Carpathian Journal of Earth and Environmental Sciences, February 2011, Vol. 6, No. 1, p. 297 - 308

THE SOURCE OF DUST STORM IN IRAN: A CASE STUDY BASED ON GEOLOGICAL INFORMATION AND RAINFALL DATA

Hadi GERIVANI[1], Gholam Reza LASHKARIPOUR[1], Mohammad GHAFOORI[1] & Nader JALALI[2]

[1]Department of Geology, Ferdowsi University of Mashhad e-mail: h.grivani@iiees.ac.ir

[2]Soil Conservation and Watershed Management Research Institute of Iran

Abstract: In recent years, dust storms coming from western neighboring countries are drastically increased dust storms and affecting western and even central part of Iran. This phenomenon is caused a lot of environmental and socio-economic problems. A few studies have been carried out to determine the sources of dusts. Most of them have been done base on satellite images and metrological information which were reviewed in this paper. Geological maps and information on wind erosion susceptible land can help to determine the areas for dust materials producing. In this paper, dust sources which determined by the previous studies were compared by geological unites map and the map of mean annual rainfall of susceptible areas in the western neighboring countries. This research can be help to find the impact of geological units on the wind erosion lands for finding dust storm sources in the states of western parts of Iran.

Keywords: Dust storm, geological map, dust material, susceptible land, wind erosion, rainfall, Iran, Iraq,

1. INTRODUCTION

Dust storms, one type of dust event, are in most cases the result of turbulent wind (Miller et al., 2008), which raise large quantities of dust from desert surfaces and reduce visibility to less than 1 km. This dust reaches concentrations in excess of 6000 μg/m^3 in severe events (Song et al., 2007). Dust storms cause soil loss from the dry lands, and worse, they preferentially remove organic matter and the nutrient-rich lightest particles, thereby reducing agricultural productivity. Also the abrasive effect of the storm damages young crop plants. Other effects that may impact the economy are: reduced visibility affecting aircraft and road transportation; reduced sunlight reaching the surface; effects on human health of breathing dust. One of the notable dust storm is 524 BC storm in which 50,000 strong army of Cambyses II (a Persian king) supposedly buried by a sandstorm in route to the Siwa Oasis. According to Herodotus, Cambyses sent an army to threaten the Oracle of Amun at the Siwa Oasis. The army of 50,000 men was halfway across the desert when a massive sandstorm sprang up, burying them all.

Dust Storms are prevalent in arid and semiarid regions, particularly in subtropical latitudes. This event frequency is closely related to local climate conditions (such as rainfall and temperature) as well as land surface features, including snow cover duration, vegetation cover, and soil texture (Nickling & Brazel, 1984; Sun et al., 2003 a, b).

There is an increasing interest in the atmospheric transport of mineral dust. Effects of dust can be summarized in tow groups: short-term effects in human life such as disturbing transportation systems by decreasing visibility, causing health problem by caring associated viruses, bacterium and atomic particles, damaging engines and reducing agricultural crops, and long-term effects in environment and climate of earth such as global temperature through the absorption and scattering of solar radiation, cloud formation (Toon, 2003), convectional activity (Wong & Desler, 2005), sulfur dioxide levels in the atmosphere either by physical absorption or by heterogeneous reactions (Adams et al., 2005) and atmospheric carbon dioxide levels (Ridgwell, 2003).

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, Iraq, Jordan, southern part of Turkish, Saudi Arabia, Kuwait and Syria that are concerned in this study as main sources of dust storms of Iran have arid and semiarid climate and are located in the dust belt. However, the Middle East is well known for its arid and semi-arid environment with frequent and severe dust- and sand storms. This region most affected by dust, in the world, next to Africa, (Kutiel & Furman, 2003).

During the last years, dust storms frequencies and intensities have increased significantly in Iran. This has affected human health in the southern provinces of Iran like the southwestern Khuzestan Province and the nothern part of southeastern Sistan and Baluchistan Provinces (Misconi & Navi, 2010). However, these storms have seriously disturbed the life of the people in the region and have put even their breathing in trouble let alone with their work and other useful activities and the intensity of these storms and their consequences have worried people. The increase in the intensity of dusts seems to be due to drought as well as adverse use of natural resources in Iran and in the neighboring countries which have caused the surrounding habitats and deserts go beyond the natural erosion threshold and make the situation worse gradually. Low rain in south and southwest parts, dryness and lessening water in lagoons and ponds (Fig. 1), not growing desert plants and consequently intensifying winds from February and March months in 2007, have caused an increase of 20 to 30 percent in dust in this region (Jalali & Davoudi, 2008). Moreover, Iraq is one of the main sources for dust storm in Iran. Dam projects by neighboring countries are drastically reducing the flow of the Tigris and Euphrates and helping to turn a once-fertile plain into desert in this country.

Reasons of dust storms increasing and sources of dusts are two main subjects for researching in Iran. Some studies based on satellite images and metrological data have been conducted to determine the locations of Iran's dust sources which are reviewed in this paper. We think there is a problem with not only dust source studies in Iran but also maybe the world studies and that is less concerning and even neglecting geological data and maps. In this paper, we compare dust sources, determined by before metrological and remote sensing base studies, with geological units and, finally, present zonation map of dust production susceptibility prepared by classifying geological unites base on their susceptibility of producing dust particles and using mean annual rainfall map of the Middle East.

2. SOURCES OF DUST STORMS

Deserts are main sources for dust storm around the world. The Sahara is the world's largest desert, and plays a significant role in the atmospheric global circulation (Cuesta et al., 2009). The Sahara is the world's most significant source of mineral dust in the atmosphere (Tanaka & Chiba, 2006). Deserts and ancient lakes are covered by fine grained material of Quaternary sediments that is shown in the geological maps.

