Effects of Wind Erosion and Soil Salinization on Dust Storm Emission in Western Iran

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Abstract. Dust storms are known as hazardous problems in western part of Iran. Iraq is one of the main sources for dust storm arriving to the western part of Iran. The Radial Basis Function Network model (RBFN) has been used to assess wind erosion hazards in the source area of dust storms over several western Iranian cities. Normalized Difference Salinity Index (NDSI) was used to determine the changes in the source area salinity over the studied years. The RBFN model has been used to assess the wind erosion severity of all land uses in the source area. Generally, NDSI values of all land uses in 2003 were higher than those in 2013. The maximum and minimum mean NDSI values were seen in severely dissected plains and mountainous lands, respectively. The observed differences in the wind erosion hazard maps of 2003, 2005, 2007, 2009, 2011 and 2013 were due to the changes in vegetation percent. Soil salinization caused the source area vegetation degradation and wind erosion exacerbation. So, the occurrences of dust storms in Western parts of Iran have become more frequent. The \textit{in situ} observations showed that there were two, five, five, twelve and nine records of pervasive dust storms in western parts of Iran in 2003, 2005, 2007, 2009 and 2011, respectively.

Key words: Dust storm, Soil salinization, Wind erosion
Introduction

Soil erosion by the wind is recognized as an important mechanism for dust storm creation (Gillette et al., 1972; Gillette, 1974; Gillette and Goodwin, 1974; Gillette and Walker, 1977; Gillette, 1978; Gillette et al., 1980). Dust storms arise from the soil surface by surface wind (Kind, 1992; Loosmore and Hunt, 2000). Dust aerosols were eroded from the arid soils (Tegen and Lacis, 1996; Liao and Seinfeld, 1998; Seinfeld and Pandis, 1998; Forster et al., 2007). Wind erosion is mainly occurred in the arid and semiarid areas where precipitation is rare, vegetation is sparse, wind is strong and frequent and the loose ground surface material is susceptible to be blown away by wind (Skidmore, 1986; Hagen, 1991).

Iraq is one of the main sources dust storm in western part of Iran (Prospero et al., 2002; Kutiel and Furman, 2003; Gerivani et al., 2011; Karimi et al., 2012). Effects of dust storm depend on soil surface wind speed and properties (Marticorena and Bergametti, 1995). Dust storms spread abroad by the source area wind erosion (Gillette, 1974; Gillette and Goodwin, 1974; Gillette and Walker, 1977; Gillette, 1978; Gillette et al., 1980). Wind erosion rates were strongly affected by plant cover (Li et al., 2007; Okin, 2008).

Some of well known wind erosion models are WEQ (Wind Erosion Equation), WEPS (Wind Erosion Prediction System) and RWEQ (Revised Wind Erosion Equation). Since these models have been developed on the basis of different environmental conditions and data availability, their applications to the other areas despite tedious work of calibration do not end necessarily into satisfactory results. The RBFN (Radial Basis Function Network) model represents a simple method for quickly classifying wind erosion hazards by the means of GIS (Huading et al., 2007). So, the RBFN model has been used in this study to classify wind erosion hazards.

RBFN is a wind erosion assessment model that has six main factors. Fine sand in soil, sandy land percent, mean relief degree of land surface, the intensity of wind energy, vegetation percent and the degree of soil dryness are the six indices of RBFN model (Huading et al., 2007). Salinity has considerable adverse impacts on plant (Lauchli and Epstein, 1990). It adversely affects the plant growth and development. An excess of soluble salts in the soil leads to osmotic stress, specific ion toxicity and ionic imbalances (Munns, 2003) and the consequences of them can be the plant death (Rout and Shaw, 2001). Ashraf et al. (2004) found that increasing salt concentrations caused a significant reduction in vegetation cover. Salinization transforms fertile and productive land to the barren one (Ghassemi et al., 1995). Dust storms and wind erosion are increased with the spread of soil salinity (Kokelj et al., 2012). So, increasing soil salinity caused widespread vegetation death and low vegetation cover causes the increased risk of wind erosion (Munson et al., 2011).

NDSI can be used for predicting salinity and sodicity (Aldakheel et al., 2005; Odeh and Onus, 2008). Khan et al. (2001) concluded that NDSI could be used to identify different salt classes based on the dry surface crust. NDSI gives good results in detecting salt-affected lands (Tripathi et al., 1997; Odeh and Onus, 2008). Setia (2011) has expressed that the vegetated areas should have a lower NDSI than non-vegetated ones. The present study was aimed to study the effects of wind erosion and soil salinization on dust storm emission in Western Iran.

