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Identification of the sources of dust storms in the City of Ahvaz by HYSPLIT.

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ABSTRACT: Dust particles have dangerous impacts on human health, the environment, and the economy. Recently dust storms, originating from Arabian countries, have increased remarkably, affecting western and central parts of Iran. HYSPLIT model and the mean monthly maps of AAI (Absorbing Aerosol Index), surface skin temperature, and top soil layer moisture from OMI (Ozone Measurement Instrument) have been used to study the origins and trajectories of suspended particles of dust storms from wind erosion during the warm period in 2010. According to HYSPLIT Model, during their move from their source areas to the downwind ones, dust particles could arrive at city of Ahvaz in different directions: (a) NW-SE (the dust particles are transported from north western region of Iraq and eastern Syria), (b) W-E (the dust particles are transported from central parts of Iraq to the south western and western parts of Iran). Also, inspecting dust emission potential with the aerosol index data from Ozone Measurement Instrument (OMI) shows a persistent intense dust activity in north western parts of Iraq and eastern Syria, hitting South-West of Iran, especially the city of Ahvaz. As a result, the main origins of dust particles in the city of Ahvaz include north west Iraq as well as east Syria.

Kewwords: Absorbing Aerosol Index (AAI), dust events, numerical modeling, Ozone Measurement Instrument (OMI).

INTRODUCTION

Dust storms mostly happen throughout desert regions of the world, specifically during springtime. They are responsible for the injection of massive amounts of mineral dust grains into the atmosphere. Dust aerosols have a wide range of impacts on global climate, ambient air quality, atmospheric chemistry, and biogeochemical mechanisms (El-Askary et al., 2006; Dey et al., 2004). Wet and dry deposition remove dust particles from the atmosphere. While wet deposition is dominant during long-term transport over oceanic areas, dry deposition removes larger dust aerosols near the origin areas. The riskiest city of Iran, namely Ahvaz, the capital of Khuzestan province, Iran, is close to Iraq, Syria, Saudi Arabia, and Kuwait, the main dust sources of the region. This city is significantly hit by mineral dust, carried by a

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hot dominant northwesterly wind during the spring, Shimali Wind, which can carry large amount of dust particles from southern regions of Iraq (Goudie & Middleton, 2001). In particular, the country of Iraq should be an issue of great concern, as it has extensive areas of sand desert (nearly 40% of the country's total area). There is an increase in the desertification rate in this country due to the intensive drought of 1999, inconvenient land use, deforestation, military activities during the war period, unstable political condition, and lack of internal decision-making power (Goudie & Middleton, 2001). There are different developed techniques to locate dust hotspots and trajectories. Analysis of particle trajectory, numerical simulation, analysis of dust observations and meteorological information, Satellite imagery and remote-sensing method, mineral detectors, and geological models are the main tools to investigate dust storms (Ashrafi et al., 2014; Givehchi & Arhami, 2013; Aliabadi et al., 2015). Furthermore, to investigate the potential dust source locations as well as more persistent dust mobilization regions, Aerosol Index (AI) data, taken from Total Ozone Mapping Spectrometer (TOMS) on the Nimbus 7 satellite, along with Aerosol Optical Depth (AOD) data, taken from Moderate Resolution Imaging Spectroradiometer (MODIS), have been processed (Esmaili et al., 2006; Liu et al., 2011; Miller, 2003; Prospero et al., 2002; Qu et al., 2006; Givehchi & Arhami, 2013).

There have been few studies conducted to identify dust sources and trajectories by means of modeling techniques in Iran; with a great number of these studies, frequently employing satellite images and meteorological data analysis (Ashrafi et al., 2014; Akbary & Farahbakhshi, 2015; Cao et al., 2015; Broomandi and Bakhtiarpoor 2016). Using the WHO database, Ahvaz is the first polluted city in the world, with an annual average particulate matter concentration of 372 μg/m^3 (WHO, 2006). Identifying dust hotspots and pathways, which leads to dust storms in Iran, is of high account. The present study has used numerical modeling techniques (HYSPLIT Model), mean monthly maps of AAI (Absorbing Aerosol Index), surface skin temperature, and top soil layer moisture from OMI (Ozone Measurement Instrument) in order to investigate the trajectories and origins of suspended dust aerosols of dust storms. Finally, results can be used to decrease and control the level of dust particles.

