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# Characteristics of TSP Loads during the Middle East Springtime Dust Storm (MESDS) in Western Iran

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**Abstract** Dust storm is one of the most important environmental problems in the west of Iran. To indicate the environmental impact of these phenomena, the characterization of dust storm loads is vital. The objective of this study is to identify the mineralogical and chemical composition, trace elements, and microorganisms of dust particles deposited during a springtime dust storm event over the west of Iran to obtain total suspended particulate. Dust samples were collected from four cities in the west of Iran during dust storms in two spring seasons of 2011 and 2012. In addition to determining the sources of dust samples on the dates of sampling, synthetic approaches including remote sensing technique of dust detection, physical–meteorological model called HYSPLIT, and analysis of weather map were used.

XRD analyses of airborne dust samples indicate that the mineralogy of airborne dusts is dominated by calcite and quartz; additionally, gypsum, albeit, muscovite, clinochlore, and dolomite are other minerals in springtime dust storm. XRF analyses indicate that the most important chemical components of airborne dusts are $SiO_2$, $CaO$, $Al_2O_3$, $Fe_2O_3$, and $MgO$. The Atomic Absorption analysis was performed to determine the concentration of heavy metals including Fe, Cr, Pb, Zn, Cd, Co, Cu, and Ni. Concentration of heavy metals was Fe>Zn>Cr>Ni>Pb>Cu>Co>Cd, respectively, and average concentration of heavy metals on Middle East springtime dust storm (MESDS) occurrences were higher than values proposed by the World Health Organization. Microorganism analysis shows that the *Bacillus* species (41.25 %) is dominant, then *Micrococcus* (10.3 %), *Staphylococcus* sp. (7.61 %), *Klebsiella* (4 %), *Escherichia coli* (2.7 %), and *Enterobacter* sp. (1.8 %); *Aspergillus* sp. (21.07 %), *Candida albicans* (5.7 %), *Rhizopus* (2.24 %), *Penicillium* sp. (1.04 %), and *Mucor* (0.89 %) genera were fungal species that were isolated in the (MESDS). Basic sources for scattering of dust in the west and southwest of Iran are Iraqi desert, desert lands in the north and northeast of Arabian Peninsula, east and southeast of Syria, also occasionally Sahara desert and Khuzestan province in southwestern of Iran.

**Keywords** Dust storm · Mineralogy · Chemical composition · Microorganism · West and southwest of Iran

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## Introduction

Dust storm is one of the most important natural phenomena and a kind of severe natural disaster that begins and diffuses under the influence of atmospheric systems. It occurs frequently in desert lands and their surrounding areas in arid and semi-arid regions (Miri et al. 2009). The main factors influencing the amount of dust in the air include precipitation, vegetation cover, wind velocity, and soil particle size of dust-generating sources

(Ta et al. 2004). The major sources of dust in the Northern Hemisphere are located in the 'dust belt' which extends from 20° to 30°N and are developed under the subtropical high-pressure subsidence (Kalderon-Asael et al. 2009). Al-Dousari et al. (2012) showed that there were seven major sources of dust storm trajectories in the world including the west and south Sahara Desert, the east of Sahara Desert, east Sudan and Ethiopia, the northern Arabia, Gobi Desert, Taklimakan Desert, and Australian Desert.

Dust storms have high priority in air quality management schemes because they have considerable impacts on local, regional, and even global scales both in short and long periods of time (Wang et al. 2005; Fairlie et al. 2007). The reasons as to why dust emission has global impacts include: one, dust particles can remain in the atmosphere for long periods of time and affect local and regional weather and climate (Shi et al. 2005); and two, dust can be carried over long distances in the atmosphere (Zhu et al. 2007). However, the residence time of dust particles depends on dust particle size, meteorological condition, wind speed, wind blowing time, rainfall, height and direction of mountains. In addition, the regional dust is associated with bad effects on human health (Prospero et al. 2008; Bennion et al. 2007; Meng and Lu. 2007). Also, absorption and scattering of solar radiation by dust particles in the atmosphere can have a major effect on air temperature (Toon 2003), solar radiation budget in the earth (Maghrabi et al. 2009), agricultural activities, land use and soil formation (Fung and Tegen 1995), delivery of iron to the oceans (Goudie 2009), reduction of visibility, road transportation and traffic, etc.

Over the past decades, Middle East dust storms have caused many problems for the residents of South and Southwest regions of Iran. During the recent years, there has been an increase in the trend of dust storm activities in this region, especially in spring and summer (Khoshakhlagh et al. 2012). Now, this trend is changing into the main persistent environmental problem in Iran and the Middle East region. Middle East dust storms have great impacts on the quality of the inhabitant's lives, visibility and transportation, microclimate, ecosystem, communication systems, and consequent crisis, such as eco-social and environmental problems in the west and southwest of Iran.

The meteorological, mineralogical, geochemical, and microbiological characteristics of airborne dusts in the Middle East were studied and documented in recent research (Rashki et al. 2012; Zarasvandi et al. 2011; Hojati et al. 2011; Al-Dabbas et al. 2010). However, there are limited studies about the mineralogy, element composition characteristics, and the potential microbiological impact of airborne dusts on human health in the west of Iran. The aim of this study is to (1) understand the possible source(s) of dust storms in the west of Iran using the synoptic and remote sensing methods; and to (2) determine the element composition, mineralogical, trace metals and microbiological characteristics of dust particles in

the west and southwest of Iran in the springs of 2011 and 2012.

## The study area

Iran is located in the west of Asia, and in the arid and semi-arid belts (Hojati et al. 2011). The annual rainfall ranges from 224 to 275 mm, and the central Iran has remarkable dust emission sources, which are one of the most prominent dust sources in the dust belt. The study provinces from which sampling was performed, include two provinces of Kermanshah (45.24°–48.30° E and 33.36°–35.15° N), and Khuzestan (47.42°–50.39° N and 29.58°–32.58° N) which are located near the Iranian border with Iraq in western Iran (Fig. 1, Table 1). This region comprises 40 cities and a population of more than 6,000,000. Topographic elevations in these provinces vary between 0 m (in beaches) and 3,701 m (Menar Mountain in Khuzestan province). The northern parts of the region (Kermanshah and northern Khuzestan), especially the mountainous areas, experience cold weather in winter and warm weather in summer. In mountainous areas, the annual mean of minimum temperature in the coldest month is less than −4 °C (in January). The southern parts of Khuzestan province, especially the low elevations and coastal areas, experience tropical weather. The annual mean of maximum temperature in the warm period is about 50 °C (in July) and the minimum winter temperature is 9 °C (in February).