3. REVIEW OF STUDIES ON THE SOURCE OF DUST STORMS OF IRAN

Local climate of Iran is very different whereas the north of it, coastline plains of Caspian Sea, has a very wet climate with heavy forestry lands, and Albors and Zagros mountain belts has very cold climate with heavy snow in the winters. The central and eastern parts of the country and the coastline of Persian Gulf has arid and semiarid climate with hot and dry deserts that can be sources of dusts. For example, Sistan region in the eastern part of it suffer from strong dust storm which blow from north to south during April to August (Miri et al. 2009). But the most main winds in the country blow from west to east (Fig. 2). Therefore, for determine the source of Iran dust storms; western adjacent countries must be concerned.

During the last two decades, dust storm intensities and frequencies have increased significantly for two times, once from 1984 to 1988 and other time from 2005 up to now (The activity and effect of the dust storms appeared from late winter of 2005 and almost adapted in 2006 and then intensified in 2007 again and the intensity of storms and their frequency have reached its maximum). After 1984-1988 dust storm periods, a study for determining the source of dust storms in the Middle East was conducted by Walter & Wilkerson (1991). Other two studies were conducted during the last years, one of them by Esmaili et al. (2006) in Sharif University and another one by Jalali & Davoudi (2008) in Soil Conservation and Watershed Management Research Institute (SCWMRI).

Moreover, Ginoux et al. (2001) and Kutiel & Furman (2003) studied source of dust in the Middle East, including Iran. Methods and results of these studies have been reviewed following.

Figure 1. Drying of Hawizeh/Al-Azim lagoons (south-east of Iraq) in recent years.

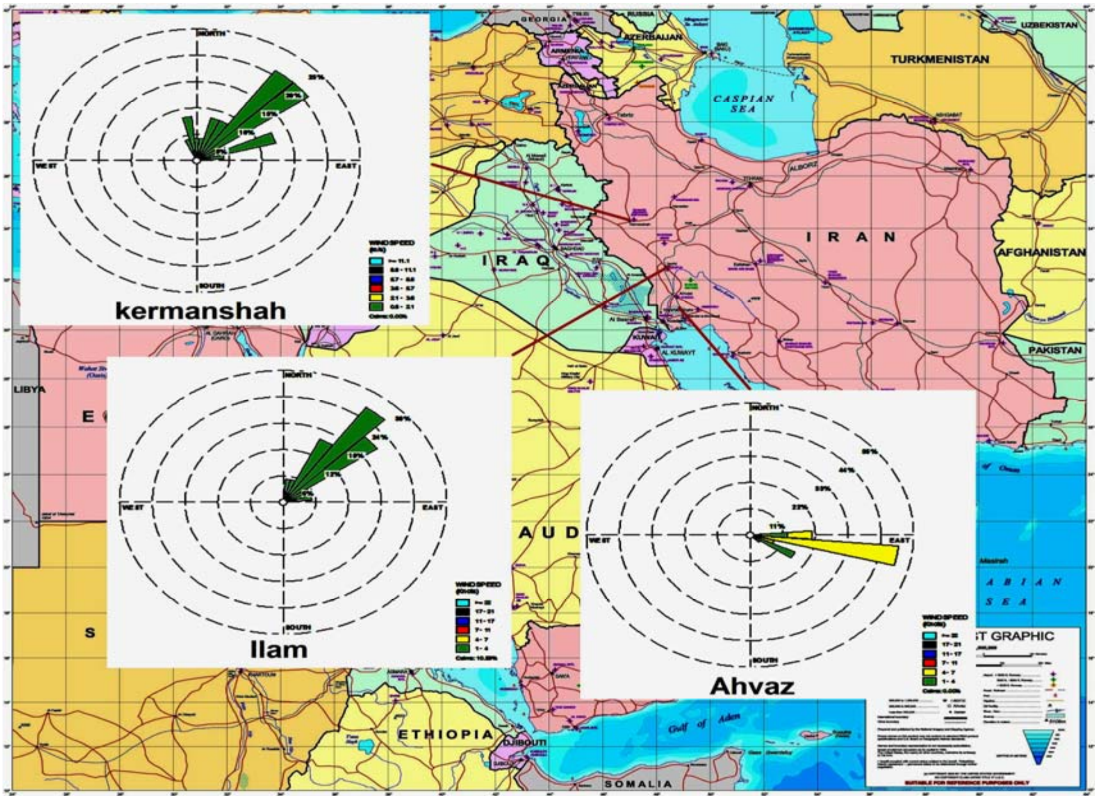

Figure 2. Wind rose diagram for tree meteorological stations including Kermanshah, Ilam and Ahvaz in the west of Iran (Data from Iranian Meteorological Organization, www.weather.ir)

3.1. The Mesopotamian dust sources determined by Walter and Wilkerson, 1991

The Mesopotamian source region includes Syria, Iraq, western Iran, and the northeastern Arabian Peninsula. Individual source of dust storm in this region, including 14 areas shown in Figure 3, was somewhat examined by Walter & Wilkerson (1991). All these storms have a west to north wind component. Large-scale pressure systems such as fronts are not discussed because such systems carry widespread dust along with them and prevent detection of the actual source areas (Walter & Wilkerson, 1991).