MATERIALS AND METHODS

The study area, the city of Ahvaz, located at 48˚40' longitude and 30˚20' latitude, was chosen to study the air quality modeling during warm period in 2010. It occupied 8152 km^2 in southwestern Iran with 1,500,000 inhabitants during the studied period. Its climate varied from arid to humid with the warm period lasting from April to September, and the cold period from October to March. The annual average maximum temperature in summer was about 47˚C (in July) and minimum temperature in winter was about 8˚C (in March). The annual mean precipitation amount was 173.4 mm with the maximum amount of 85mm in March. Also, the annual evaporation was about 3097 mm. Ahvaz is influenced by southwestern winds of the North.

The absorbing aerosol index (AI) data, taken from the current Earth Probe Total Ozone Mapping Spectrometer (TOMS), is illustrated as the difference between the calculated (including aerosol effects) spectral contrast of the 360 and 331 NM wavelength radiances and the contrast, measured from the radiative transfer theory for a pure molecule (Rayleigh particles) atmosphere (Prospero et al., 2002). It has been calculated mathematically in the current version-8 Nimbus-7 TOMS (1979-1993), version-2 Aura OMI (Ozone Monitoring Instrument) (2004-present), and Earth Probe TOMS (1996-present) algorithms, as:

$$AI = 100\left\{\log_{10}\left[\left(\frac{I_{360}}{I_{331}}\right)_{meas}\right] - \log_{10}\left[\left(\frac{I_{360}}{I_{331}}\right)_{calc}\right]\right\} \quad (1)$$

where $I_{360\ calc}$ uses derived reflectivity from the 331 nm measurements. The Aerosol Index is defined simply as:

$$AI = 100\left\{\log_{10}\left(\frac{I_{360\_meas}}{I_{360\_calc}}\right)\right\} \quad (2)$$

The Aerosol Index is capable of discovering the smoke, volcanic ash, and dust over all terrestrial surfaces such as ice, snow-covered surfaces, and deserts. These aerosol types have also been discovered intermixed with clouds and upper cloud heights. The AI can detect absorption from non-absorbing aerosols very well, as it is capable of measuring UV radiation absorption by desert dust and smoke. Positive AI values are connected with UV absorbing aerosols, specifically smoke, volcanic ash, and mineral dust aerosols. While, negative AI values are connected with non-absorbing aerosols (e.g. sea salt and sulfate particles) with both natural and non-crustal origins (Torres et al., 1998). The cloud presence is represented by AI values, almost equal to zero. When explaining the results, it should be noted that some surface effects, such as ocean color and sea-glint, may also increase the AI.

The aim of this section is to identify relatively strong and persistent dust origins, which hit South-West Iran, especially the city of Ahvaz. Primarily, monthly mean maps of OMI AAI data for all 11 years of the OMI record have been used. OMI AAI values typically almost range from zero to four (showing a remarkable presence of intense smoke or dust storm). Monthly AAI data below a specified value have been used as threshold filters to omit minor dust events. The monthly average AAI products have been inspected to distinguish which value has yielded the most firm patterns (Prospero et al., 2002). Also, in order to investigate the role of the surface skin temperature and top soil layer moisture in dust emission potential in the studied area, the mean monthly maps of OMI surface skin temperature and top soil layer wetness for all 11 years of the OMI records have been studied (http://giovanni.sci.gsfc.nasa.gov).

In order to analyze the origins and trajectory of dust aerosols, Online HYSPLIT.4 ((HYbrid Single-Particle Lagrangian Integrated Trajectory) model has been used with a 1°×1° resolution meteorological data (http://ready.arl.noaa.gov/HYSPLIT.php) (Draxler & Hess, 1998). HYSPLIT includes three types of trajectories, which can be computed: Normal, Matrix, and Ensemble. The pathways from a matrix distribution of locations of an area are computed using Matrix trajectory, but multiple pathways from one position by all-possible deviations in X, Y, and Z are calculated, using Ensemble trajectory. The meteorological field resolution can lead to uncertainty in the modeling. In order to reduce this uncertainty, Ensemble trajectory has been used to compute all possible pathways (Draxler & Hess, 1998).

