	251528.22	3.89
Rock	15408.63	0.24	15340.41	0.24	0	0
Urban	14602.95	0.23	42223.41	0.65	27620.46	0.43
Cropland	807040.62	12.49	1606958.64	24.87	799918.02	12.38
Water	126908.55	2.01	103907.7	1.61	-25730.91	-0.40
Wetland	216908.55	3.36	149809.5	2.32	-67099.05	-1.04
Sand	18563.21	2.87	205736.76	3.18	20123.55	0.31
Swamp	254964.33	3.95	161932.05	2.51	-93032.28	-1.44
Aquaculture	0	0	10086.84	0.16	0.16	0.16

Figures

Figure 1

Location of the study area (OLI image in 2017 and digital elevation model) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

land use/cover maps of Khuzestan province in 1984, 1992, 2002 and 2017 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 3

Land use/cover change of Khuzestan province in 1984, 1992, 2002 and 2017

Figure 4

Land use/cover changes of Khuzestan province from 1984 to 2017 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 5

Forward trajectory (48 h) in one day of hot seasons and cold seasons as example Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 6

MODIS satellite true color image and AOD product in Jun a (17th) b (18th) 2016 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 7

Visibility data of AQM stations in June 2016