## Sampling and methods

### Sampling

In this study, five severe dust storms were considered in the west and southwest of Iran that occurred in the spring seasons of 2011 and 2012 (Table 2; Fig. 2). Sampling was performed based on the intensity of dust storm in each city; so the frequency of sampling was different in some periods for different cities. The air sampling was performed in Ahwaz City, in the center, and Mahshahr City, in the South of Khuzestan province; and Kermanshah City, in the center, and Qasre-Shirin, in the west of Kermanshah province. The distance of visibility during the sampling time was less than 500 m. Dust samples were collected to obtain total suspended particles (TSP) by using the high-volume air samplers (HVA) (Anderson and TCR models) and the fiberglass filters used to get dust particles. The flow rate of the HVA sampler was 1 $M^3$/min. But, because the HVA sampler was not available in Qasre-Shirin City, the low volume air sampler (model: S2) with fiberglass filter for sampling of TSP was used. After the calibration of air sampler, the sampling stations in urban areas were located at the height of 2 m above the ground. The
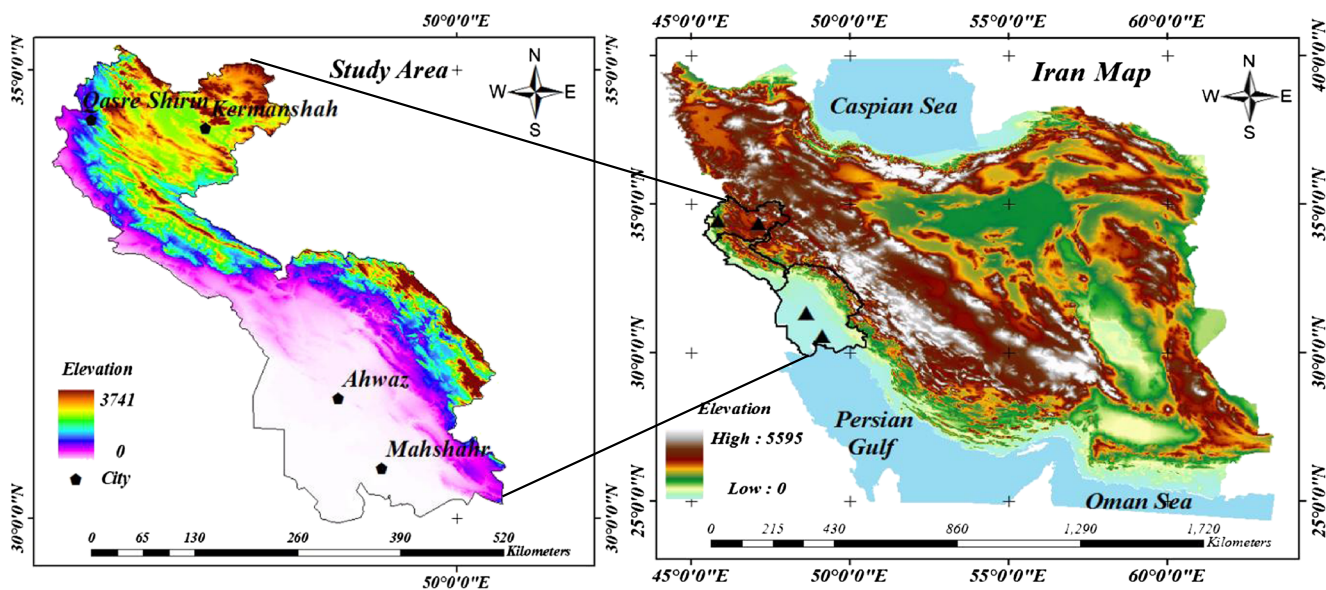
**Fig. 1** Study area

sampler was run continuously for a period of 24 h. The air volume for each sample was calibrated to standard sea level pressure using the average pressure, which was automatically measured every 30 min in each sampling period. In addition, in order to remove the potential adherent impurities in sampling instruments, the device was washed with deionized water (Yao et al. 2002; Shahsavani et al. 2012). Finally, samples of dust collected by the sampler on filters were placed in a closed container and kept in 4 °C before analysis to avoid secondary contamination (Shen et al. 2009).

The studying dust development and its source in the spring seasons of 2011 and 2012

In order to detect the dust, the data of Moderate Resolution Imaging Spectroradiometer (MODIS) sensor from NASA's Aqua and Terra satellites were used. These images make it possible to recognize and measure aerosol columns loading from the surface to the upper atmosphere (Amanollahi et al. 2011). The MODIS has 36 spectral bands ranging in wavelength from 0.4 to 14.4 μm and can analyze the atmospheric

**Table 1** Climatic characteristics of sites selected for dust collection (1998–2009) data from Iranian Meteorological Organization (2012)

| City | Elevation (m) | Mean annual temperature (°C) | Mean annual precipitation (mm) | Mean number of dusty days per year |
|---|---|---|---|---|
| Ahwaz | 22/5 | 25/9 | 239 | 73 |
| Kermanshah | 1,318 | 15 | 435 | 32 |
| Qasre Shirin | 333 | 20/1 | 421 | 38 |
| Bandar-e Mahshahr | 6/2 | 25/6 | 213 | 47 |

phenomenon such as temperature, clouds, aerosols, and surface properties (Huang et al. 2007). For geometric correction, ground control points with 2,500 warp points were used and were resampled by the nearest neighbor method. Also, dust storms were detected based on brightness temperature characteristics. In this method the images radiance values were converted to brightness temperature through the inverse Planck function (Xia 2010) (Eq. 1):

$$T = \frac{hc}{\lambda \; ik \; In\left(\frac{2hc^2}{L(\lambda i)\lambda i^5} + 1\right)} \tag{1}$$

Where $T$ is brightness temperature, $h$ is Planck's constant ($6.6265 \times 10{-}34$ Js), $c$ is velocity of light ($2.998 \times 10^8$ m/s), $k$ is Boltzmann's constant ($1.3806558 \times 10{-}23$ J/K), $L$ ($\lambda i$) is calibrated spectral radiance, and $\lambda i$ is central wavelength (in micrometre). Ackerman (1997) investigated the sensitivity of thermal infrared bands to dust and found that brightness temperature difference between 3.7 and 12 μm, and brightness temperature differences between 11 and 12 μm allow dusting extraction. Since bands 31 and 32 (11 and 12 μm) are within the thermal infrared range, the brightness temperature difference between 11- and 12-μm bands in the spectrum can be used for the detection of dust storms from other climatic phenomenon such as clouds and deserts lands (Huang et al. 2007). Because the effect of dust storms in radiation reduction in band 31 is more than in band 32; thus, the brightness temperature for band 31 will be less than the value of band 32 and will be negative for dust ($\Delta BT31{-}32{<}0$).

Following the above mentioned procedure, the HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model was used to determine the main sources of dust storm

**Table 2** Date and locate of sampling

| Sample | Collection date | Mean TSP Concentration (µg/m$^{-3}$) | Locate of Sampling |
|---|---|---|---|
| DS1 | 4 April 2011 | 1,953 | Kermanshah, Ahwaz, Qasre shirin |
| DS2 | 13 April 2011 | 3,900 | Kermanshah, Ahwaz, Mahshahr |
| DS3 | 3 Jun 2011 | 4,500 | Kermanshah, Ahwaz, Mahshahr, Qasre shirin |
| DS4 | 19-20 April 2012 | 315 | Kermanshah, Qasre shirin |
| DS5 | 24May 2012 | 1,003 | Kermanshah, Qasre shirin, Ahwaz |

by using a backward trajectory approach in the study periods. The HYSPLIT model is a complete system for computing trajectories, complex dispersion, and deposition simulations by using either puff or particle approaches. It consists of a modular library structure with main programs for each primary application: trajectories and air concentration (Draxler 2007). In this study, the 4.9 version of HYSPLIT model and FNL data were used for running the model. Indeed, FNL data

are NCEP data which are reanalyzed by Air Resource Laboratory (NOAA). The horizontal resolution of this data is 0.5°× 0.5° and for 26 vertical levels (100 to 1,000) with six-hourly step time from 2007 are available. The six-hourly archive data were taken from NCEP's GDAS. The GDAS is the final run in the series of NCEP operational model runs; therefore, it is known as the Final Run at NCEP and includes late achieved conventional and satellite data.

Also, because the development of dust storms in the Middle East are related to atmospheric flows, surface pressure, intensity of winds and humidity in desert lands; thus, weather maps were used for determining dust storm tracks and, eventually, dust storm sources in study periods. The analyzed parameters, in a six-hourly global data analysis with 2.5°×2.5° resolution from the NCEP/NCAR reanalysis, included sea level pressure, geopotential height, U (zonal) and V (meridional) components of winds in surface charts.