RESULTS AND DISCUSSION

Fig. 1 illustrates the mean monthly AAI distribution, Surface skin temperature, and Top soil layer wetness from OMI for the last 11 years. The absorption concentrations of aerosol are notable during warm period (April- September) especially in May, June, and July in the studied area. All detected aerosol in Figure 1A are essentially due to the mineral dust. While during cold period (October- March) there is significantly less dust activity in the area, especially in January. Also, the surface skin temperature has increased considerably during the warm period, especially in July, while top soil layer moisture has decreased notably in this period. During the cold period the top soil layer wetness has increased in contrast with the surface skin temperature.

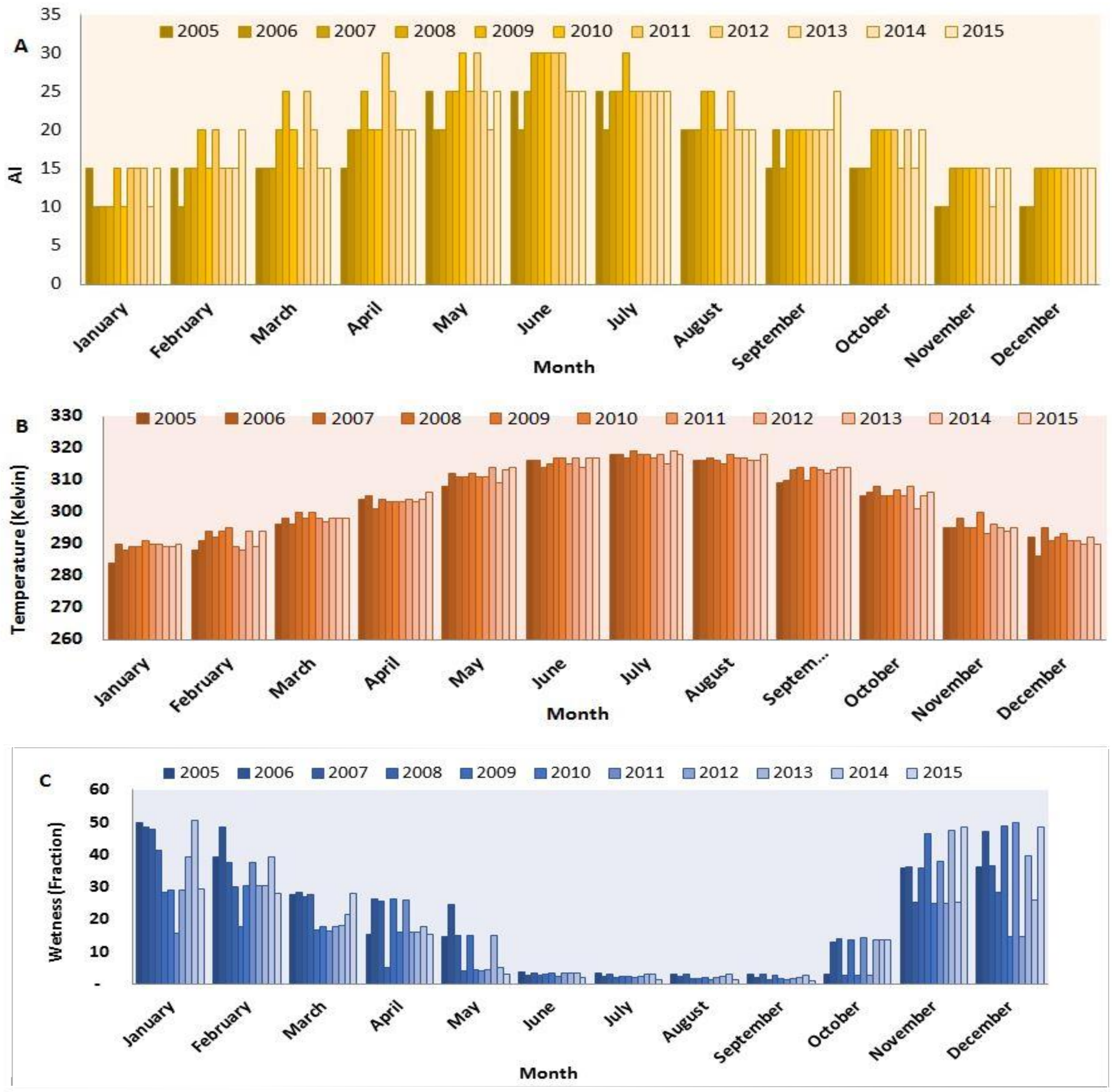

Fig. 1. The mean monthly AAI Distribution (A), Surface Skin Temperature (B) and Top Soil Layer Wetness (C) from OMI for the last 11 years

