Evaluation of dust sources in Iran through remote sensing and synoptical analysis

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Abstract: Mineral dusts, as the most important type of aerosols, play an important role in climate forcing and terribly affect human health, living in the vicinity of large persistent emission sources; especially located in the arid or hyper arid regions of Middle Eastern countries like Iran. In this paper, we systematically examine the TOMS satellite absorbing aerosol product (AI) over a 25-year period (1979–2004) for the evidence of local persistent dust sources, and simultaneously evaluate the most related synoptical parameters to dust emission derived from data records of more than 150 synoptical weather stations located all around the country. The TOMS satellite data show that on a global scale the dominant sources of mineral dust are mainly located in the vicinity of salt/dry lakes or large basins of internal drainage which are assumed to be very prone sources of dusts.

Keywords: Iran; Mineral dust; Aerosols; TOMS; Synoptical parameters

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1 Introduction

There is increasing interest in the atmospheric transport of mineral dusts and monitoring their paths to find the associated hot spots where emitting large quantities of the particles into the atmosphere. Mineral dusts may play an important role in climate forcing by altering the radiation balance in the atmosphere through the scattering and absorption of radiation.

Mineral dusts could also affect climate indirectly by affecting cloud nucleation and optical properties. In addition, dusts can serve as a reaction surface for reactive gas species in the atmosphere and for moderating photo chemical processes (Prospero et al., 2002).

While a lot of progress has been made in characterizing the importance of mineral dusts in global-scale processes, there has been less progress in identifying the main prominent sources of large-scale dusts, the environmental processes that affect dust generation in local scale, and the meteorological factors that affect the subsequent transport.

The results of many field programs have identified specific types of environments that seem to be sources of mineral dusts. Similarly, many studies have characterized dust generation on a micrometeorological scale. These have shown that dust mobilization is extremely sensitive to a wide range of factors, including the composition of the soils, their moisture content, the condition of the surface, and wind velocity (Gillette, 1981, 1999).Besides the above, there are some other related synoptical parameters to the intensity of dust emission, such as temperature, number of dusty days and visibility below 2 kilometres, that can be used in local scale studies of mapping dust sources.

Remote sensing is another useful method for monitoring dust propagation in the atmosphere. Total Ozone Mapping Spectrometer (TOMS) yielded data that can be used to map the distribution of absorbing aerosols which are largely comprised of black carbon, emitted primarily from biomass burning regions, and mineral dust, most commonly emitted from sources in arid regions but also from occasional volcanic eruptions (Herman et al., 1997; Torres et al., 1998).

Because TOMS measurements are made in the ultraviolet (UV) spectrum and because the UV albedo of continental surfaces is low and relatively invariant, TOMS can readily detect absorbing aerosols over land surfaces as well as water. With TOMS one can clearly observe the occurrence of large dust events over the continents and subsequently follow the movement of large-scale plumes over the oceans (Herman et al., 1997).

While it is not possible to make an objective distinction between aerosol derived from biomass burning and that from dust sources, such a distinction can be made in a general way based on the aerosol measurements from satellite products in comparison with ground based measurements from climatic and synoptic weather stations near the study areas, and general knowledge of these regions (land use, agricultural practices, etc.).

In this paper, we systematically examine the TOMS satellite absorbing aerosol product (AI) over a 25-year period (1979–2004) for evidence of local persistent dust sources and simultaneously evaluate the most related synoptical parameters to dust emission, such as temperature, wind speed, number of dusty days and visibility derived from data records of more than 150 synoptical weather stations located all around the country.

Local identification of major sources will enable us to focus on critical regions and to characterize emission rates in response to environmental conditions. With such knowledge we will be better able to improve global dust models and to assess the effects of climate change on emissions in the future.

2 Characterization of the study area

The largest and most persistent sources are located in the Northern Hemisphere, mainly in a broad "dust belt" that extends from the west coast of North Africa, over the Middle East, Central and South Asia, to China. There is remarkably little large-scale dust activity outside this region (Prospero et al., 2002).

Dust sources, regardless of size or strength, can usually be associated with topographical lows located in arid regions with annual rainfall under 200–250 mm.

Iran is one of the countries which is located in the arid to semiarid region, with annual rainfall between 224–275 mm and has remarkable dust emission sources which are one of the most prominent ones in the dust belt shown in Figure 1.

Although the source regions themselves are arid or hyper arid, the action of water is evident from the presence of ephemeral streams, rivers, lakes, and playas. Most major sources have been intermittently flooded as evidenced by deep alluvial deposits. Historical records of dust storms in Iran show that during the past decade dust storms have increased in intensity especially in the south eastern part of the country. Population growth and a need for more food, increase to land use changes and decrease soil productivity which leads farm lands being more abandoned. Besides these activities, natural desertification processes and climate changes increase dust sources.