Dust storms load analysis methods

a. Mineralogy

Different mineral components in airborne dust samples were analyzed by X-ray diffractometer (XRD). The XRD technology is one of the best methods for determining the
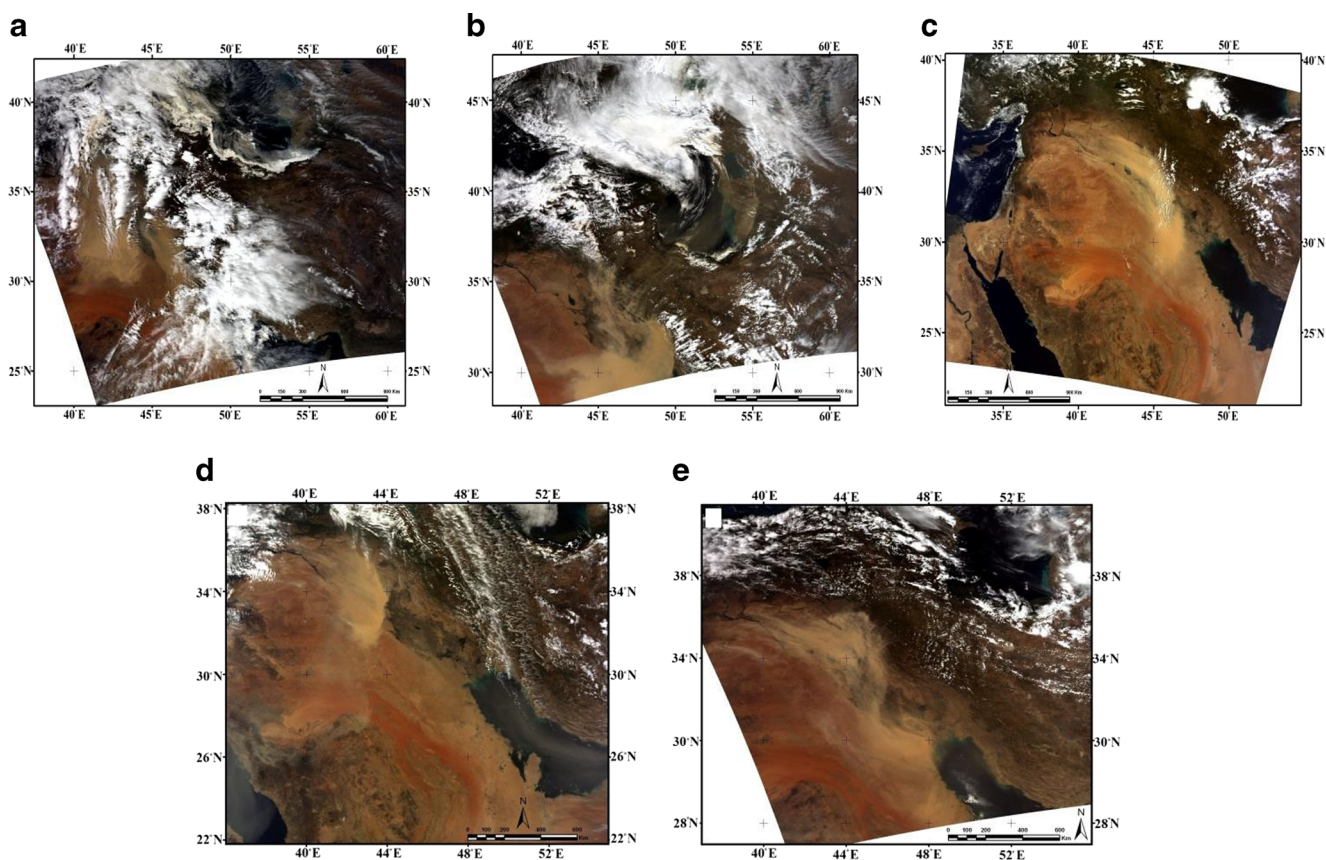


**Fig. 2** Satellite images of dust storm days on the dates of sampling using MODIS imagery

minerals. Different minerals have different lattices and crystal structures and thus different inter-planar spacing's. The XRD technology identifies the phase of mineral powder by measuring the inter-planar spacing (Shao et al. 2007). The XRD analysis was performed in the Tarbiat Modares University Laboratory (Iran). The model of X-ray diffractometer was X Pert MPD—Philips (Netherland), which is equipped with Co Ka radiation at the wavelength of 1.78897 A°. The range of $2\theta$ was 2–60° with a scanning step of 0.02°/s. The XRD data were analyzed by Diffract and PwderX softwares. Then, the spectra obtained from XRD analysis with the standard patterns of minerals were compared and identified.

b.   Element composition and trace element analysis

Analyses of chemical composition and trace element characteristics of dust storm are an essential approach in studies on the environmental impacts of dust storms. Knowledge of the chemical composition of airborne dusts is important for clarifying the likely source(s) of dusts and understanding their possible effects on environmental health, soils, precipitation, ocean biogeochemistry, and weathering (Goudie and Middleton 2006). Chemical compositions of the samples were performed by X-ray fluorescence spectroscopy (XRF) in the Tarbiat Modares University Laboratory (model: PW2404-Philips/ Netherland). The instrument was equipped with an Rh tube and fused borate glass beads. For this analysis, after sample preparation, 3 g of each dust sample were pressed into pills using Elvacite.

Analyses of toxic trace elements, in order to determine major trace elements Fe, Pb, Zn, Cd, Co, Cr, Cu, and Ni concentration of airborne dust were performed using an Atomic Absorption Spectrophotometer (Model: Spec AA 220/Varian). The instrument was equipped with an air acetylene burner, D2 lamp and Varian hollow cathode lamp. To prepare dust samples for atomic absorption analysis, 1 g from each dust sample was added to 10 cm$^3$ HClO$_3$ and HNO$_3$. Then, the mixture was digested for an hour, at 40 °C and for 4 h at 140 °CC on Hot Plate Digester instrument. Then, the mixture was cooled and diluted with distilled water to 25 cm$^3$ of volume.

c.   Microorganism analyses

Microorganisms were characterized by culture-based assays. For bacteria analysis, dust samples were cultured in BHI agar, MacConkey agar, and blood agar medium and, then, incubated at 24–36 h under microaerophilic environment at 37 ° C. All strain was characterized and identified using Gram staining, biochemical test, and their morphology.

Usually, bacteria were found in large numbers in the environmental dusts and soils; thus, the direct colony count was difficult. The bacteria were isolated by serial dilution method and BHI agar, MacConkey agar and blood agar medium according to their morphologies. At this stage, the tenfold dilution method was used in order to count and identify the growing bacteria (Al-Dabbas et al. 2010). In tube one, 1 g of dust sample was added in 9 ml of distilled water to get 1:10 dilution; then, 1 ml was added to the second tube on 1:10 dilution, followed by a twofold serial dilution. The procedure was gradually followed until we obtained a 1:10,000,000 ($1 \times 10^{-10}$) dilution (Al-Dabbas et al. 2010). Then, $10^{-6}$ to $10^{-10}$ dilution were cultured in BHI agar and incubated at 24 to 36 h under ambient conditions at 37 ° C. Finally, to identify and isolate gram-positive and gram-negative bacteria, dust was diluted in blood agar and MacConkey's mediums were cultivated and incubated at 24–36 h under ambient conditions at 37 ° C.

For fungi analysis, samples were cultured in Subaru dextrose agar. The medium was exposed to the atmospheric dust for approximately 24 to 36 h and then plates were incubated at room temperature for 72 h. All strains were characterized using morphological and biochemical tests.

## Results and discussion

Determination of dust provenance

Usually the annual dust cycle is associated with seasonal shift in westerly winds, rainfall and soil moisture (Engelstaedter et al. 2006). Many studies show that the main atmospheric circulation patterns in dust days are Mediterranean trough, Red Sea trough and Azores Sub-Tropical high pressure for 500-hPa level, Sudan low pressure and Gang low pressure for sea level pressure (Khoshhal Dastjerdi et al. 2012). Also for dust formation in the Middle East, the thresholds of surface wind speed in warm and cold periods are 6 and 8 m/s, respectively. In order to identify dust sources in 2011 and 2012 springtime dust storms in the west of Iran, based on the surface and the upper levels weather maps of the day before the dust occurrence, the backward trajectory scattering of dust during the 24 h before the dust storm was recorded in meteorological stations in the study area and using remote sensing methods in dusty days.

By using remote sensing methods, six regions, in the west of Iran, were recognized as the main sources of dust emission for the west of Iran (Samadi 2011) (Fig. 3). But after reviewing the satellite images of other dates of dust storms, we recognized that Sahara desert in the north of Africa and arid lands in Khuzestan providence in Iran were also the secondary sources for dust emission in the Middle East region. As a result, the pressure gradient between the Azores high pressure system and the thermal low pressure system, located over the Arabian Peninsula, directs from west to east, leading to a stronger pressure gradient between Asia and northeast of Africa and causing a greater amount of dust in the event by
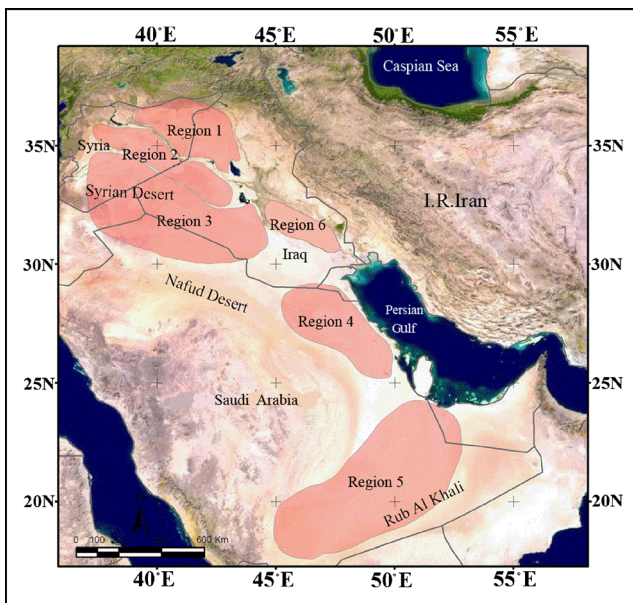
**Fig. 3** Main sources of dust emission for the west of Iran (Samadi 2011)

carrying a large amount of dust from Northeast Africa deserts to Asia (Awad and Mashat 2013).