According to Figure 2, it can be seen that in isolated origin areas the AAI values are relatively high and the aerosol distributions suppose a characteristic shape, persisting from month to month. Some examples are Central parts of Iraq, Kuwait, North-Eastern parts of Saudi Arabia, and South-Western parts of Iran. Persistence of this specific area of intense dust activity suggests that locations in this area are specifically appropriate for dust generation. Comparing the mean monthly AAI distribution with top soil layer wetness and surface skin temperature in the warm and cold periods for all 11 years shows a good agreement. As any decrease in soil moisture content during warm period increases the concentrations of absorbing aerosol (which is due to the rise of surface skin temperature) (Fig. 1B, C). The soil moisture content has a remarkable role in sand and dust emission potential along with soil texture and differences in the soil organic matter content that aggregate size distribution and stability. This is because of the soil moisture, contributing in the strength of inter-particle bonds by increasing the development of a humid film between the particles (Aimar et al., 2011; Li et al., 2006; Funk et al., 2008). In contrast to other effective factors, soil wetness content is highly variable in both spatial and temporal scales. The actual emission is prevailed by the real moisture content of a certain soil layer (the first top-centimeters in the case of wind erosion) (Aimar et al., 2011).

The HYSPLIT model has been used to investigate the backward trajectory of the dust dispersion in Ahvaz (31, 31 N and 48, 65 E), Khozestan province, during the warm period in 2010. The dispersion pathways of dust grains have been tracked through 6-hour intervals up to 24 hours before dust particles reached the station in atmospheric heights of 500 m. In fact, the wind direction has been estimated 24 hours before the dust storm reached the station. The main reason for this elevation is the tracing of the first dust particles' path one day before occurrence in the western borders. Also, the particles at the height ≤500 m are relatively coarse as well as heavy grains, which can alter the horizontal visibility effectively.