3.2. Ginoux et al. studies for Middle East's dust sources including Iran

Prospero et al. (2002) have shown that the source can usually be associated with topographic lows which have a deep accumulation of alluvial sediments formed during the late Pleistocene or Holocene. These sediments are composed of fine particles which are easily eroded by winds. In the study of Ginoux et al., (2001) they assume that the most probable sources are related to the degree of depression and the dust database was developed using topography and dust sources regions identified using satellite data from the Total Ozone Mapping Spectrometer (TOMS). The TOMS instrument measures the amount of ultraviolet absorption by dust aerosols by taking the ratio of 331 nm and 360nm measured radiance to the calculated radiances based on a model Rayleigh scattering atmosphere (Herman et al., 1997). The database uses TOMS observed sources that are associated topographical depressions where sediments accumulate, such as the Lake Chad Basin. The source areas are assigned a source strength value between 0 and 1.0. The data is given on a global 1° × 1° grid and is re-interpolated to the MM5 grid used in the CARMA dust model by Barnum et al (2004) (Fig. 4).

As it is shown in figure 3, the most parts of the Middle East are the source of dust. The most significant source regions are located in the western side of Syria, central and southern part of Iraq and a band parallel to the southern coastline of Persian Gulf which can be the main sources of Iran's dust storms.

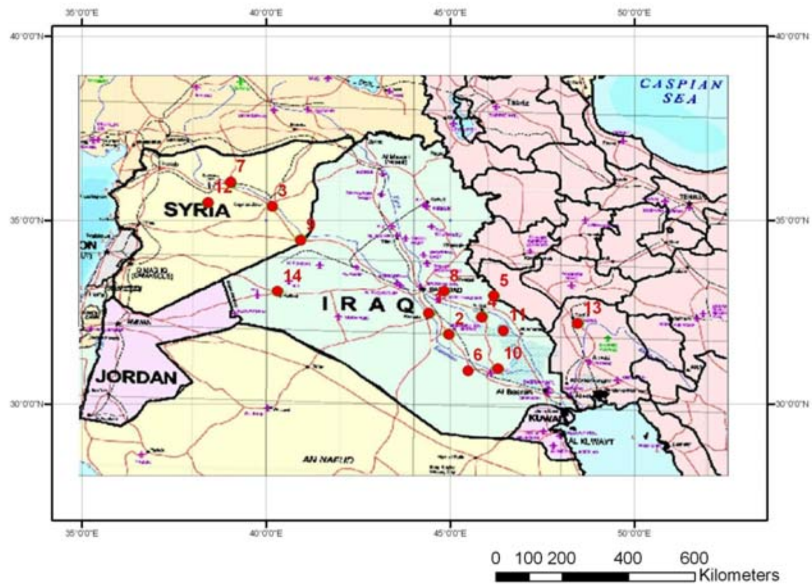

Figure 3. Spatial distribution of sources and the origins of dust storms before 1991 (Walter & Wilkerson, 1991)

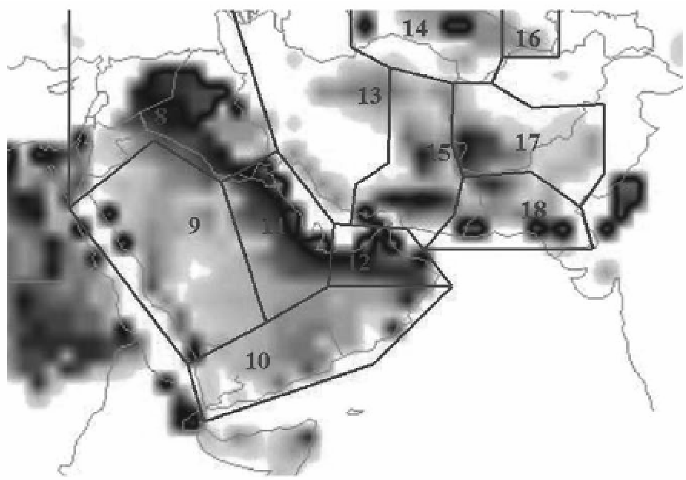

Figure 4. Dust source regions over the Middle East including Iran on a 0–1.0 scale, plotted with 0 (white) being a non-source region and >0.6 (grey to black) represents the most significant source regions (Barnum et al., 2004).

3.3. Dust storms in the Middle East studied in University of Haifa

The spatial and temporal characteristics of dust storms in the Middle East were studied by an analysis of the visibility reduction in that region. Eight “three-hours” mean values for each month for a period of 21 years (1973–1993) were used. Data were subjected to cluster analysis of their temporal behavior. Sudan, Iraq, Saudi Arabia and the Persian Gulf, are the regions that reported the greatest occurrence of dust storms. Dust storms in Iran, north-eastern Iraq and Syria, the Persian Gulf and southern Arabian Peninsula are more frequent in summer. In western Iraq and Syria, Jordan, Lebanon, northern Israel, northern Arabian Peninsula and southern Egypt they occur mainly in the spring, while in southern Israel and in the Mediterranean parts of northern Egypt, in winter and spring. Figure 5 shows spatial distribution of the maximum occurrence of visibility reduction in percent of the time.

3.4. Evaluation of dust sources in Iran through remote sensing and synoptically analysis

Esmaili et al. (2006), in Sharif University, 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. Esmaili et al. based on the recent studies (up to 2006), reported the main dust sources in Iran as following:

- *Dust source area located in the 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 km^{24}), which appears to consist largely of salt flats (Gill, 1996) and particularly centered over the western part of the basin (in the region close to Tehran) where there are many large drai-nage channels and a number of ephemeral lakes and marshes, including a large intermittent salt lake, Daryacheh-ye Namak (1807 km^2).

- *Dust source located 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-JazMurian, 1087 km^2). 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 & Pease, 1999).