Materials and Methods

The RBFN model has been applied to assess the wind erosion severity of the
source area. Wind erosion hazards had been assessed by the use of RBFN model. Standard values of RBFN model indices (fine sand in soil, sandy land percent, mean relief degree of land surface, the intensity of wind energy, vegetation percent and the degree of soil dryness) were extracted by the use of RS and GIS software (Huading et al., 2007). Among all RBFN model indices, only the vegetation percent index (EVI) has been changed in the studied years (Table 1).

Fine sand in soil and sandy land percent as two RBFN model indices were calculated by the following method:

The particle size distribution for the individual soils is described by four populations: clay, silt, medium or fine sand and coarse sand (Blott and Pye, 2001). We derived global estimates from the soil texture class data given in the Food and Agriculture Organization (FAO)/United Nations Educational, Scientific and Cultural Organization soil map of the World (Zobler, 1986). The texture categories are fine, medium, coarse or mixtures of them. In terms of standard soil textural triangle (Fitzpatrick, 1980) based on the studies of Tegen et al. (2002), we assume that the coarse texture category includes sands, loamy sands and sandy loams.

The medium texture category includes sandy loams, loams, sandy clay loams, silt loams, silt, silt-clay loams and clay loams with <35% clay. The fine texture category includes clays, silt-clays, sandy clays, clay loams and silt-clay loams with >35% clay.

The sand, silt and clay particles percent in each texture category is estimated from the centroids of the appropriate texture classes in the textural triangle. Mean relief degree of land surface and the degree of soil dryness have been extracted from a geographical map and ratio of regional rainfall and heat precipitation in Iraq. The intensity of wind energy has been obtained for each pixel (Swera, 2005). EVI (Enhanced Vegetation Index) has been used to express the vegetation percent index. The source area has been divided in 1 km² pixels. The mean values of EVI for each pixel were calculated using the red and NIR reflectance (Equation 1) (Huete et al., 2002):

\[
EVI = \frac{G \times (NIR - RED)}{NIR + C_1 \times RED + C_2 \times BLUE + L}
\]

Where

- EVI = Enhanced Vegetation Index
- C1 and C2 are the coefficients designed to correct the dust aerosol scattering and absorption which use the blue band to correct the dust aerosol influences in the red band (C1=6, C2=7.5).
- G = a gain factor (set at 2.5)
- L = a canopy background adjustment (set at 1.0) (Nagler et al., 2005)

Based on Tables 1 and 2, the wind erosion hazards map in the source area of western part of Iran’s dust storms has been prepared for 2003, 2005, 2007, 2009, 2011 and 2013 (Fig. 1).

To determine the changes in the source area salinity over time, Landsat images were acquired during summer months (in 2003, 2005, 2007, 2009, 2011 and 2013) when agricultural land use would be near its lowest value and the evaporation near its highest one (Gibson, 2012). After the images were processed, they were converted to the NDSI (Equation 2). This index was derived by dividing the differences of red and NIR to their sum.

\[
NDSI = \frac{[\text{Band 3} - \text{Band 4}]}{[\text{Band 3} + \text{Band 4}]} \quad \text{(Equation 2)}
\]

The GIS software used in this paper is ArcGIS 9.3; RBFN model was run by MATLAB software.

**Results**

The input indices of the RBFN model for 2003, 2005, 2007, 2009, 2011 and 2013 were estimated and illustrated in Table 1. The mean EVI values are the only modifiable indices of RBFN model which have been changed across various study years (Table 1). The maximum and minimum values for EVI were 0.16 and 0 for flat to undulating plains of 2003 and
severely dissected plains of 2009, respectively (Table 1). Values were standardized and indices 1–6 respectively represent the contents of fine sand in soil, sandy land percent, mean relief degree of land surface the intensity of wind energy, mean EVI and the degree of soil dryness. The indices of the RBFN model for 2003, 2005, 2007, 2009, 2011 and 2013 across the source area were summed up to prepare the wind erosion hazard classes of land uses (Table 2). The most severe wind erosion rates in all land uses were found in 2009 and the lowest rates of wind erosion were seen in 2003 (Table 2). Wind erosion hazard maps for 2003, 2005, 2007, 2009, 2011 and 2013 were shown in Fig. 1. The maximum extent of area with severe and very severe wind erosion hazard classes was found in 2009 and 2003, respectively (Fig. 1).