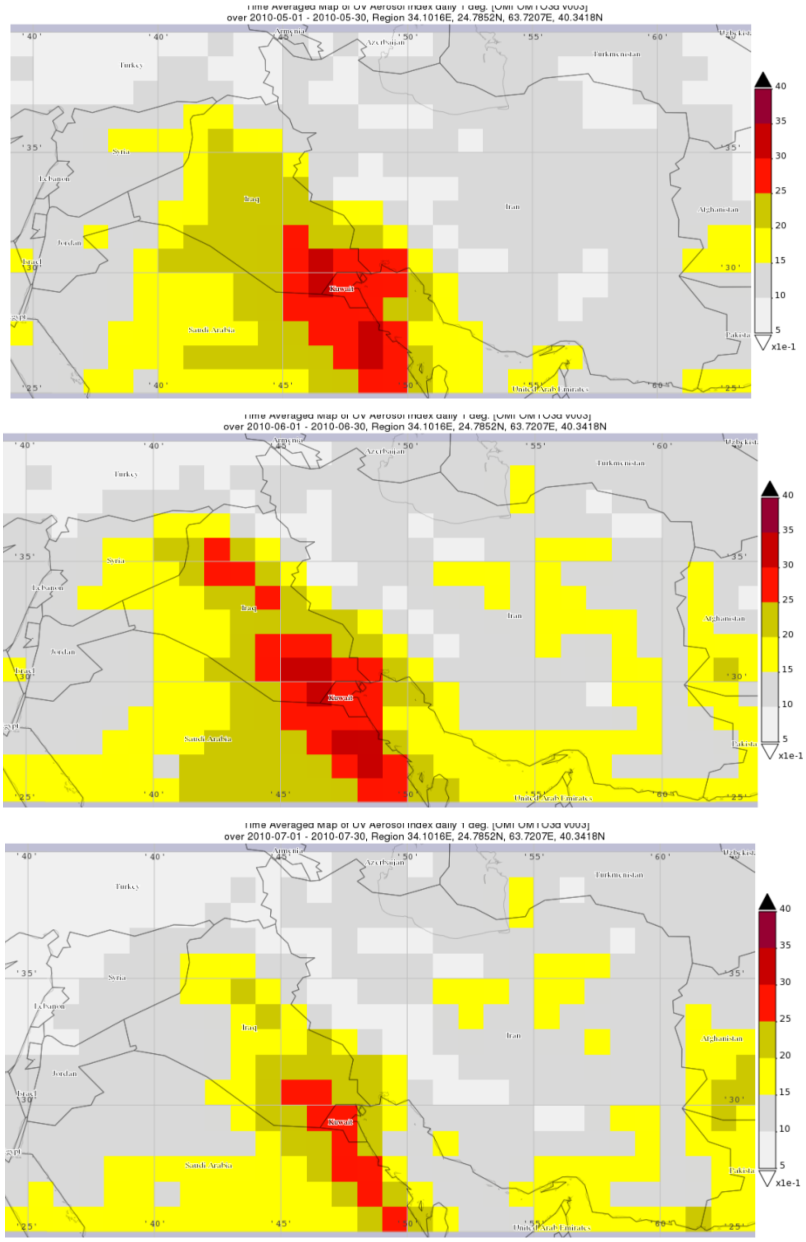

Fig. 2. The mean monthly AAI variation for the months of May, June, and July in 2010 in the studied area

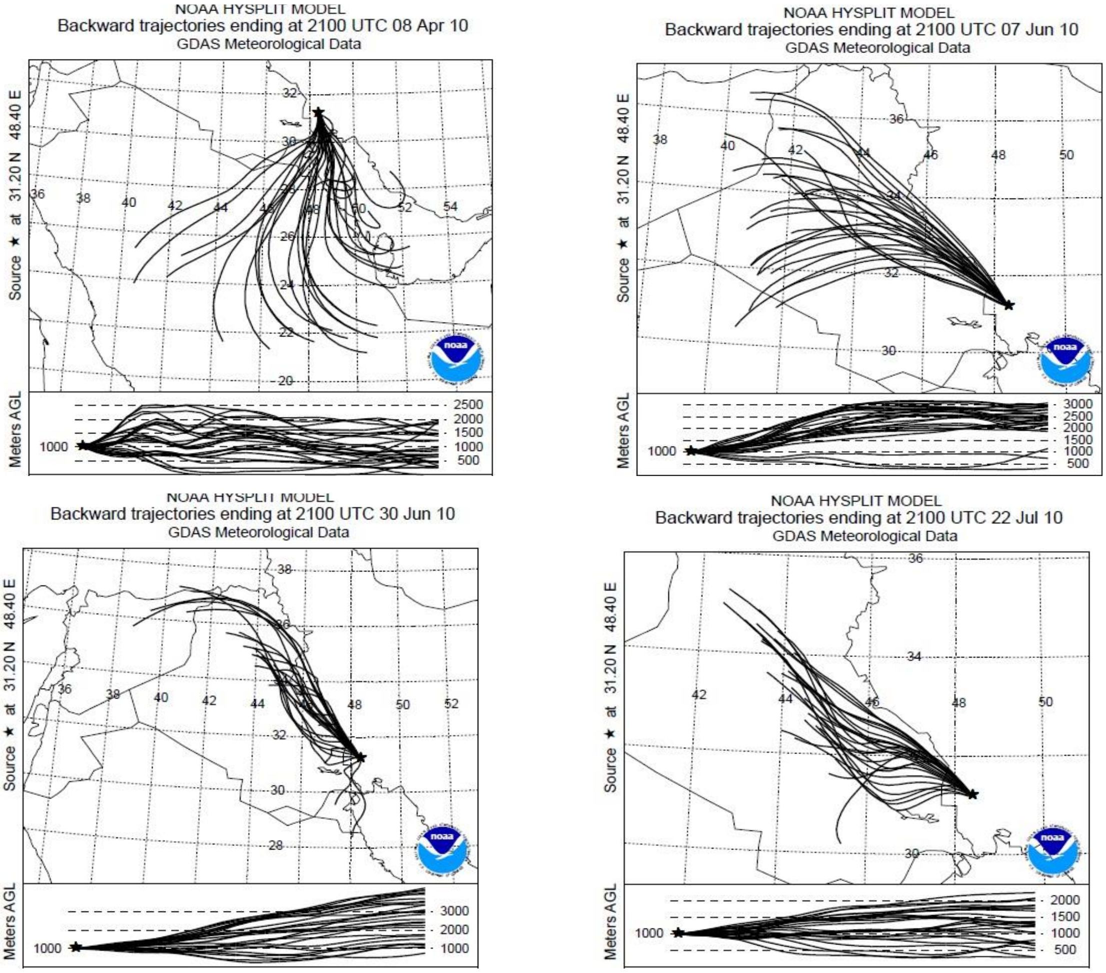

Fig. 3. HYSPLIT Back trajectory simulation, Ahvaz in (Left to Right) April 10th, June 7th, July 22nd, and July 30th 2010.