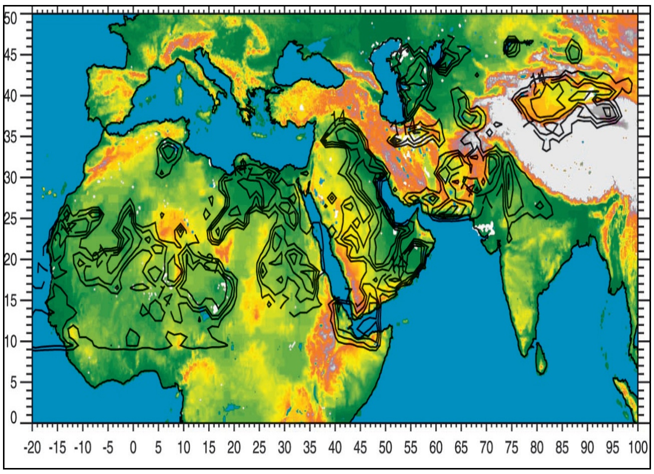


Figure 1 Dust sources in the global dust belt and their association with topographic relief (Prospero et al., 2002).

3 Synoptical data and analyses methods

In this paper, we systematically evaluate the most related synoptical parameters to dust emission, such as temperature, wind speed, number of dusty days and visibility below 2 kilometres, derived from data records of more than 150 synoptical weather stations located all around the country.

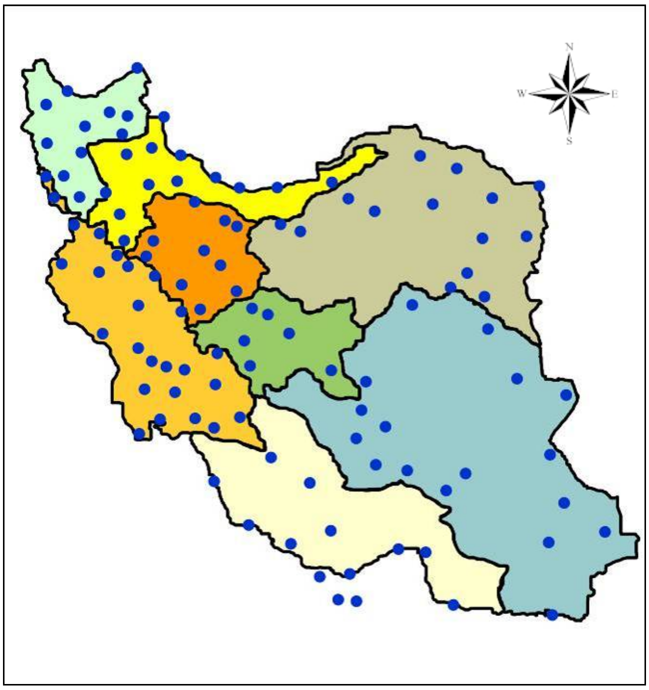


Figure 2 Spatial distribution of the synoptical stations all over the country and climatological clustering. Each cluster is shown by different colour.

Synoptical analyses of the parameters should be performed based on climatic clustering of the synoptical stations which is shown in Figure 2 by different colours.

For the assessment of spatial and regional trends of synoptical parameters, we applied two common trend detection methods, Mann-Kendall and Spearman's Rho tests, to the synoptical time series collected at the number of individual stations which has been active for at least the 15 year duration in data measuring, so climatic changes are properly considered in time series analyses.

The test results (such as trend direction and significance level) are then mapped and interpreted in terms of their spatial distribution. Mapped results for monthly number of dusty days and measured at 51 stations monthly days, with visibility below 2 kilometres measured at 60 stations in the country between 1951 and 2000 appear in Figures 3 and 4 as examples. The information depicted on the maps include, for each sampling site, an identifier, a trend direction, and the trend significance level. The site identifier is presented as a four-digit alphanumeric code. The trend detection is depicted by a triangle, pointing upward for an increasing trend and downward for a decreasing trend. A green solid circle is used to denote a site having no trend. The significance of the trend is illustrated by the colour of the triangle.