The weather map in April 3, 2011 [Fig. 4( A-1)], shows the formation of a low height in westerly waves in 500 hPa, causing a trough in the eastern Mediterranean Sea. Mediterranean trough is one of the main atmospheric circulation patterns in the formation of dust in the Middle East (Khoshakhllagh et al. 2012). Also, the expansion of the tongue of Sudan's low-pressure over Iraq and northeast of the Arabian Peninsula leads to an increase in pressure gradient in the Middle East with tongue of Siberian High pressure that, in turn, causes an increase of wind speed up to more than 8 m/s in the region. As a result, the formation of an unstable zone at the surface-level convergence area and under the upper-level divergence area, as well as a lack of moisture at the surface sediment level in the Middle East desert lands lead to dust formation. By horizontal flows and their movements toward Iran, the dust storms transfer to the study area. Consideration the backward trajectories in 24-h before that dust particles arriving at meteorological stations, and of satellite images in dusty days shows that the main sources of dust are arid regions in the middle and south of Iraq and northeast of the Arabian Peninsula [Fig. 4(B-1) and (C-1)].

Similar to the previous period, Mediterranean deepened trough is the main atmospheric circulation pattern in 500 hPa for the formation of dust storm in the north of Iraq on April 13, 2011 [Fig. 4(A-2)]. The placement of the trough in westerly winds and of a cyclone in the middle of Iraq through to northern Turkey leads to an intensification of pressure gradient and an increase of wind speed up to more than 8 m/s around the cyclone. However, this does not result in the generation and high-volume ascension of dust particles from the deserts of Iraq.

The 500-hPa patterns [Fig. 4(A-2)] show sub-tropical high-pressure center in the south of the Arabian Peninsula and its placement causes stable conditions in this region. The sea level map [Fig. 4(A-2)] shows that the expansion of thermal low pressure in the Arabian Peninsula causes a more unstable condition in the region. In the same vein, an increase of wind speed and a lack of humidity lead to dust storms especially in the central and eastern deserts of the Arabian Peninsula. In this period, the dust storm in the southwest of Iran was most extreme. The secondary sources of dust storm in this period were the border areas of Syria and the middle regions of Iraq, and the main sources were desert lands in the north and northeast of the Arabian Peninsula [Fig. 4(B-2) and (C-2)].

In the third case (June 2 and 3, 2011), because the location of sub-tropical high pressure in June is in the north of Africa and in the center of the Arabian Peninsula, the activity of westerly migrating systems is limited to higher latitudes and causes a stable atmosphere in low latitudes in the Middle East (in Iran and Iraq). So, in this period, the formation of dust storm is the result of thermal conditions on the surface. In warm periods in the Persian Gulf and the Sea of Oman, the Persian Gulf low pressure is the main atmospheric circulation pattern in sea level pressure [Fig. 4(A-3)]. As a result, the increase of air temperature causes expansion of the tongue of Persian Gulf low-pressure center to Iraq. The lack of moisture, the increase of wind speed, and unstable atmospheric conditions are caused by the ascending of surface air parcels which continue to form the dust storm in Iraq and the border of Syria and the Arabian Peninsula. The tracing of dust particles in satellite images showed that the sources of dust storms were located in the common border of Syria and Iraq, center and south of Iraq and northeast of the Arabian Peninsula [Fig. 4(B-3) and (C-3)].

Since the maximum time of dust particles arriving at the western borders of Iran was 12 to 24 h and, in this period, dust particles at the end of the day arrived at the borders of Kermanshah province, the weather map of April 19, 2012 was analyzed. In this period, the main sources of dust storm included the desert lands of eastern Syria and western Iraq. The formation of trough in the 500 hPa and of cyclone at sea level in the east of the Mediterranean Sea resulted in intensifying the unstable condition and increasing the wind speed in Syria and the borders of Iraq [Fig. 4(A-4)]. Also, the lack of humidity supply caused the ascension of dry air and the formation of dust occurrences in this period. The trajectory of dust particles and satellite images [Fig. 4(B-4) and (C-4)] showed that the main sources of dust were the Syrian Desert, arid lands in central Mesopotamia (the area between the west bank of Euphrates and the east bank of Tigris), and southern Iraq.

The last period was May 2, 2012: The weather map showed that the main factors leading to dust storms were the expansion
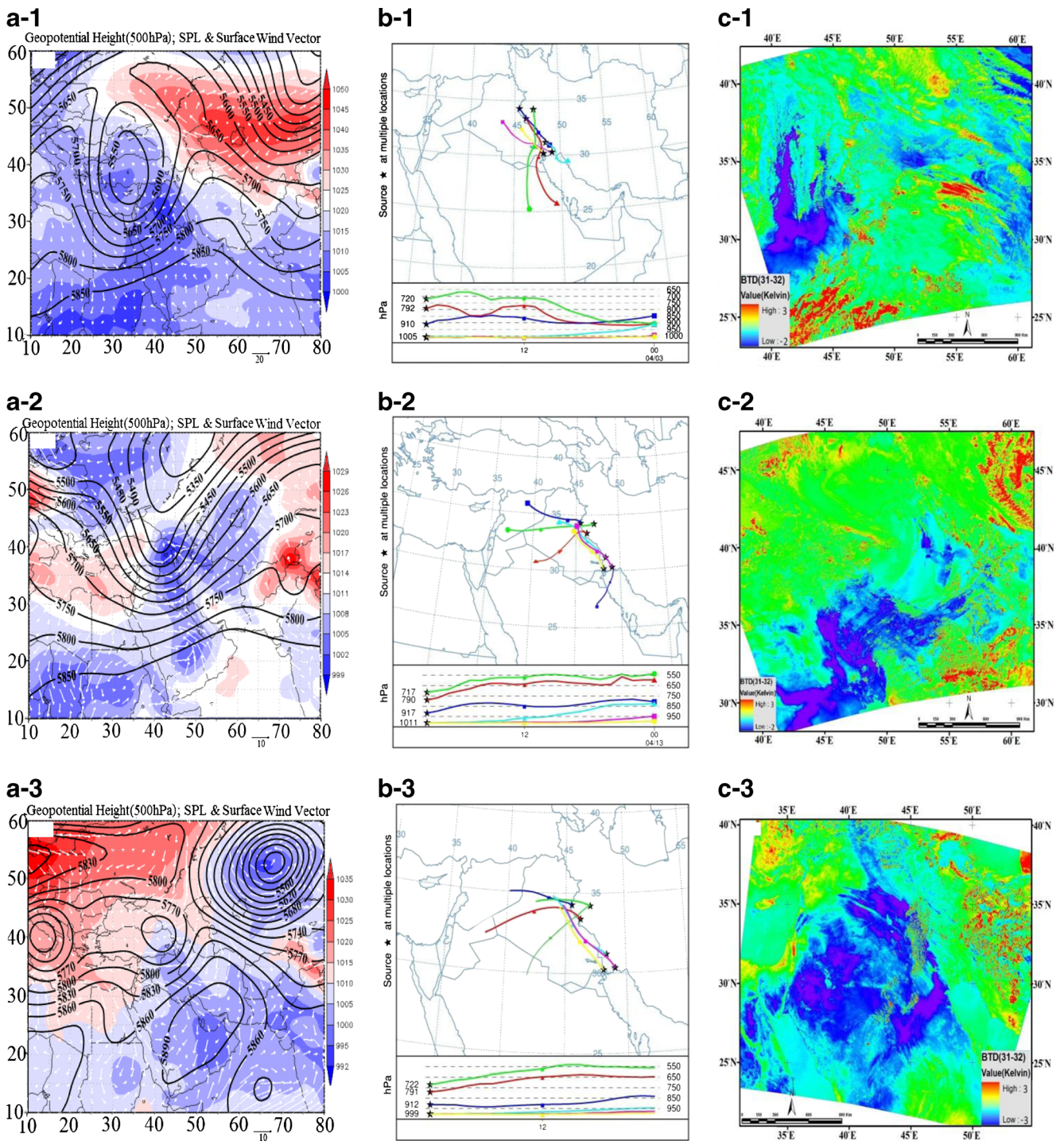
**Fig. 4** Weather map include: (*A*) Geo-potential height in 500-hPa level (contours), sea level pressure (*shaded*), wind direction (*vector*); (*B*) backward trajectory of dust particles—outputs of HYSPLIT model; (*C*) detection and tracking of dust storm over the Middle East using MODIS imagery (note: the negative quantities are Middle Eastern dust storms). *1*, *2*, *3*, *4*, and *5* for (*A*) and (*B*) are: 03 April 2011, 12 April 2011, 02 June 2011, 19 April 2012, 23 May 2012, and for (**c**) are: 04 April 2011, 13 April 2011, 03 June 2011, 19 April 2012, 24 May 24 2012, respectively