<table>
<thead>
<tr>
<th>Land Use Types</th>
<th>Index 1</th>
<th>Index 2</th>
<th>Index 3</th>
<th>Index 4</th>
<th>Index 5 Average EVI</th>
<th>Index 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat to undulating plains</td>
<td>0.08</td>
<td>0.92</td>
<td>0.83</td>
<td>0.09</td>
<td>0.16</td>
<td>0.13</td>
</tr>
<tr>
<td>Flat to undulating plains, poor traction in wet soils</td>
<td>0.76</td>
<td>0.13</td>
<td>0.18</td>
<td>0.83</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Near lakes and in depressions</td>
<td>0.82</td>
<td>0.11</td>
<td>0.23</td>
<td>0.38</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Flat to gently rolling plains, hills and mountains</td>
<td>0.65</td>
<td>0.43</td>
<td>0.43</td>
<td>0.15</td>
<td>0.12</td>
<td>0.11</td>
</tr>
<tr>
<td>Severely dissected plains</td>
<td>0.87</td>
<td>0.15</td>
<td>0.16</td>
<td>0.82</td>
<td>0.05</td>
<td>0.04</td>
</tr>
<tr>
<td>Flat to undulating plains with numerous irrigation channels, high water table and row crop</td>
<td>0.06</td>
<td>0.82</td>
<td>0.85</td>
<td>0.18</td>
<td>0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Mountains</td>
<td>0.09</td>
<td>0.87</td>
<td>0.67</td>
<td>0.11</td>
<td>0.16</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Index 1 = contents of fine sand in soil; Index 2 = percentage of sandy land; Index 3 = average relief degree of land surface; Index 4 = the intensity of wind energy; Index 5 = average of EVI; Index 6 = fine sand in soil.


<table>
<thead>
<tr>
<th>Land Use Types</th>
<th>Wind Erosion Hazard Class</th>
<th>2003</th>
<th>2005</th>
<th>2007</th>
<th>2009</th>
<th>2011</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat to undulating plains</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>Slight</td>
<td>Slight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flat to undulating plains, poor traction in wet soils</td>
<td>Moderate</td>
<td>Severe</td>
<td>Severe</td>
<td>Very Severe</td>
<td>Moderate</td>
<td>Severe</td>
<td></td>
</tr>
<tr>
<td>Near lakes and in depressions</td>
<td>Severe</td>
<td>Very Severe</td>
<td>Severe</td>
<td>Very Severe</td>
<td>Severe</td>
<td>Very Severe</td>
<td></td>
</tr>
<tr>
<td>Flat to gently rolling plains, hills and mountains</td>
<td>Slight</td>
<td>Slight</td>
<td>Moderate</td>
<td>Severe</td>
<td>Moderate</td>
<td>Moderate</td>
<td></td>
</tr>
<tr>
<td>Severely dissected plains</td>
<td>Severe</td>
<td>Very Severe</td>
<td>Severe</td>
<td>Very Severe</td>
<td>Severe</td>
<td>Very Severe</td>
<td></td>
</tr>
<tr>
<td>Flat to undulating plains with numerous irrigation channels, high water table and row crop</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Slight</td>
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</tr>
<tr>
<td>Mountains</td>
<td>Slight</td>
<td>Slight</td>
<td>Slight</td>
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</table>
maximum and minimum mean NDSI values were seen in severely dissected plains and mountainous lands, respectively (Fig. 2). Generally, NDSI values of all land uses of 2003 were higher than those of 2013 (Fig. 2).
Discussion

Mean annual precipitation of Iraq is 161 mm (Bou-Zeid and El-Fadel, 2002; AL-Timimi and AL-Jiboori, 2013) which reflects the characteristics of arid and semi-arid regions (Zhu-Guo et al., 2005).

Dust storm emissions in the western part of Iran have been intensified by several involved factors in Iraq. These factors are aridity, inappropriate distribution of rainfall, drought episodes, farmlands abandon, over grazing, construction dams and highest amount of water required for optimal crop production. The effects of these factors on the occurrence of dust storms in the Western parts of Iran are discussed below.

Western and central parts of Iraq's annual precipitation takes place during winter where summer agricultural activities suffer from water shortages (Zakaria, 2012). These regions' rainy seasons start in November and late May (Al-Khalidy, 2004). Summer was mentioned by Kutiel and Furman (2003) to be the time of dust storms' frequent occurrence in Iran, North-Eastern Iraq, Syria, Persian Gulf, South Arabia, Yemen and Oman.

Western and Central parts of Iraq's geographical location in a dry area which is characterized by water scarcity and low annual rainfall (Al-Ansari and Knutsson, 2011) with uneven distribution (FAO, 1987) is believed to be the major sources of dust storms in the area (Al-Jumaily and Ibrahim, 2013).