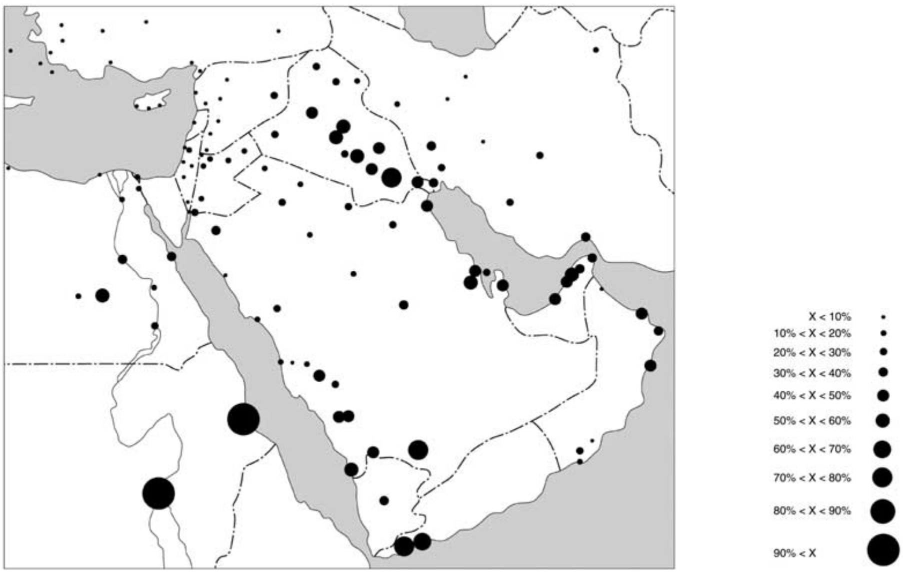

Figure 5. Spatial distribution of the maximum occurrence of visibility reduction in (%) of the time. Circles sizes’ are proportional to percentage of visibility reduction (Kutiel & Furman, 2003).

- *Two prominent cluster of sources, shown in figure 6, including Sistan basin and Al-Howizeh/Al-Azim marshes:* Sistan basin centered at ~31' N, 61.5' E, which is characterized by widespread ephemeral lakes and swamps, and makes the natural border between Iran and Afghanistan. Al-Howizeh/Al-Azim marshes straddling the Iran-Iraq border.

3.5. Study conducted in SCWMRI

In this study, MODIS satellite images of Iran and adjacent countries for a period of four years (2005 to 2008) were used to determine the sources of dust and areas affected by dust storms. Areas influenced by dust storms and sources of dust were detected by automatic classification of the Images (clustering) for calculating optical thickness and by visual interpretation of MODIS satellite images, respectively. Figure 7 and 8 show distribution of dust sources in 2005 and 2008, respectively.

Figure 9 shows areas influenced by dust storms that are graded in 6 levels: areas without dust storm, areas with one week, two weeks and three weeks dust storm, areas with less than one month dust storm and areas with more than one month dust storms. In this figure, dust sources are graded in three levels too: sources with high, medium and low effect in dust storms of Iran.

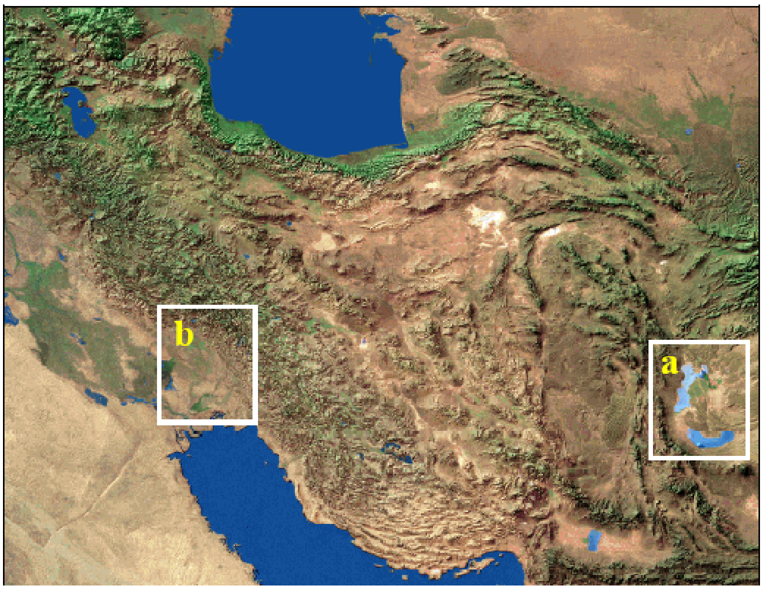

Figure 6. Two prominent mineral dust sources in Iran: (a) Sistan basin and hamuns, (b) Al-Hawizeh/Al-Azim marshes.

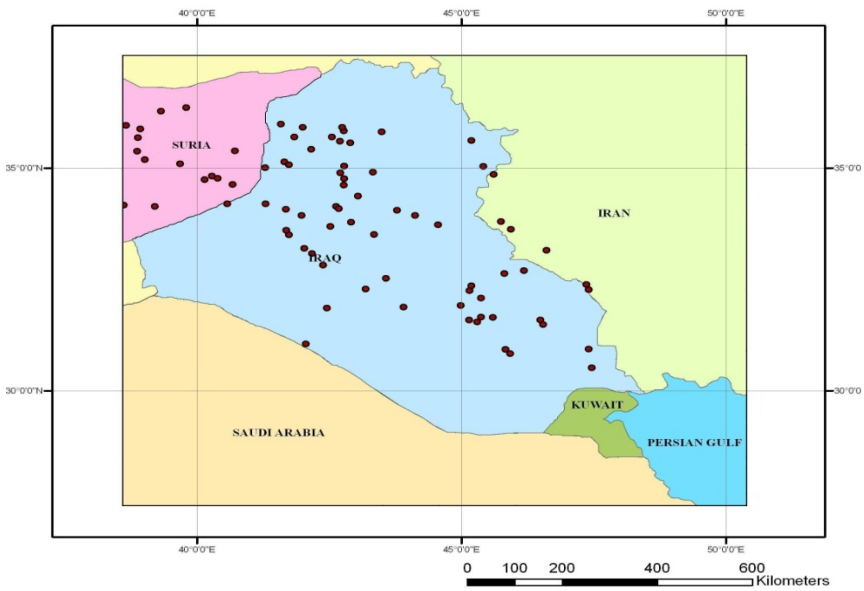

Figure 7. Spatial distribution of sources and origins of dust storms of 2005 (Jalali and Davoudi, 2008)