of the tongue of Gang low-pressure center to the Persian Gulf, Iraq, and Syria. Also, the atmospheric pattern in 500 hPa was that of the Mediterranean deepened trough [Fig. 4(A-5)]. So, the creation and emission of dust were under the influence of expanding thermal low pressure at the surface level of the

Persian Gulf and Iraq; and consequently, they intensified the unstable condition and increased the wind speed in the desert lands of this region. As a result, the ascension of dry air led to the formation of dust in the Middle East and its transference to the west of Iran. The trajectory of dust particles and satellite
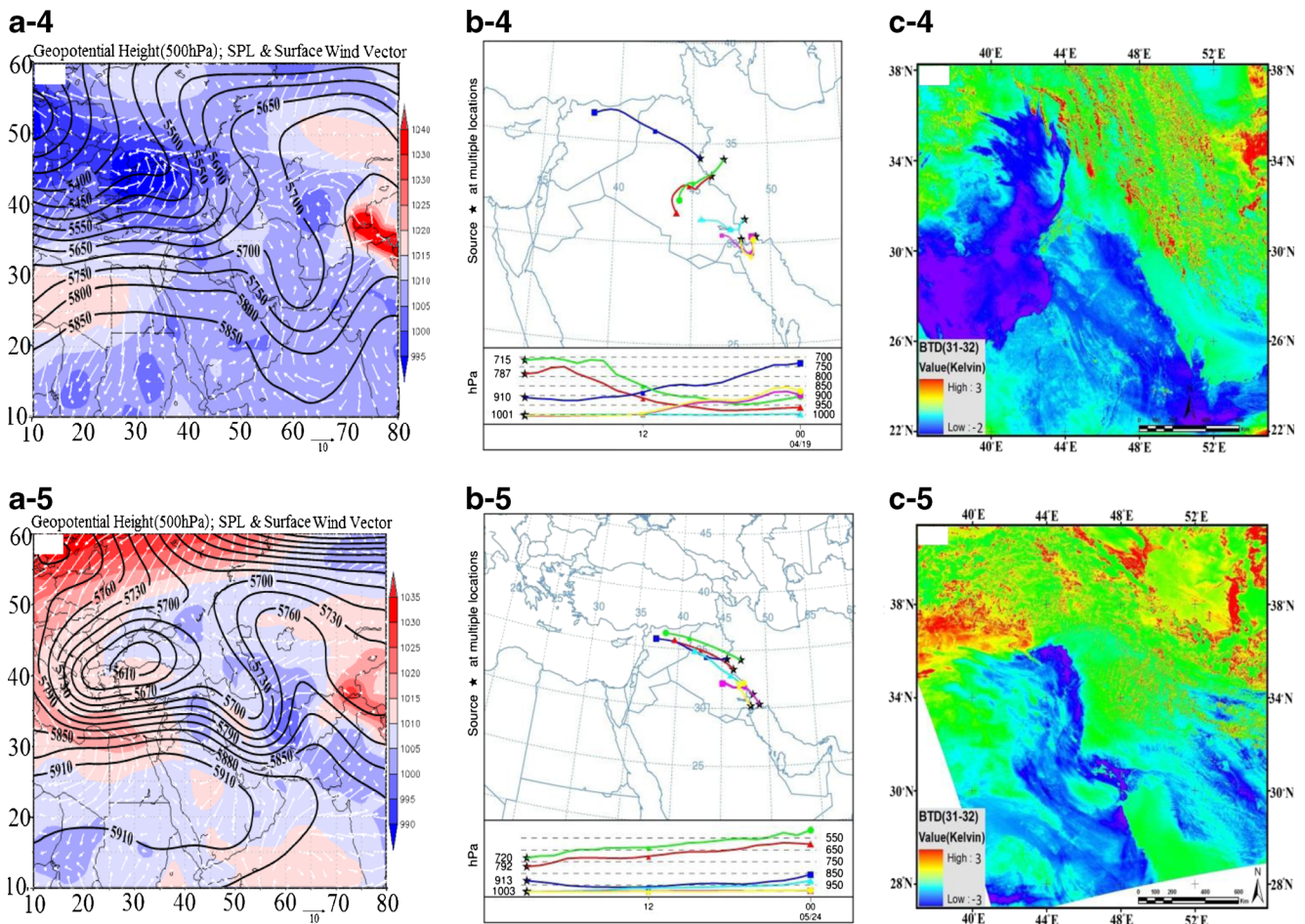
**a-4** Geopotential Height(500hPa); SPL & Surface Wind Vector

**b-4** Source ★ at multiple locations

**c-4**

**a-5** Geopotential Height(500hPa); SPL & Surface Wind Vector

**b-5** Source ★ at multiple locations

**c-5**

**Fig. 4** (continued)

images [Fig. 4(B-5) and (C-5)] showed that the main sources of dust in this period were the Syrian Desert, desert lands in the west, middle and south regions of Iraq. Finally, Table 3 categorizes the main sources of five dust storms in the springtime of 2011 and 2012. In comparison with Boloorani et al. (2012), who founded that the major sources of dust in the west of Iran were the area between Euphrates and Tigris in the middle and south regions of Iraq, Rub' Al Khali desert, and Saharan desert, and also, in comparison with Notaro et al. (2013), who founded that the main sources of dust in Saudi Arabia were An Nafud desert, Ad Dahna desert, Rub' Al Khali desert, Saharan desert and Iraqi desert, the results of the present study show that the primary sources of springtime dust storm in the west of Iran include Iraqi desert, Syrian desert, Saudi Arabian deserts, and Hoor Al-Hoveyzeh lagoon in Khuzestan province, in the southwest of Iran.

The mineralogy of dust samples

The mineralogy of dust depends on the geology and soil of the source area and its climate conditions. By mineralogical study, the main source of dust in the deserts and sedimentary basins

of the Middle East can be detected. Also, by studying clay mineral composition of dust samples, the source of dust storms is traceable (Ganor and Foner 1996). By detecting the mineralogical content of dust, the mechanism of dust variability and continental providence of dust source can be partially understood (Sokolic et al. 1998). A large number, but similar variety of minerals, was observed in all samples (Fig. 5, Table 4). The mineralogical content of dust samples showed that major mineral particles in the samples were composed of carbonate and silicate minerals. Based on XRD analysis, major particles in all samples were calcite and quartz. The abundance of calcite and quartz in all samples indicated the detrital sedimentary origin in the source of dust storms (Zarasvandi et al. 2011). The mineralogical characteristics are consistent with the element composition (Table 5). This finding also well reflects the variability of the carbonate composition in Middle East springtime dust storm (MESDS) in western Iran. Many studies about the geology of the Middle East reported that Khuzestan province as well as the middle and eastern regions of Iraq were probably the main source of carbonate in dust storms in western Iran (Raespour 2008; Engelbrecht et al. 2009). Also, a similar mineralogy

**Table 3** Dust storm sources in case studies

| Dust Storm | Source(s) of dust storm |
| --- | --- |
| DS1 | Middle of Iraq, deserts lands in south east of Iraq and north east of Arabian Peninsula |
| DS2 | South and southeast of Syrian desert, west and middle Iraq, North of Arabian Peninsula a region called Nafud desert, the coastal region in east of Arabian Peninsula |
| DS3 | South of Syrian desert, North of Arabian Peninsula (Nafud Desert), middle and south of Iraq |
| DS4 | Syrian Desert, The area between the west bank of Euphrates and east bank of Tigris, deserts lands in south of Iraq |
| DS5 | Syrian Desert, desert lands in west of Iraq, the area between Euphrates and Tigris in middle and south of Iraq |

with predominant carbonates and quartz was reported for dust occurrences in the Middle East (Singer et al. 2003), Saudi Arabia (Kalderon-Asael et al. 2009), and Iraq (Awadh 2011). Quartz, calcite, albeit, muscovite, clinochlore, and dolomite were common minerals in all samples but other minerals such as gypsum, orthoclase, actinolite, and palygorskite were present only in some of the samples.