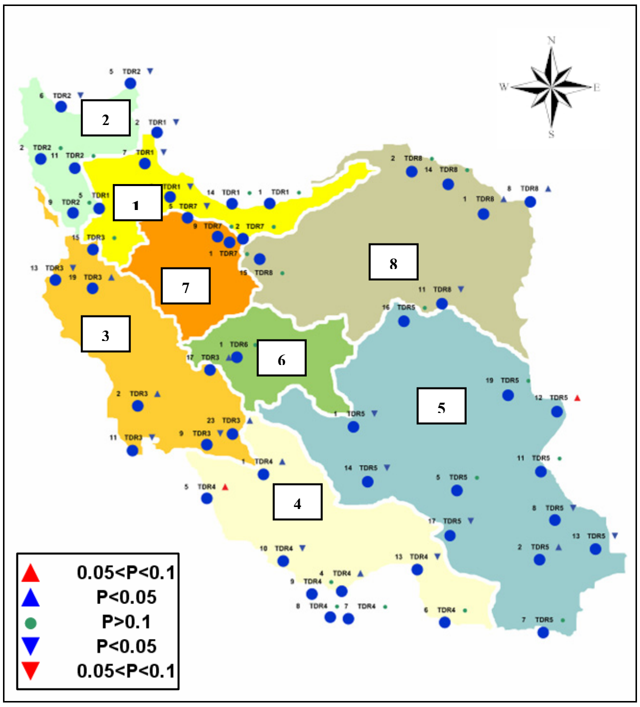


Figure 3 Monthly number of dusty days trend results based on Mann-Kendall test index. (The significance level is denoted by P).

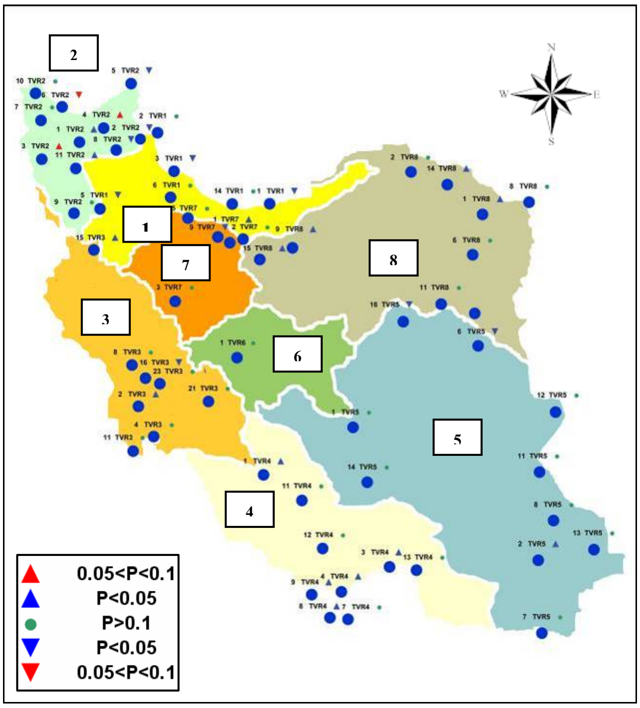


Figure 4 Monthly days with visibility below 2 kilometers trend results based on Mann-Kendall test index. (The significance level is denoted by P).

Similarly, some other synoptical parameters were tested and mapped individually to have general spatial and regional assessments.

4 Remote sensing analyses

In this paper we also systematically examined the TOMS absorbing aerosol product (AI) over a 25-year period (1979–2004) except the years 1994 and 1995, for evidence of persistent dust sources.

The TOMS data show that on a global country scale the dominant sources of mineral dusts are mainly located in the natural borders between Iran and neighbouring countries like Iraq, Afghanistan and Pakistan. Besides the mentioned regions, there are some dust sources in the large intermountain basin south of the Alborz Mountains which are stretched to the central deserts consisting largely of salt flats. TOMS also shows that there are large seasonal changes in dust distribution patterns and that these patterns often display a characteristic geometry. Although these patterns may change seasonally, sometimes disappearing during some seasons, they appear year after year. A cursory examination of maps reveals that the geometry of the TOMS aerosol distributions over specific regions can often be associated with geomorphological features, in particular, topographical lows in arid or semiarid regions.

The TOMS aerosol index is a measure of how much the wavelength dependence of backscattered UV radiation from an atmosphere containing aerosols (Mie scattering, Rayleigh scattering, and absorption) differs from that of a pure molecular atmosphere (pure Rayleigh scattering). Quantitatively, the aerosol index AI is defined to be