The occurrence of dust storms over several western Iranian cities is higher during spring and summer when vegetation percent shows the reductions in the source areas. So, recent years' drought conditions caused the source areas' vegetation degradations and the occurrences of Western Iranian dust storms have become more frequent.

During the studied years, RBFN model indices comparisons indicate that among all RBFN model indices, only the vegetation percent index has been changed (Table 1). Other RBFN model indices are pedological or topographic parameters which could not be altered by the amount of precipitation. So, according to the RBFN model, the observed differences in the wind erosion hazard maps (Fig. 1) of 2003, 2005, 2007, 2009, 2011 and 2013 are due to the changes in vegetation percent index. Vegetation coverage is one of the key factors influencing wind erosion (Yan et al., 2011).

The maximum and minimum values of vegetation percent index (EVI) of land uses were ranged from 0.16 to 0 (Table 1). The highest and lowest values of vegetation percent (EVI) were found in 2003 and 2009, respectively (Table 1).
Generally, the vegetation percent index (EVI) in all land uses of 2003 was higher than that of 2013 (Tables 1 and 2).

Iraq’s precipitation was above the mean annual precipitation for the years 2000–2006 (Becker, 2014). By 2005, after 5 consecutive wet years, perennial plants were growing in the previously bare spaces. Consecutive wet years increased the power of perennial plant species establishment (Peters et al., 2012; USDA, 2012). But vegetation index (EVI) percent of 2003 was higher than that of 2005 (Table 1).

There is an explanation in this regard after several consecutive wet years; nutrient depletion is known to happen in the arid ecosystems (Ettershank et al., 1978; James and Jurinak, 1978; Fisher et al., 1988). This phenomenon could lead to decrease the plant growth in source area of western Iran’s dust storms. Nutrient depletion may cause a decrease in vegetation cover in 2005; despite the mean rainfall in 2005, it is almost same as that of 2003 (Becker, 2014). On one hand, competition for space and light could limit the growth. Competitive interactions were probably minimal after a drought but they could be suddenly intensified after a consecutive year of high precipitation and high growth (Hessing et al., 1996).

The highest and lowest values of NDSI were found in 2003 and 2009, respectively (Fig. 2). Visual comparisons of mean NDSI values in all land uses during the studied years (2003, 2005, 2007, 2009, 2011 and 2013) indicate that the highest and lowest values of NDSI were found in 2003 and 2009, respectively (Fig. 2). So, soil salinization and soil wind erosion had an almost consistent trend.

The results of present study found NDSI as a reciprocal of vegetation percent index (EVI) which gives lower values for the vegetation cover. These results are in agreement with the results reported by Chandana et al. (2004) and Setia (2011) researche. Soil salinity was found as a severe environmental hazard that affected the plant establishment ability. Soil salinization reduces plant growth and may even cause the plant death.

As compared with in situ observations, there were two and five records of pervasive dust storms in western parts of Iran in 2003 and 2005. In 2013, Iraq and other Middle East countries have been in drought conditions. There were more than 10 observed dust storms in 2013 in the western part of Iran.

In general, the mean vegetation percent index (EVI) in all land uses of 2009 was less than that of all the other studied years (Table 1). Iraq’s 2007-2009 drought episodes correspond to a two-year driest case since 1940 (Trigo et al., 2010). This adverse environmental consequence continued until 2010 (Gibson, 2012) although its intensity was reduced.

In situ observations comparison indicated that there were five records of pervasive dust storms in western Iran in 2007. The number of pervasive dust storms in western Iran in 2009 and 2011 was twelve and nine, respectively. Iraq’s annual precipitation of 2011 was lower than 15 mean years (Becker, 2014).

The availability of water causes the plant biological activity in the arid and semi-arid areas (Lambers et al., 1998). In the arid and semiarid regions, precipitation pulses are important triggers for biological activity (Huxman et al., 2004). Precipitation caused better establishment of plant species in Iraq. Plants grow rapidly following the onset of wet season and remain as ground cover for several months until being dried, grazed and trampled by livestock and fires have removed their effectiveness in sheltering and protecting the soil surface (Ehrlich et al., 1997; Herrmann et al., 2005; Linderman et al., 2005). Drought led to the extensive destruction of vegetation cover and expansion of wind erosion (Zhibao et al., 2000). So, drought conditions caused the source areas’ vegetation degradations' increment and the occurrences of western Iran dust storms have become more frequent.
Wind erosion (Gomes et al., 2003) and soil salinization (Zhang, 2011) are known as natural processes that had been shown to be exacerbated by anthropogenic activities. Agricultural lands have been reduced drastically due to water scarcity. There are lots of abandoned farmlands in Iraq. Thousands of hectares of farmlands are abandoned every year (ICARDA, 2013). Several years’ cultivation and soil salinization process have caused that this area became a dust storm source area.