Gypsum was observed in DS2, DS4, and DS5 that indicates a playa origin with evaporative minerals in the Middle Eastern dust storm. The back trajectory of HYSPLITE model shows that air masses ending at the west of Iran for DS2 originated from the north and south of the Syrian Desert, An Nafud Desert, and desert lands in the Northeast of the Arabian Peninsula. For DS4 and DS5, air masses were carried nearly in the same pathway to the west of Iran, which were originated air masses directly coming from the east of Syria, the middle and south regions of Iraq (the area between Euphrates and Tigris). The presence of gypsum in mentioned samples shows that the mineral dust originating from the north and south of the Syrian Desert, north of the An Nafud Desert, northeast of the Arabian Peninsula, and the middle of Iraq carried abundant gypsum. Therefore, evaporative minerals such as gypsum may serve as a useful tracer for the origin of dust in the Middle East. The presence of palygorskite in some samples could be used for recognizing the source of dust occurrences (Hojati et al. 2011). Palygorskite was probably derived from paleo-lacustrine sediments (Velde 1995) and is common in soils and sediments of arid and semi-arid regions with unstable climate and with precipitation levels of lesser than 300 mm (Singer 1989). The existence of Palygorskite was reported in the sediments and soils of the northern and southern deserts of Iraq (Al-Juboury 2009), Jordan (Shadfan and Dixon 1984) and the Arabian Peninsula (Shadfan et al. 1985).

So, the presence of palygorskite in most samples confirms that the sources of dust storm in the west of Iran are arid and semi-arid regions in Iraq, Jordan, the Arabian Peninsula, and Syria. The most varied mineralogy was seen in samples DS1

and DS5 which could be indicative of various sources, and the least varied mineralogy was seen in sample DS2 which indicated a limited source area. The results of mineralogy were in agreement with other studies on the mineralogy of the Middle Eastern dust storm, such as studies by Zarasvandi et al. (2011), Awadh (2011), Rashki et al. (2013), and Hojati et al. (2011). A similar mineralogy with predominant carbonates and silicates was reported for the falling dust sediments in Saudi Arabia (Modaihsh 1997). Al Dabbas et al. (2010) showed that the major minerals in Iraq dust storms were quartz 58.6 %, feldspars 17.3 %, calcite 15.4 %, and gypsum 5.5 %. About the mineralogy of dust storm in other parts of the world, Shen et al. (2009) showed that the major minerals in the East Asian dust storm were illite, kaolinite, chlorite, quartz, alkali, feldspar, plagioclase feldspar, calcite, and dolomite. Results of the mentioned studies show that carbonate provides a useful tool for tracing the provenance of long-range atmospheric transferred Asian dust to regional sources while evaporative minerals such as gypsum are useful for detecting the origin of dust in the Middle East. Also in another study, feldspar and quartz were common minerals in Harmattan dust in Africa (Changling et al. 2007) whereas the main components of minerals in MESDS were carbonates (mainly calcite) and silica (mainly quartz).

Element composition and trace elements analysis

The main factor that influences the element composition of dust particles is the mineralogy of dust source. Previous investigations show that the main chemical components of airborne dust particles in most dust storm areas of the Northern Hemisphere are $SiO2$ (59.99 %), $Al_2O_3$ (14.13 %), $Fe_2O_3$ (6.85 %), CaO (3.94 %), MgO (2.60 %), and $K2O$ (2.35 %) (Goudie and Middleton 2006). Element composition of dust samples in the spring seasons of 2011 and 2012 (Table 5) shows the predominance of silicate and carbonate minerals, i.e., $SiO_2$ (34.82 %), CaO (20.48 %), and $Al_2O_3$ (8.44 %). $SiO_2$ was the most abundant as compared to the other elements (Table 5) similar to those of normal airborne dusts worldwide. In comparison, the mean concentration of major elements including $SiO_2$, $Al_2O_3$, and $Fe_2O_3$ in MESDS was less than those of normal airborne dusts worldwide, but the mean concentration of CaO in MESDS was more than the normal level of element composition worldwide. Based on element analysis results, we suggest that the silicates (quartz) have a greater abundance. Due to the abundance of CaO, Carbonates are another important constituent of the dust samples. Thus, the abundance of $SiO2$, CaO, and MgO in airborne dusts in western Iran is mainly due to the presence of quartz, calcite, and dolomite that are the main mineral element components of dust particles. Also, the abundance of quartz in dust storm and sand dunes—indicating mature sediments—and quartz is a function of the weathering intensity, while the abundance of

**Fig. 5** XRD patterns of TSP collected during severe dust storms in DS1 (*A*) and DS2 (*B*)
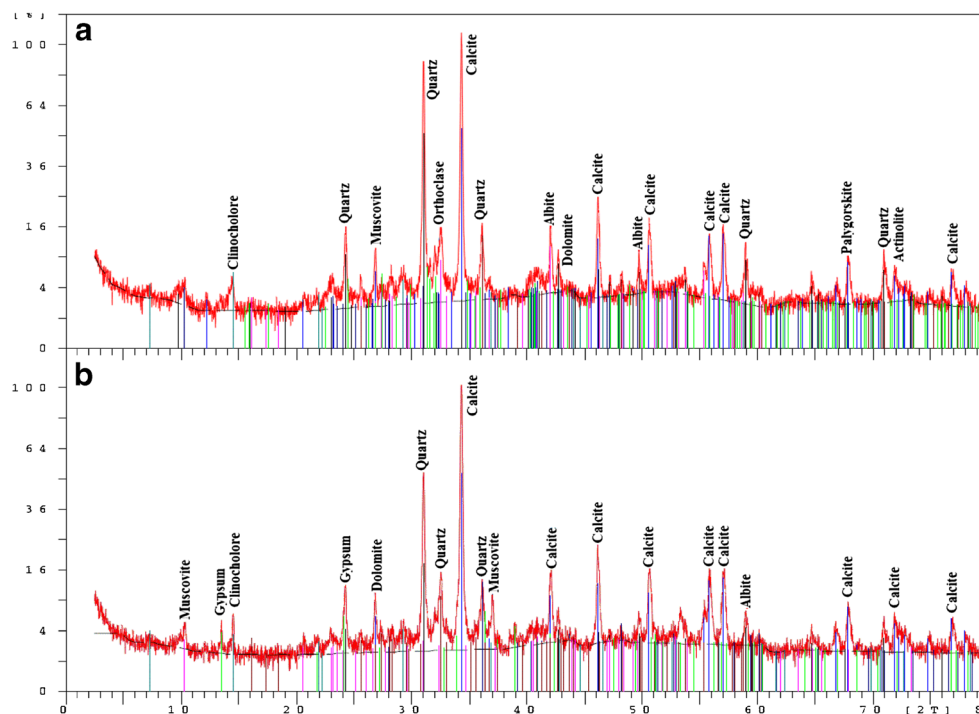


alkalis ($K_2O$ and $Na_2O$) reflects the high quantity of feldspar, relatively indicating immature sediments (Awadh 2011). Thus, the abundance of silicates in MESDS indicates mature sediments in the sources of dust. The mean of loss-on-ignition (LOI) was 23.88 % and values of this in the range of 3–40 % indicate decomposition of hydrated minerals (Engelbrecht et al. 2009). Zarasvandi et al. (2011) showed that the mean concentration of element components of dust storms in the west of Iran were 37.9, 13.5, 10.9, and 10.5, respectively for $SiO_2$, CaO, $Al_2O_3$, and MgO. Also, Engelbrecht et al. (2009) found that the main oxide composition of $PM_{10}$ and $PM_{2.5}$ in Middle Eastern dust storms were $SiO_2$, CaO. In another study, Rashki et al. (2013) showed that the most important oxide compositions of the airborne dust in the Sistan region in the

east of Iran were $SiO_2$, CaO, $Al_2O_3$, $Na_2O$, and MgO. These studies show a similar abundance in the element composition of MESDS with airborne dusts from other parts of the world and are in accordance with other studies on the oxide composition of Middle Eastern dust storms.