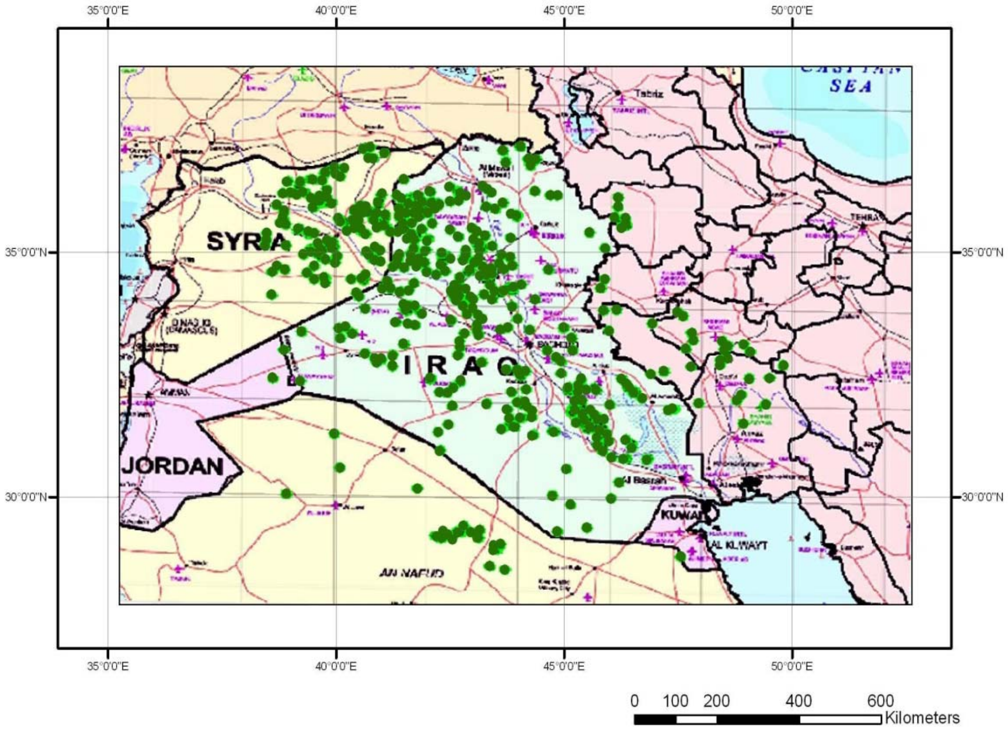

Figure 8. Spatial distribution of sources and origins of dust storms of 2008 (Jalali & Davoudi, 2008)

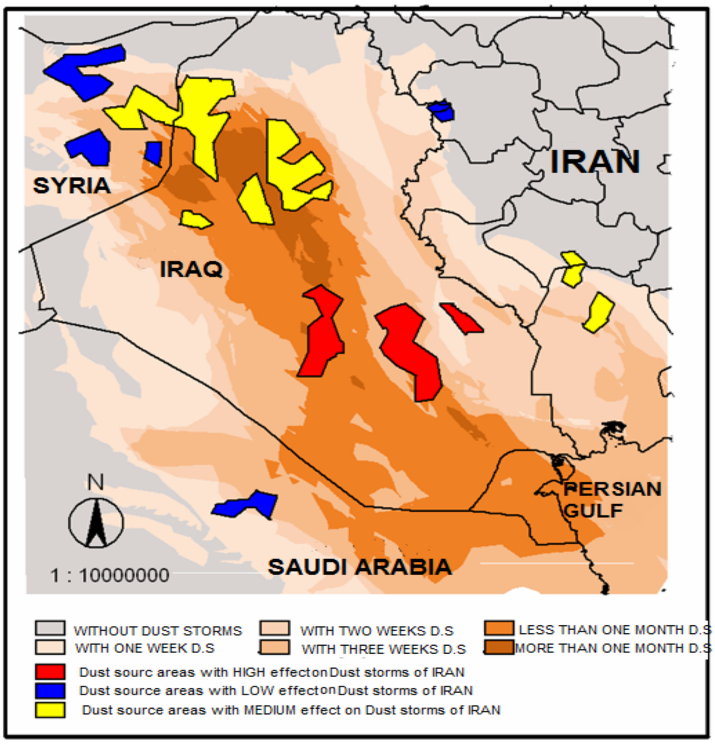

Figure 9. Zonation of dust sources and areas influenced by dust storms (Jalali & Davoudi, 2008).

4. PRIMARY ZONATION OF DUST SOURCE BASE ON GEOLOGICAL MAPS AND MEAN ANNUAL RAIN FALL

Different parameters, mentioned by researchers, that affect occurrence of dust storms, can be summarized as: *land surface features* including snow cover duration, vegetation cover, and soil texture (Nickling & Brazel, 1984; Sun et al., 2003a,b), *local climate conditions*, such as rainfall and temperature, and *wind velocity*: when wind velocity exceeds a threshold value (which is a function of land surface), suspension, saltation, or creep may transport sand particles over long distances (Gillette, 1981; Li et al., 2002), depending on the strength of the weather system and the size, shape, and density of the sand particles (Zhou et al., 2002). Geological maps and information's can help us to assessment the soil texture that are very useful for small scale studies that is usually purpose of dust storm researches.