Figure 3 indicates that there are two main paths to transfer the dust to the country: (a) NW-SE (in which dust particles are transported from the northwestern region of Iraq and eastern Syria) and (b) W-E (where the dust particles are transported from central regions of Iraq to the southwestern and western parts of Iran). According to the results, the NW- SE is the main path for the dust particles' transportation to Ahvaz, which reduces horizontal visibility below 1000 m in the city (IR.DOE, 2016). The second route is less abundant than the first one. As can be seen in Fig.3, dust particles has followed the same path from NW-SE to the city of Ahvaz. Accordingly, results indicate Shimali winds (prevailing northwesterly winds that kick up small desert sand and silt along Euphrates and Tigris river basins) are responsible for transporting dust particles from western parts of Iraq, eastern Syria, and Jordan to Ahvaz city during warm period (Sissakian et al., 2013). In particular, Iraq is an important sand and dust storm origin in the Middle East. Both local and regional reasons cause sand and dust storms in Iraq. Changes in the regional climatic are one of the important causes to develop sand and dust storms in Iraq, mainly environmental changes (like desertification, land degradation, and drying of the marshes), not to mention the remarkable decline in the annual amount of precipitation. Military activities are the most effective local reason, mainly in the Iraqi Southern Desert (Sissakian et al., 2013). Results of other studies (Mehrabi & Jafari, 2015; Mofidi & Jafari, 2011; Taghavi et al., 2013; Zolfaghari

& Hashemi, 2011) demonstrated that the main dust sources in Iran are northern parts of Saudi Arabia, central to northern parts of Iraq, and Eastern and central parts of Iraq and Syria. But, Ataee and Ahmadi (2011) showed the main dust storm sources of south-western parts of Iran are western parts of Baghdad and burned and dry Al-Howizeh/ Al-Azim marshes, located in the Iran- Iraq border. Furthermore, the results of mean monthly AAI distribution for the last 11 years are in agreement with HYSPLIT model outputs.

CONCLUSION

The origin identification and trajectory modeling of dust storms in the city of Ahvaz due to the wind erosion was conducted in the current study, which analyzed the long-range transport of a severe dust storm in Ahvaz during the warm period in 2010. During the transportation from source areas to downwind areas, dust particles could arrive at Ahvaz city via different directions: (a) NW- SE (from the northwestern region of Iraq and eastern Syria), (b) W- E (from central parts of Iraq to the western and south western parts of Iran), causing severe air pollution in Ahvaz. Regarding the vulnerability of this area to wind erosion, confirmed by AAI data inspection from OMI, it can be dispersed by wind, affecting the areas which are far from this region including agricultural lands. The impacts of dust storms on the economy can be visibility reduction, affecting road and aircraft transportation, reduction of sunlight reaching the surface, and increasing cloud formation that results in the heat blanket effect. The climatic changes and the amount of available water in the main two rivers are the important reasons for the increased frequency of sand and dust storms in Iraq. Any changes in the average annual precipitation, temperature, and the level of available water in the rivers have resulted in the dry and barren lands. What is more, high temperature and drought have caused decomposition of the top soil layer and absence of the vegetation cover, both leading to greater occurrence of sand and dust storm. Due to the worldwide dispersion of this natural disaster, it is necessary to locate hotspots, and take the effective and functional stabilizing methods of highly erodible regions immediately. Stopping the flow of sand upwind (wind barriers and wind breaks, vegetation…), stabilizing loose soil (vegetation, mulching…) and surface binders (chemical coatings, watering…) are different stabilizing methods which could be useful in reducing the vertical dust emissions. Future studies need to focus on the effective techniques for the soil, topography, climate and vegetation cover properties of each hotspot.

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