Comparison of element concentration in five periods of sampling (Table 5) shows that the major elements in sample DS2 are different from others. This indicates that the sources of dust storms were different from one another. Because the source of dust occurrence in this sample was mainly the northeastern parts of the Arabian Peninsula and sand shores of the Persian Gulf, the mineral compositions were different. Also, because the sources of dust particles in other samples were similar to some extent, the element composition of dust samples was partly the same.

In addition to element composition, various heavy metals are present in MESDS samples. Air quality is defined by its three aspects of physical, chemical, and biological characteristics as the characteristics of air influence its suitability for human activity and other organisms (Al-Hurban and Al-Ostad 2009). Heavy metals cause air, soil, water, and vegetation pollution which can be a threat for human health and the ecosystem. The sources of heavy metals fall into two categories: natural and anthropogenic (Al Dabbas et al. 2010). Nowadays, with the development of industrial activity and increase in the number of vehicles, an increase of heavy metals in the atmosphere is observed. For example, the possible anthropogenic sources for Cd are household-waste combustion and fossil-fuel burning, and for Pb, it includes leaded gasoline, fuel combustion, industrial processes, and solid waste

**Table 4** Mineralogy of spring time dust storm in the west of Iran

| sample | Major minerals | Minor minerals |
|--------|----------------|----------------|
| DS1 | Calcite, quartz | Albeit, Orthoclase, Muscovite, Clinochlore, Dolomite Actinolite, Palygorskite |
| DS2 | Calcite, quartz | Muscovite, Gypsum, dolomite, Clinochlore, Albeit |
| DS3 | Calcite, quartz | Orthoclase, Albeit, Muscovite, Clinochlore, Dolomite, Palygorskite |
| DS4 | Calcite, quartz | Albeit, Gypsum, Dolomite, Muscovite, Clinochlore, Palygorskite |
| DS5 | Calcite, quartz | Albeit, Orthoclase, Muscovite, Clinochlore, Dolomite, Palygorskite, Gypsum |

**Table 5** Element composition and trace element of springtime dust storm in western Iran

| Samples | DS1 | DS2 | DS3 | DS4 | DS5 | Mean |
|---|---|---|---|---|---|---|
| Major elements (%) | | | | | | |
| $Na_2O$ | 0.61 | 1.43 | 0.6 | 0.68 | 0.98 | 0.87 |
| MgO | 4 | 3.48 | 5.08 | 4.36 | 4.2 | 4.22 |
| $AL_2O_3$ | 8.22 | 6.17 | 10.55 | 9.24 | 8.04 | 8.44 |
| $SiO_2$ | 37.52 | 28.33 | 38.69 | 36.46 | 33.13 | 34.82 |
| $P_2O_5$ | 0.17 | 0.17 | 0.22 | 0.18 | 0.17 | 0.18 |
| $SO_3$ | 0.44 | 0.61 | 0.29 | 1.01 | 0.83 | 0.63 |
| Cl | 0.2 | 0.78 | 0.12 | 0 | 0.48 | 0.306 |
| CaO | 20.29 | 25.99 | 15.97 | 18.08 | 22.08 | 20.48 |
| $K_2O$ | 1.19 | 0.82 | 1.57 | 1.47 | 1.09 | 1.22 |
| $TiO_2$ | 0.62 | 0 | 0.68 | 0.69 | 0.37 | 0.472 |
| $Fe_2O_3$ | 4.18 | 3.77 | 5.09 | 4.74 | 4.1 | 4.368 |
| Sr | 0.04 | 0.06 | 0.03 | 0.03 | 0.03 | 0.038 |
| Zr | 0 | 0 | 0.02 | 0 | 0 | 0.004 |
| LOI | 22.39 | 28.38 | 21.07 | 23 | 24.56 | 23.88 |
| Heavy metals (PPM) | | | | | | |
| Fe | 3,700 | 2,100 | 2,800 | 1,600 | 3,200 | 2,680 |
| Pb | 78 | 120 | 109 | 93 | 146 | 109.2 |
| Cd | 10 | 5 | 16 | 9 | 12 | 10.4 |
| Zn | 520 | 432 | 405 | 448 | 556 | 472.2 |
| Ni | 132 | 142 | 84 | 96 | 102 | 111.2 |
| Co | 22 | 13 | 31 | 10 | 29 | 21 |
| Cr | 126 | 145 | 118 | 115 | 138 | 128.4 |
| Cu | 44 | 63 | 33 | 52 | 58 | 50 |

combustion (Banerjee 2003). The dust particles can absorb suspended heavy metals that were produced by industrial activity or vehicles and increase air pollution. In this study, eight trace elements are studied including iron (Fe), lead (Pb), copper (Cu), cobalt (Co), cadmium (Cd), chromium (Cr), nickel (Ni), and zinc (Zn). Five samples, collected in the spring seasons of 2011 and 2012 in the west and southwest of Iran, were detected (Table 5). The most abundant heavy metals in samples were Fe (2680), Zn (472.2 ppm), then Pb (109.2 ppm) and Ni (105 ppm) per cubic meters of air.

Iron was detected in all samples at levels of 1,600–3,700 ppm and Cu was detected in all samples at high concentration levels up to 78–146 ppm. Cd was detected with varying levels between 5 and 16 ppm, while Ni, a possible human carcinogen, was detected at levels ranging from 84 to 132 ppm (Table 5). DS5 in comparison to the other samples had high levels of Pb and Zn. DS3 had high levels of Cd and Co in comparison with other samples and the maximum values of Ni, Cr and Cu were detected in DS2. The latter indicates the possibility of high levels of these eight metals in the source or in the path of dust transference (Table 3). The highest total concentration of these toxic trace metals was detected in sample DS1.

The increase of heavy metals in the atmosphere is a threat for human health in the west of Iran. For example, the nickel is commonly associated with fine particles, in the air, of diameters ranging from 0.6 to 10 μm, which are common in dust storms. The permissible exposure limit for Ni in ambient airborne dust is 1 mg/m$^3$—higher than 10 mg/m3 of Ni is dangerous for human health. Long-term exposure to nickel can produce disorders in the respiratory system and produce dermatitis (Razos and Christides 2010). The concentration of Pb in the air, in dust occurrences, is higher than the permissible exposure limit (50 μg/m$^3$). The results of heavy metal concentration tests in this study are in agreement with other studies on heavy metal and chemical composition concentration in Middle Eastern dust storms and also in other parts of the world (Al Dabbas et al. 2010; Chinnam et al. 2006; Shen et al. 2007).