In recent years we have gained a much clearer picture of the main source regions for dust emissions at a global scale. This has demonstrated the primacy of the Sahara and has highlighted the importance of some other drylands, including the Middle East, Taklamakan, southwest Asia, central Australia, the Etosha and Mkgadikgadi pans of southern Africa, the Salar de Uyuni of Bolivia and the Great Basin in the USA. Most of the major source regions at the present day are large basins of internal drainage (Bode´ le´, Taoudenni, Tarim, Seistan, Eyre, Etosha, Mkgadikgadi, Uyuni and the Great Salt Lake). In these studies, some geological conditions have been mentioned as dust sources that are gathered in table 1. Lake sediments, dry river beds, deltaic sediments, sandy lands and alluvial fans mentioned as dust source that all mainly composed of fine and medium grain size sediments.

Geological map of our study area, prepared by Haghipour (2009), include rocks (older than Quaternary) and Quaternary sediments (Q1 and Q2). Quaternary sediments are separated into 5 unites including: fluvial, alluvial, sand dune, loess and playa. Fluvial is defined as a kind of sediments consisting of materials transported by a stream as suspended or laid down. Alluvial is defined as kinds of soils consisted of clay, silt, sand and gravel or similar unconsolidated detrital materials deposited during comparatively recent geologic times by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream or on its flood plain or delta, or as a cone of fan at the base of the mountain slope. Sand dune is defined as an accommodation of loose sand heaped up by wind, commonly found along low-lying seashores above high-tide level, more rarely on the border of large lakes or river valleys, as well as in various desert regions, where there is abundant dry surface sand during some part of the year. Loess is a term for a widespread, homogenous, commonly, nonstratified, porous, friable, slightly coherent, usually highly calcareous, fine grained blanket deposit (generally less than 30 meter thick), consisting predominantly of silt with subordinate grain sizes ranging from clay to fine sand. Playa is a term that is used for dry, vegetation-free, flat area at lowest part of an untrained desert basin, underlain by stratified clay, silt or sand, and commonly by soluble salts (Bates, & Jackson 1980).

The soil grain size of the geological unites is one of the most important parameters to estimate the susceptibility of geological unites to emission dust materials. Suspended dust particles have a bimodal size distribution (Hoock, 1984). Smaller particles are only a few microns in diameter, but most range from 20 to 40 microns. Particles capable of traveling long distances usually have diameters of less than 20 microns (Gillette, 1979) that are including salt, gypsum, clay (less than 2 microns) and silt (2 to 74 microns).

Accordingly, rocks have no susceptibility, fluvial, alluvial and sand dune may have low susceptibility and playa and loess probably have high susceptibility of dust emission. Other groups of sediments, shown in geological map, are old and new dry lakebeds which, in this area, consisted of fine grain size sediments, gypsum and salt. Old dry lakebeds usually are some compacted then have low susceptibility, but new lakebeds are loose and have high susceptibility.

Table 1. Geological conditions mentioned as dust emission sources around the world.

Row	Geological Conditions	Location	References
1	palaeo-lake sediments	Bode´ le´ depression (north of Africa)	Warren et al., 2007; Schwanghart & Schu¨ tt, 2008
2	piedmont alluvial fans	Chinese deserts	Wang et al. 2006
3	sandy lowlands	China and Mongolia	Zhang et al., 2008
4	dry river beds	Makran coast of Pakistan and the ephemeral rivers of Namibia	Eckardt & Kuring, 2005
5	lake sediment	Sistan Basin (Iran and Pakistan)	Hickey & Goudie, 2007
6	deltaic sediment	Sistan Basin (Iran and Pakistan)	Hickey & Goudie, 2007
7	River bed sediments	Tokar Delta of Sudan	Hickey & Goudie, 2007
8	Swamp sediments	Sistan Basin (iran and Pakistan)	Esmaili et al., 2006
9	Marsh sediments	Al-Howizeh/Al-Azim (Border of Iran and Iraq)	Esmaili et al., 2006

To check this grading of susceptibility, dust sources determined by Walter & Wilkerson (1991) and Jalali & Davoudi (2008), for 2005 and 2008 dust storms of Iran, plotted on the geological map (Fig. 10).

All the areas were determined by Walter & Wilkerson (1991) as dust source areas are located on Quaternary sediments, 6 areas on alluvial and 7 areas on playa and loess; expect point 14 (shown in Fig. 8) that is located on old dry lakebeds and streambeds. This is in accordance with susceptibility grading of geological unites, but it must be noted that sometimes older than Quaternary sediments, as area 14, may have susceptibility of dust emission because it is erodible. Assessing of erodibility of old sediments and rocks is possible in bigger scale and more detailed geological maps. The maximum occurrence of visibility reduction, as a sign of dust producing ability, for Middle East, studied by Kutiel & Furman (2003) are higher in around group B (Fig. 8) that shows the sediments of this area, which are Playa and Loess sediments, are more susceptible. Dust sources with high effect on dust storms, studied by Jalali & Davoudi (2008), for 2005 and 2008 dust storms, are also located around group B.