Vegetation reduces wind speed at the soil surface, prevents much of the wind force from contacting soil particles and causes the wind erosion reduction (Lyon and Smith, 2010).

Many factors such as animal feeding operations may also contribute to dust emissions due to wind erosion (Gillies et al., 2005).

Overgrazing in Iraq’s rangelands has reached the stage of causing soil erosion and has severely reduced the carrying capacity of the rangelands (Kaul and production has been recorded in Iraq and some other countries reflecting the ineffective use of irrigation in these countries (Doell and Siebert, 2002). High amount of water required for crop production caused loss of vegetation cover and wind erosion exacerbation.

Conclusion

Among all RBFN model indices, only the vegetation percent index has been changed across the study years. The highest and lowest values of NDSI were found in 2003 and 2009, respectively. The highest and lowest values of vegetation percent were seen in 2003 and 2009, respectively. Source area soil salinization caused vegetation destruction. Iraq’s vegetation reduction has reached the stage of causing wind erosion. It is well known that wind erosion was known as a main mechanism for dust storm creation. *In situ* observations comparisons indicate that there were two, five, five, twelve and nine records of pervasive dust storms in Thalen, 1971). During drought periods, vegetation cover levels are reduced (either naturally or at an accelerated rate by overgrazing) leading to the increased wind erosion rates, decline in soil fertility and in soil moisture storage capacity (McTainsh and Strong, 2007). So, overgrazing in Iraq’s rangelands causes the vegetation destruction in drought conditions. This factor exacerbates the wind erosion and dust storm occurrences in the west of Iran.

On the other hand, Iraq is meeting water shortages and the problem is becoming more serious with the progress of time. The main water resources of Iraq (Tigris and Euphrates Rivers) suffer from severe reductions in their discharges due to the construction of dams on both banks of the rivers inside Turkey and Syria (Al-Ansari and Knutsson, 2011; Zakaria, 2012). Dams cause major water balance changes and wetland drying in South-eastern Iraq. Dried wetlands are suitable dust aerosol sources.

Nevertheless, the highest amount of water required for optimal crop western Iran for 2003, 2005, 2007, 2009 and 2011, respectively.

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اثر فرسایش بادی و شوری خاک بر وقوع طوفان‌های خاک در غرب ایران

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چکیده. در غرب ایران، طوفان‌های خاک به عنوان یک مساله زیان‌آور شناخته می‌شوند. کشور عراق به عنوان یکی از منابع اصلی تأمین بار برای وقوع طوفان‌های خاک در غرب ایران شناخته می‌شود. در این تحقیق از مدل RBFN برای بررسی شدت فرسایش بادی در منطقه منشأ طوفان‌های خاک غرب ایران استفاده گردید. نتایج پژوهش نشان داد که تغییرات شوری خاک در سال‌های 2003، 2005، 2007، 2009 و 2011 اثر تغییر در صدای پوشش گیاهی و نشان داد که تغییرات ناشی از فرسایش بادی در منطقه منشأ طوفان‌های خاک غرب ایران حاصل شده است. نتایج پژوهش نشان داد که مقدار عددي شاخص شوری در سال‌های 2003 و در همه کاربری‌ها از سال 2013 زیادترا است. به طور کلی، به‌میزان و (NDSI)
کمترین مقدار کمی شاخص NDSI به ترتیب در دشت‌های شدید شور و قليایی و اراضی کوهستانی دیده شده است. شوری خاک باعث تخریب پوشش گیاهی گردیده و خطر وقوع فرسایش بادی را به ترتیب در دشت‌های شدید افزایش داده است. تعداد دفعات وقوع طوفان خاک در غرب ایران زیادتر شده است. مطالعات میدانی نشان داد، تعداد دفعات وقوع طوفان‌های خاک افزایش یافته در سال‌های 2003، 2005، 2007، 2009 و 2011 به ترتیب 2، 5، 12 و 9 بار گزارش گردیده است.

کلمات کلیدی: طوفان خاک، شور شدن خاک، فرسایش بادی

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Variations of Water Soluble Carbohydrate in Plant Organs of Bromus tomentellus and Festuca ovina in Three Phenological Stages

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