$$AI = 100 \log_{10}\left[\frac{I_{360}^{Meas}}{I_{360}^{Calc}}\right]$$

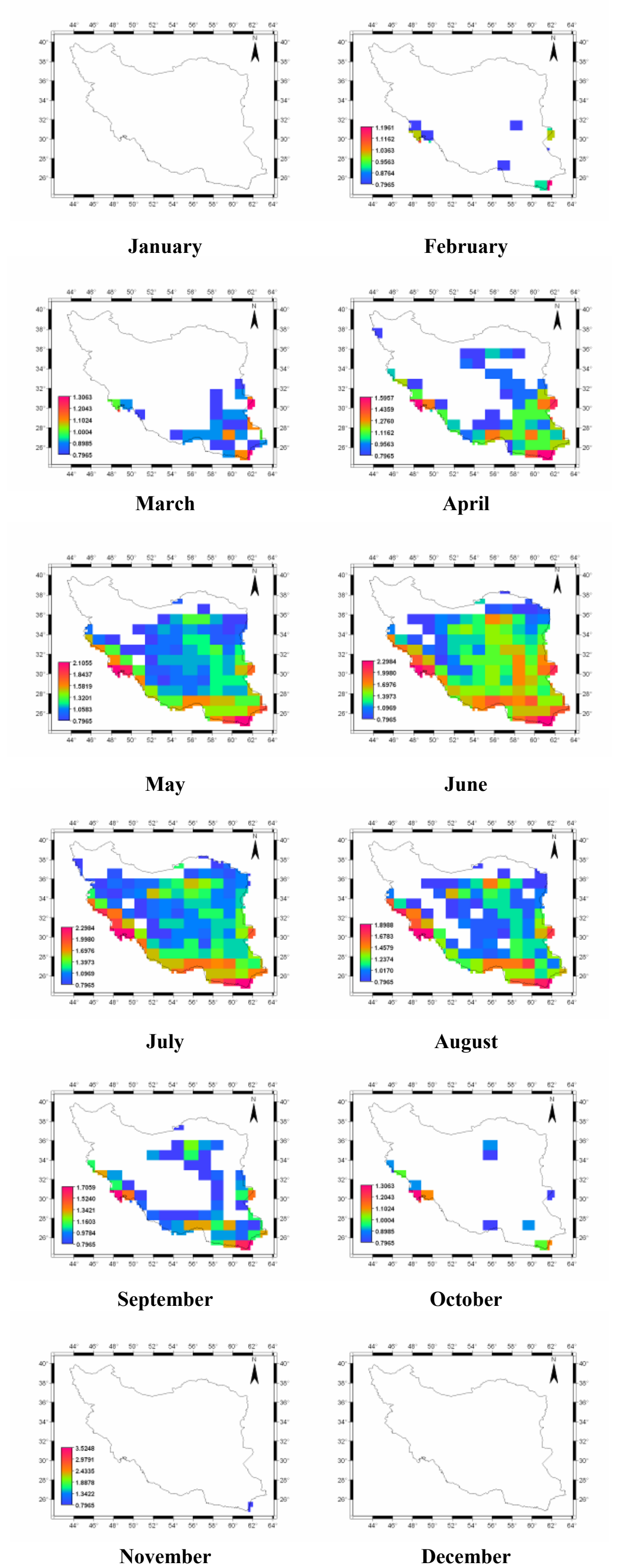
Where, I_{360}^{Meas} is the measured 360 nm EP-TOMS radiance and I_{360}^{Calc} is the calculated 360 nm EP-TOMS radiance for a Rayleigh atmosphere.

Under most conditions, AI is positive for absorbing aerosols and negative for not absorbing aerosols (pure scattering).(Hermann et al. 1997 and Torres et al. 1998)

Dust activity, for example at 1992 which is shown in Figure 5, is visible over much of the country for about half of the year. Activity is low during the winter, grows strong in March–April, and increases to a maximum in May, June and July when much of the country is covered with dust. The dust maximum observed by TOMS matches the monthly occurrence of dust storms as reported by meteorological stations.

We also identified and characterized major dust source regions on the basis of the appearance of persistent spatial-temporal patterns in the TOMS aerosol distribution.

There are two well defined active areas, most clearly seen all the year. One extends along the eastern side of the country and located at the tail end of a large closed inland basin, in one of the driest regions of the world, and a second are marshes straddling the west borders with Iraq. These two regions also stand out in both the TOMS AI and the monthly related synoptical parameters.



	January	February	March	April	May	June	July	August	September	October	November	December
		1.19	1.30	1.60	2.10	2.30	2.30	1.90	1.70	1.31	3.52	
		1.12	1.20	1.44	1.85	2.00	2.00	1.68	1.52	1.20	2.28	
		1.04	1.10	1.28	1.58	1.70	1.70	1.46	1.34	1.10	2.43	
		0.96	1.00	1.12	1.32	1.40	1.40	1.24	1.16	1.00	1.90	
		0.88	0.90	0.96	1.06	1.10	1.10	1.00	0.98	0.90	1.34	
		0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	

Figure 5 TOMS absorbing aerosol product (AI) measured over the country at the year 1992.

This information coupled with a knowledge about local environments enables us to identify those characteristics that are important for dust generation.