Microorganism analyses for isolating bacteria and fungi

Airborne dust can carry microorganisms from its source to other regions which are exposed to dust (Kakikawa et al. 2008). Microorganisms in dust have a potentially detrimental effect on human health and may cause allergenic diseases (Griffin et al. 2001).
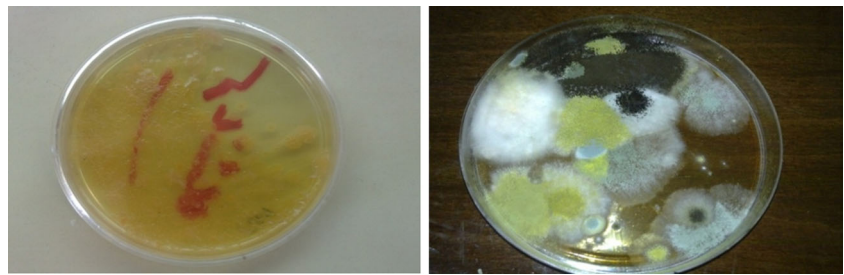
We aimed to detect bacteria and fungi in dust occurrences using culture and biochemical tests. All five samples in the current study were assessed for the presence of bacteria and fungi and test results for all dust storms were positive (Fig. 6). Usually, the abundance of microorganism in dust storms is due to the growth of these organisms on the culture media used for sampling. The best dilute for colony count and determination of the percentage of species were $10^{-6}$, $10^{-7}$, and $10^{-8}$. Also, the number of colonies that grew in the samples DS1, DS2, DS3, DS4, and DS5 were $8 \times 10^9$, $7 \times 10^9$, $6 \times 10^9$, $5.4 \times 10^9$, $7.3 \times 10^9$, and $8 \times 10^9$, respectively. Results reflect that the most frequently identified bacteria were *Bacillus* genera (41.25 %), then *Micrococcus* (10.3 %), *Staphylococcus* sp. (7.61 %), *Klebsiella* (4 %), *Escherichia coli* (2.7 %), and *Enterobacter* sp. (1.8 %), respectively. Fungal species from *Aspergillus* sp. (21.07 %), *Candida*

*albicans* (5.7 %), *Rhizopus* (2.24 %), *Penicillium* sp. (1.04 %), and *Mucor* (0.89 %) genera were the most frequently isolated in MESDS. One of the genetic advantages of fungi is that they are capable of producing spores. Spores enhance survival during the transference and periods of prolonged environmental stress (Griffin 2007).

The abundance of fungi in the dust storms depended on many factors including temperature, pH, element composition, nutrient and moisture content, and members of other phylum (Gans et al. 2005).Thus, the bacteria and fungi were most abundant during the period from April to June because the temperature and the relative humid weather in the study area were suitable in this period. Also, the highest frequency of dust storm occurrences in the west of Iran was in spring. So, microbial pollution in the spring could be at its highest level. Many

**Table 6** Microorganisms isolated from springtime dust storms in western Iran

| Microorganism | Classification | Percentage | Comment |
|---|---|---|---|
| *Bacillus* sp. | Bacteria\Gram+ rod | 41.25 | Common found in environment such as soil (Yang et al. 2003); potential human pathogen (Hoult and Tuxford 1991) |
| *Micrococcus* sp. | Bacteria\Gram+ cocci | 10.3 | Common found on water, dust and soil. As well as found on airborne dust in Egypt (Awad 2007). Can be an opportunistic pathogen, particularly in hosts with immunocompromised systems |
| *Staphylococcus aureus* | Bacteria\Gram+ cocci | 1.34 | Commonly found on the skin and hair; potential human pathogen; found in airborne dust in Middle East (Awad 2007; Al-Dabbas et al. 2010) |
| *Staphylococcus pneumonia* | Bacteria\Gram+ cocci | 4.93 | |
| *Non-pathogen Staphylococcus* | Bacteria\Gram+ cocci | 1.34 | |
| *Escherichia coli* | Bacteria\Gram− | 2.7 | Common found in food and normally find in intestine, but some cases isolated from airborne dust (Rosas et al. 1997; Al-Dabbas et al. 2010) |
| *Klebsiella* | Bacteria\Gram− | 4 | Common fond on soil and dust; opportunistic human pathogen; found in airborne dust in Middle East Awad 2007; Al-Dabbas et al. 2010) |
| *Pseudomonas aeruginosa* | Bacteria\Gram− | 1.34 | Common fond on soil and dust. Human pathogen (Poole and McKay 2003) |
| *Enterobacter* sp. | Bacteria\Gram− | 1.8 | Found in soil and airborne dust in Middle East (Awad 2007; Al-Dabbas et al. 2010); human pathogen |
| *Aspergillus niger* | Fungi | 8.07 | Common environmental isolate; over 20 species recognized as opportunistic human pathogens and a number of different allergen-related disease types in hosts with immunocompromised systems (Griffin 2007) |
| *Aspergillus flavus* | Fungi | 13 | |
| *Rhizopus* | Fungi | 2.24 | Common found in soil; opportunistic human pathogens |
| *Mucor* | Fungi | 0.89 | Common environmental isolate; rare, opportunistic, pulmonary, disseminating, cutaneous (Griffin 2007) |
| *Penicillium* sp. | Fungi | 6.74 | Very common in temperate regions, common in soil and indoors (Griffin 2007) |

studies also showed that the concentration of air-borne microorganism was high in the spring season (Morris et al. 2011). In Table 6, all species of bacteria and fungi in all airborne dust samples are listed in percent.

This study provides evidence of bacteria and fungi associated with dust occurrences in Iran and shows that it is similar to other regions in the world. Many studies also showed that bacillus genera in bacteria and *Aspergillus* sp. in fungi were the dominant microorganisms in African countries (Griffin et al. 2003), Iraq (Al-Dabbas et al. 2010), and Saudi Arabian dust storms (Kwaasi 2003). Also, microorganisms that were detected from desert samples in Africa and Asia were identified as agents of disease among humans, animals, and plants (Kwon et al. 2002; Kellogg and Griffin 2006)

## Conclusion

1. The formation of dust storms in the Middle East is under the influence of thermal and dynamical processes in the atmosphere. Due to the dominance of each circulation pattern including Mediterranean trough or Azores Subtropical high pressure in 500 hPa and also, Saudi Arabia, Persian Gulf, Sudan, and emigrate Mediterranean low pressure at sea level, the initial condition of dust formation will be provided. In addition, the increase of wind speed and the lack of humidity lead to the formation of dust in arid regions and the deserts of the Middle East.

2. By using the remote sensing technique, weather maps and the HYSPLIT model, the major sources of airborne dusts for western Iran are suggested to be dry lake beds and rivers, alluvial deposits, and desert lands in Iraq, especially the area between the west bank of Euphrates and the east bank of Tigris (Boloorani et al. 2012), as well as Hoor Al-Azim lagoon, east, northeast, and southeast of the Arabian Peninsula, and the east of Syria; and secondary sources of dust storm are suggested to be in the west of Iran with low level quantity, desert lands of Africa and Khuzestan province in Iran.

3. The dust storm loads depend on the direction of the wind and the geological formations, soil condition, and anthropogenic installation such as industrial locations that were in the pathway.

4. The results of XRD analyses show that minerals present in the MESDS can be divided into two groups: (1) carbonates (mainly calcite); (2) silicates (mainly quartz); also gypsum, albeit, muscovite, clinochlore and dolomite are the other phases of dust storm in the west of Iran.

5. XRF analyses of dust samples show that the chemical composition of western Iran dust storm is similar to some other airborne dusts in the world. The major oxides in dust storms in the study area are $SiO_2$ (34.82 %), CaO (20.48), $Al_2O_3$ (8.44 %), $Fe_2O_3$ (4.36 %), and MgO (4.22 %).

Depending on the sources of dust storm, the chemical composition of dust particles is different, because the geology, soil condition and climate in the sources of the Middle Eastern dust storm are different.

6. Based on the atomic absorption analysis, the average concentrations of heavy metals including Zn, Pb, Cd, Cu, Ni, and Co in TSP particle were 472.2, 109.2, 10.4, 52, 111.2, and 21 PPM, respectively. The concentrations of these elements were more than permissible exposure limits in ambient condition. As a result, heavy metal pollution in dust occurrences is a dangerous factor for human health in the west of Iran. Also, the carrying of dust particles across southwestern Iran, where a considerable portion of Iran's industry and population is located, caused the increase of heavy metals concentration in dust particles.

7. Ambient airborne dust microorganisms in the atmosphere over the west and southwest of Iran were investigated by culture and biochemical analyses and the six bacteria species belonging to the genus *Bacillus*, *Staphylococcus*, *E. coli*, *Klebsiella*, *Pseudomonas* and *Enterobacter* were found in dust samples. This bacterial community contains soil bacteria, common environmental bacteria, and human pathogen. Also four isolated fungi species were *Aspergillus*, *Rhizopus*, *Mucor*, and *Penicillium*, which are common in the environment.

8. The microorganism analyses demonstrated that Middle Eastern dust storms originating from desert lands of Iraq, Syria, and the Arabian Peninsula carry viable microorganisms to Iranian regions.

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