Most of the pointes, determined as dust sources by Jalali & Davoudi (2008), for 2005 and 2008 dust storms, including groups A to H in figure 8, can be related to Quaternary sediments. Groups of Dust source points A, C, D, E, G and H are related to alluvial sediments, group B is related to New dry lakebeds and Playa sediments and group F is related to Old dry lakebeds. Other points sound not related to geological units because they are located on rocks. For example dust source points in the west of Iran are located on Rock units that are formed western side mountains of Zagros mountain belt. This may has reasons as following:

- These dust source points have been detected by visual interpretation of MODIS satellite images. To form a visible clued of dust in atmosphere as it can be detected in MODIS satellite images, dust materials are forced to release from lands along the wind direction and gather in far distance along this direction. Then this distance depends on meteorological properties of winds. For example wind with high velocity can suspend more dust materials and bigger size of them and can transport them to more far distance. Dust storms may be traced as far as 4000 km from their origin (Kutiel & Furman, 2003). In this study area, depended on winds' metrological properties, dust particles may started to release from groups A to H and gathered in far distance on the Rock units in the east of Iran, north-west of Iraq, between groups B and F, and etc.

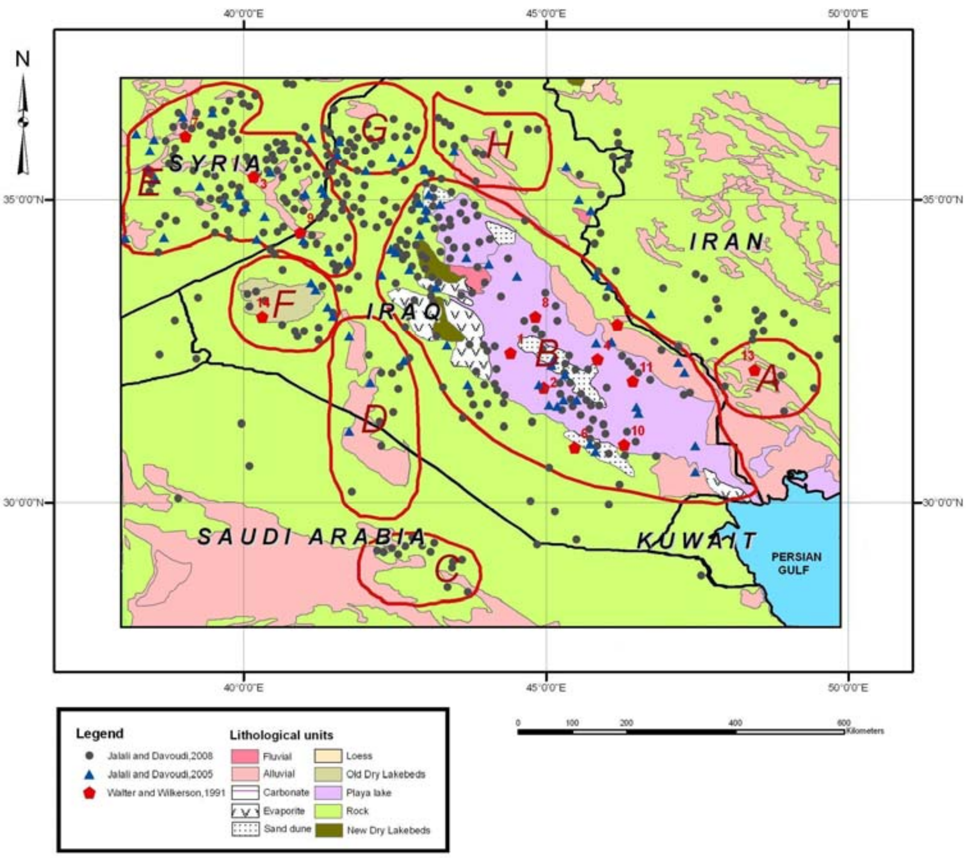

Figure 10. Zonation map of dust emission base on geological map and points of dust sources determined by Walter & Wilkerson (1991) and Jalai & Davoudi (2008).

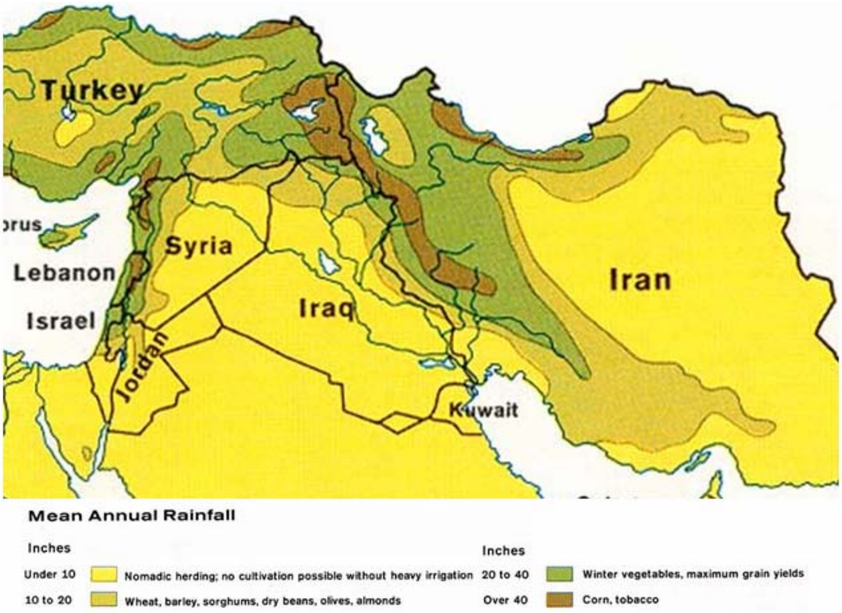

Figure 11. Mean annual rain fall (inches) in the Middle East (Central Intelligence Agency of U.S., 1973).