5 Iran main dust emission sources

Based on recent studies, one of the main dust source areas is located immediately to the south of the Caspian Sea in a large intermountain basin south of the Alborz Mountains; the source extends from Tehran (35.6_N, 51.3_E) eastward to ~60_E.As Tehran is one of the most air polluted cities in the world with considerable aerosol production which are largely comprised of black carbon (i.e., soot), emitted primarily from biomass burning, making an objective distinction between aerosol derived from biomass burning and that from dust sources has some difficulties. Within the basin is the Dasht-e-Kavir desert (48,000 km2), which appears to consist largely of salt flats (Gill, 1996) and particularly centred over the western part of the basin (in the region close to Tehran) where there are many large drainage channels and a number of ephemeral lakes and marshes, including a large intermittent salt lake, Daryacheh-ye Namak (1807 km2).

Another considerable dust activity can be seen along the coast of the Persian Gulf and the Arabian Sea of Iran and Pakistan, on the southern flanks of the mountain chain that parallels the coast. There is one particularly active source in a small intermountain valley centred at 27.5_N, 59_E. At the centre of this valley is a large salt/dry lake (Hamun-e-Jaz Murian, 1087 km2). The fact that so many of these sources in this region can be associated with salt/dry lakes suggests that the lakes themselves are important sources of dust. Many of the sources in the Iran-Afghanistan-Pakistan region contribute to the very high dust concentrations observed over the northern Arabian Sea (Tindale and Pease, 1999).

The two other prominent cluster of sources which were mentioned before shown in Figure 6, are the border ones with the former being the Sistan basin centred at ~31_N, 61.5_E, which is characterized by widespread ephemeral lakes and swamps, and makes the natural border between Iran and Afghanistan and will be discussed at the next part. The latter one are Al-Hawizeh/Al-Azim marshes straddling the Iran-Iraq border.

5.1 Sistan basin characterization

The Sistan area is located at the tail end of a large closed inland basin, in one of the driest regions of the world. It is comprised of three geographical sub-units:

- The upper plain of the inland delta of the Helmand (Hirmand) river, which is mostly drained and used for agriculture;
- The wetlands (Hamuns) covering the lower delta plain;
- A hyper-saline lake (Gowd-e-Zareh) in the lowest part of the basin, which collects the overspill from the wetlands and – in case of extreme floods – from the Helmand River. There is no outflow from this terminal lake; water is lost from Gowd-e-Zareh only by evaporation (Zolta'n Vekerdy and Remco Dost, 2006)

The Helmand River comprises the largest watershed in the Sistan basin, but other smaller rivers also feed the Hamuns, which are, from an environmental perspective, the most important parts of the Sistan area.

The basin receives much runoff from the Sistan Mountains to the west in Iran and the eastern mountains in Afghanistan. The basin is characterized by widespread ephemeral lakes and swamps; and many salt/dry lakes in the norther parts. Often huge dust plumes emerge from three of the largest hamuns, Hamun-e-Saberi (31.5_N, 61.3_E), Hamun-e-Puzak (31.5_N, 61.7_E), and Daryacheh-ye-Hamun (331.7_N, 61.1_E) and from the Gowd-e-Zareh depression a little farther to the south (29.8_N, 61.8_E).

This is shown by many satellite images. Zabol, a city located in the midst of these salt/dry lakes, reports 81 dust storms per year (*Middleton*, 1986b). In some years, dust activity is also seen in an intermountain basin to the south in Baluchistan, Pakistan; within this basin, there is a large dry lake (the Hamun-i-Mashkel, 1950 km2; 28.2_N, 63.0_E), which is another prominent source of dusts.

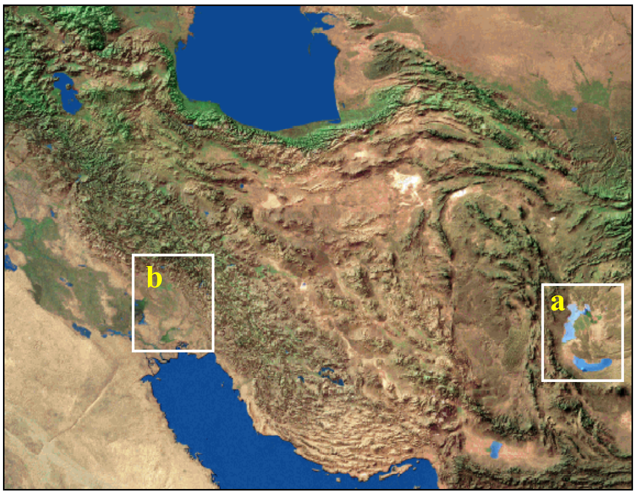


Figure 6 Prominent mineral dust sources in Iran.
(a) Sistan basin and hamuns, (b) Al-Hawizeh/Al-Azim marshes.

5.1.1 The hamun system

The Hamuns constitute an integral system that can be divided into sub-units connected to each other at high water levels, and disconnected at low water levels. Some of the sub-units receive direct inflow from rivers; others get water only from neighbouring sub-units.

The political boundary between Iran and Afghanistan splits the Hamun system, further complicating management possibilities in the area. Ninety percent of the watershed is located in Afghanistan and practically all of the wetlands' water sources originate there. The Iranian part is desert, and produces runoff only in rare cases of significant local rainfall. The Hamuns are classified as freshwater wetlands, although in cases of long water stagnation, not only is salt dissolved from the soil, but the water's salt concentration is increased through evaporation. Another source of salt is the saline return drainage from irrigation schemes.

The Hamuns are very shallow. Local experts were interviewed in January 2005 to estimate the volume of water stored in the lakes at maximum water stage. Table 1 summarizes these estimates.

Table 1 Volume estimated by local experts for the highest water stages.

	Units	Average depth (m)	Area (km^2)	Volume (million m^3)
1	Hamun Hirmand	2	2388.8	4777.5
2	Hamun-e-Puzak (Afghanistan)	3	1453.4	4360.3
2	Hamun-e-Puzak (Iran)	2	61.0	122.0
3	Hamun Saberi	3	1161.5	3484.5
	Total		5346	13025.6
4	Gowd-e-Zareh	10	2417.5	24174.9

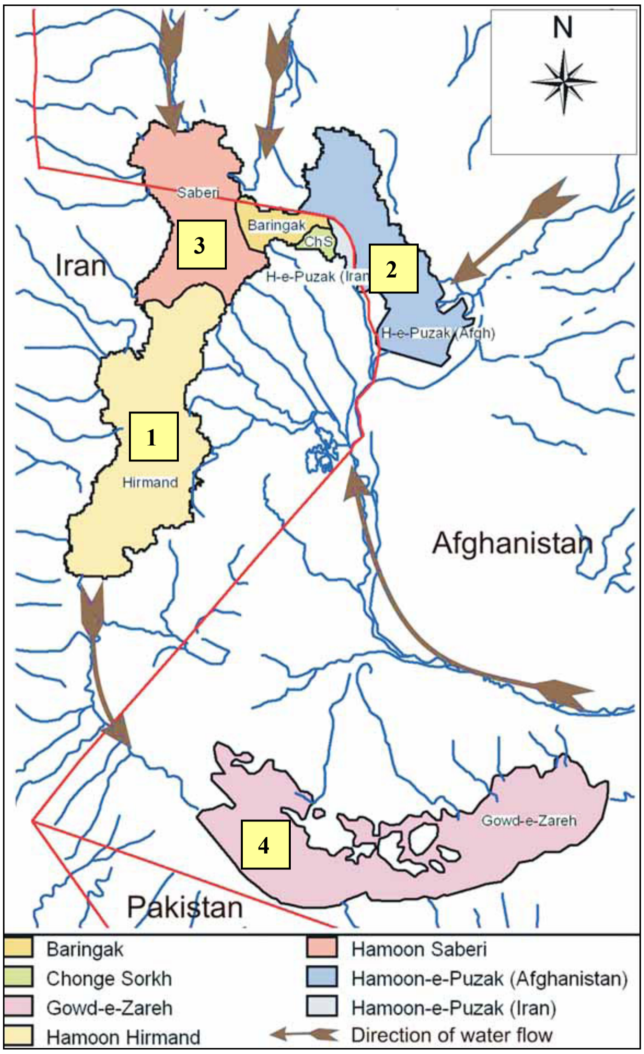


Figure 7 Subdivision of the Hamuns with the main directions of water flow. (UNEP report, History of Environmental Change in the Sistan Basin Based on Satellite Image Analysis: 1976-2005)

As mentioned before, the Hamuns are very shallow and have a very considerable tendency to convert into dry lands. It is a fact that a large part of this region can be associated with salt/dry lakes due to the high rate of evaporation and a considerable sedimentation process due to Helmand River inflow.

When these Hamuns are converted into dry lands in the arid months of the year (From April to September), the playa and tiny sediments are exposed to the atmosphere. Simultaneously, some intense low-level jets like the Sistan-120 day wind (Lavar wind), generated by the interaction between low pressure regions and high pressure ones, blow over the basin dominantly in the north-east to south-west direction. The velocity of these jets can be reached about 110 to 120 km/hr. As the plain delta is subjected to these enormous winds, they are immediately degraded. Lake deposits are generally very fine-grained, and as lakes dry up, they leave salt deposits. The salty soils inhibit plant growth, which further contributes to dust availability. So, it is a fact that the lakes themselves are important sources of dust.