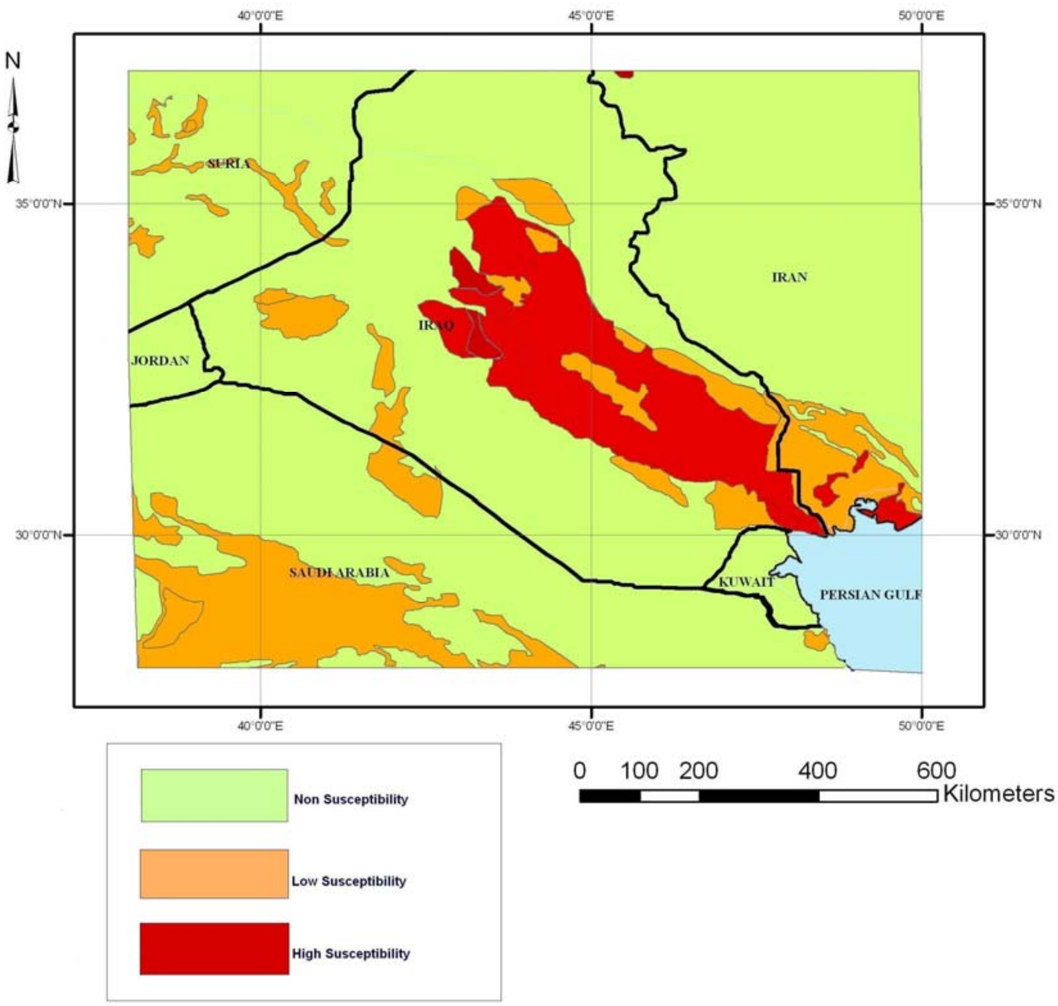

Figure 12. Zonation map of dust producing susceptibility in the Middle East, sources of dust storms in Iran and Iraq.

- Scale of the basic geologic map of this study is 1:5,000,000 and in this scale, rather small units of sediments which can be source of dusts are not shown. Scattered points of dust sources might be released by these small sedimentary units.

Accordingly, base on the geological units' susceptibility for producing dust particles, we prepared zonation map of dust producing susceptibility.

Another parameter affected dust producing susceptibility is mean annual rain fall. Total Ozone Mapping Spectrometer (TOMS) data have indicated that many of the world's major dust source regions are areas of hyper-aridity, with mean annual rainfalls of less than 100 mm (Goudie & Middleton, 2001). Some other researchers reported that dust sources, regardless of size or strength, can usually be happened in arid regions with annual rainfall under 200–250 mm. Mean annual rain fall of the Middle East (Fig. 11) shows that north-east of Syria, north of Iraq and west of Iran have more than 250 mm (10 inches) mean annual rain fall, so we omitted dust sources located in these areas and presented zonation map of dust producing susceptibility as figure 12.

5. CONCLUSIONS

In this study, zonation map of dust producing susceptibility were prepared base on geological map of the Middle East in scale of 1:5,000,000 and mean annual rainfall map and it was shown that the most of dust storms in Iran, during the recent decays, have generated by young geological unites in south-west of Iran, Iraq, Syria, and north of Arabia. This study was an example and showed that geological maps can be used for preparing zonation map of dust sources. Geological maps for most of the world have been created (for example in Iran, geological map in scale of 1:100,000 were prepared and engineering geology with larger scale are preparing) and can be used. Other effective factors in producing dust particles like precipitation, temperature and etc can be added to geological zonation with GIS. Zonation maps created in this method may be used as following:

- Using for dust storm forecasting models like CARMA- dust model (Banum, 2004).
- Estimating amount of mineral dust particles release into the atmosphere.
- Determining main dust sources and areas affected by them for land use planning and decreasing susceptibility of sources

It must be added that using large scale geological maps and estimating erodibility of soft rocks (in this study supposed have no susceptibility except area-group F, Fig. 10) increases the accuracy of the results.

ACKNOWLEDGMENT

The authors gratefully acknowledge *Ms. F. Rejaie* from Ferdowsi University of Mashhad for her help in preparation of the paper.

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Received at 18. 08. 2010
Revised at: 07. 12. 2010
Accepted for publication at: 12. 12. 2010
Published online at: 31. 12. 2010