Many of the dust storms in these regions are quite intense; and are relatively considerable compared to those in other regions around the world.

Figure 8 A dust storm due to Sistan 120 day winds at Zabol city.

5.1.2 A comparison between synoptical parameters and TOMS Aerosol Index (AI)

The TOMS satellite data show that on a global scale the dominant sources of mineral dust are mainly located in the vicinity of salt/dry lakes or large basins of internal drainage which are assumed to be very prone sources and there are large seasonal changes in dust distribution patterns which often display a characteristic geometry. A comparison of the TOMS satellite aerosol index (AI) with measured synoptical parameters by Zabol synoptical station, which is one of the most active dust emission sources in the world, shows a very reliable level of consistency.

As the temperature rises in the arid months, the rate of evaporation due to aridity and high temperature would be affected and intensifies the seasonal lakes and wetlands to dry out. So, when the generated storms due to climatic interaction of different terrains pass the region, the very tiny salt deposits and fine silts, which mainly form the bed of the wetlands, are emitted to the atmosphere and often create very intensive dust storms like the one which is shown in Figure 11.

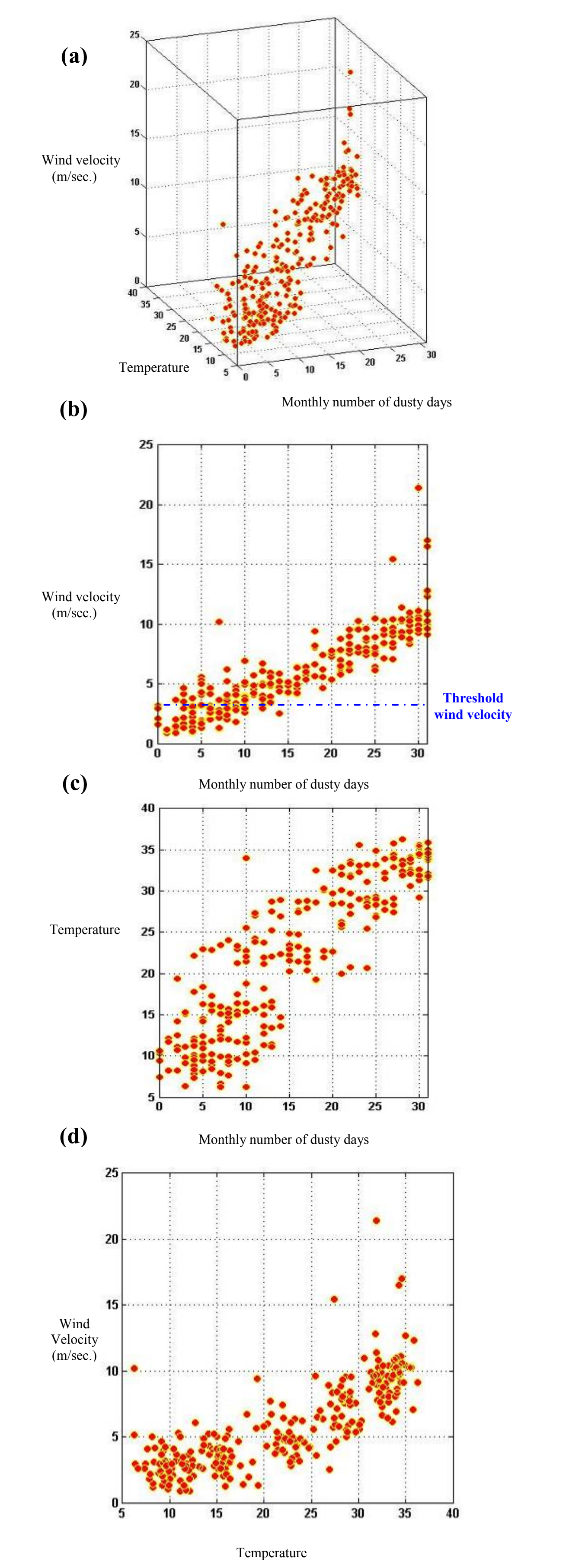


Figure 9 A comparison between measured synoptical parameters recorded by Zabol synoptical station.

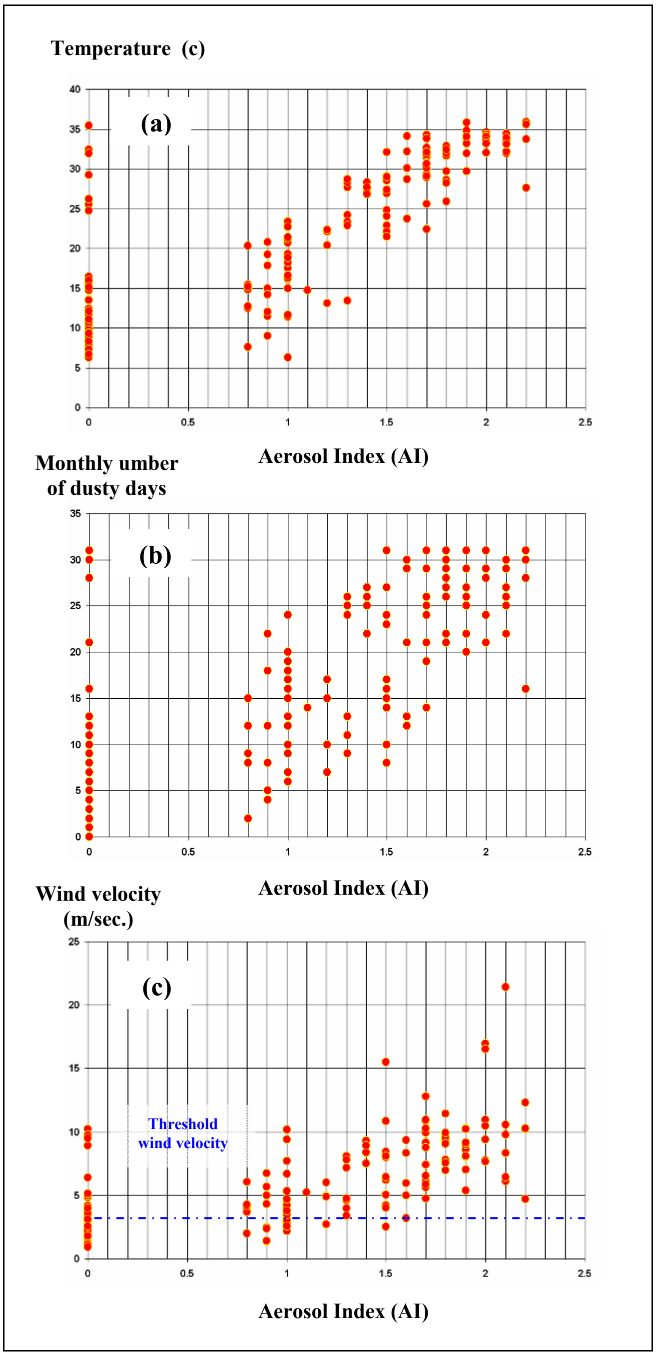


Figure 10 A comparison between measured synoptical parameters recorded by Zabol synoptical station which is the nearest station to the hamuns, with TOMS Aerosol Index (AI)

So, we can logically assume that the salt/dry lakes or large basins of internal drainage, are the most prominent dust sources. Having a comparison between temperature, wind velocity and monthly number of dusty days approved the mentioned assumption. Figure 9 illustrates the phenomenon, the higher temperature, the more intensive winds and also the more monthly number of dusty days. Besides, from Figure 10 we can actually realise the level of consistency of the relations between each of the synoptical data and TOMS Aerosol Index (AI). Regardless of the zero ones, the higher AI is corresponded to the higher value of each synoptical parameters.

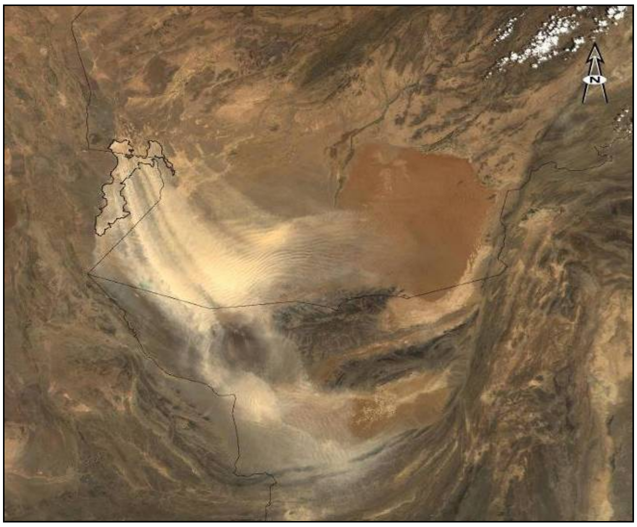


Figure 11 Wind-blown sand originating from the lakebed of the Hamuns, Captured in MODIS (Terra) image on 1 September 2004. Several satellite images show that sand plumes can cross the Persian Gulf and reach the Arabian Peninsula.

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