INVESTIGATION OF SOIL TYPE EFFECTS ON DUST STORMS DETECTION USING DAY AND NIGHT TIME MULTI-SPECTRAL MODIS IMAGES

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ABSTRACT: Dust storms are one of the main hazardous problems in arid and semi-arid regions which impact on natural resources and environment. Therefore, continuous monitoring and determination the spatial and temporal variation of dust storms is necessary. The objective of this study was to investigation the effect of different soil types in dust affected areas using satellite images and statistical analysis. Visibility data were obtained from National Geography organization of Iran for determination days with dust occurrence. In addition, MODIS images were obtained on 18, 19, 20 and 21 April 2008 and preprocessed. Processed satellite images were overlayed with the FAO soil map of Iran, four soil types selected Lithosols, Calcaric Regosols, Calic Yermosols and Orthic Solonchaks. For each soil classes 40 pixel samples were selected, randomly. Daytime and nighttime images and thermal bands have been used for dust detection. Brightness Temperature Differences (BTD) was determined in bands 31 and 32 of for MODIS daytime and nighttime images. Statistical analysis showed that mean value of pixel samples of these four soil types at both daytime and nighttime have difference, Mean comparison was conducted by Duncan’s test for determination of the most effective soil on dust detection. Results showed that in daytime images, regions with calcareous soil type because of their more heat absorption about thermal infrared wavelengths range, and consequently having maximum BTD comparing to other soil types have a significant effect on dust detection. In addition, similar results could be seen in nighttime images.

Keywords: Ackerman, Brightness Temperature Difference, Dust Storms Detection, FAO Soil Map, Remote Sensing.

INTRODUCTION

Dust storms are one of the main hazardous problems in arid and semi-arid regions which impact on natural resources and environment. Dust aerosol influence on global climate change (Wald et al., 1998). Dust particles are one of the most important parts of the earth climatic systems and can change the climate by their direct effect on radiation absorption and dispersion phenomena (Tegen et al., 1996). Iran is an arid country and more than 2/3 of its extent has occupied by arid and semiarid lands (Memarian et al., 2008). These regions of Iran are predominantly affected by high intensive dust storms. In these regions high temperature, soil salinity and high velocity of winds can dispersed soil particles and suspect them for dust phenomena (Refahi, 2006). Regarding to importance of dust storm phenomena, it is very necessary to continues detection and monitoring of dust storms and also determination of their temporal and spatial variation is inevitable. Remote sensing techniques are one of the efficient methods for dust events detection and mapping that have been recently used for identifying dust sources locations with varying degrees of success. Satellite monitoring is a powerful instrument to study on large-scale dust storms properties. Various surface radiations are determined by different satellite sensors using their spectral channels. Many algorithms have been developed by scientists for dust storms detection and also some methods for
determination affecting radiation signals on atmospheric dust detection (Husar et al., 2001).

Since the 1970s, scientists have succeeded in identifying the outbreaks of dust storms from satellite images using two different techniques, the VIR (visible Infrared) technique (Griggs, 1975; Carlson, 1979; Norton et al., 1980) and the TIR (Thermal Infrared) window technique (Shenk and Curran, 1974; Ackerman, 1989). It has been shown that the TIR technique has the distinct advantage in detecting dust storms over high albedo surfaces and in nighttimes. Dust aerosol reflection commonly increase in 0.4-2.5 μm wave length and has minimum and maximum value in channel 3 and channel 7 of MODIS, respectively. These spectral characteristics of the soil can distinguish dust from cloud and have maximum reflectance in channel 3. Thus, dust storms can be detected by mentioned spectral properties. Different indices have been presented for dust storms detection according to these properties (Qu et al., 2006; Washington et al., 2003). Ackerman (1997) discussed a tri-spectral method with 8 m, 11 m and 12 m wavelengths to detect dust storms for MODIS data. He investigated the thermal signature under different aerosol types and analyzed the impact of land surface emissivity, view angle, surface temperature, and atmospheric structure.

It has been seen from dust spectral characteristics that the strongest signals can be derived from difference between 2.13 μm and 0.469 μm having maximum and minimum values, respectively. This difference can distinguish dust storms from water and cloud. Because of this distinct difference, NDDI1 index proposed (defined) for dust detection according to equation 1.

\[
\text{NDDI} = \left( \rho_{2.13} \cdot \rho_{0.469} \right) / \left( \rho_{2.13} \cdot \rho_{0.469} \right)
\]

Where, \( \rho_{2.13} \) and \( \rho_{0.469} \) are channels 2.13 μm and 0.469 μm reflectance, respectively. NDDI index value for cloud is negative because of high reflectance in channel 2.13 μm and low reflectance in channel 0.469 μm. Also NDDI value for land surface shapes is lower than 0.28, this value is more than 0.28 for dust storms (Qu et al., 2006). Dust storms monitoring is performed by satellite images according to their physical and chemical properties, dust particles density and dispersion. Some other agents are affective in dust identifying process in addition to properties of suspended materials. Land cover diversity is one of the most important of them. The aim of this study was to investigate different soil types effect on dust storm detection process Using Daytime and Nighttime Multi-spectral MODIS Images in Iran.

**MATERIALS AND METHODS**

**Data collection and processing**

Generally most of the remote sensing researches need to specific climatic data. In this study the MODIS images have been used during the days with dust occurrences from Iran. Climatic information of these areas such as visibility data were received from National Geography Organization of Iran. The visibility data were hourly and values with visibility content lower than 1000 meter and 5 to 7 present weather code2 accepted as days with dust storm occurrence. After surveying visibility data, 18, 19, 20 and 21 on April 2008 determined as days with dust phenomenon occurrence (Figures 1 and 2). Since these days were continues; there was the possibility to have a good perception of the temporal and spatial variation of dust and assessment soil type effects on dust detection in the study area.

MODIS makes observations using 36 spectral bands including the 8.5 μm (channel 29), 11 μm (channel 31), 12 μm (channel 32) TIR channels with wavelengths from 0.41 to 14.4 μm and it has low spatial resolution of 0.25 Km, 0.5 Km and 1Km. It is a moderate resolution imaging spectroradiometer on board the NASA Earth observing system (EOS) Terra and Aqua satellites, launched in December 1999 and May 2002, respectively (Baddaock et al., 2009). MODIS products were used for determination of dust properties and monitoring of them. Before performing the image processing, they must be preprocessed such as atmospheric corrections. Atmospheric correction is related to images level and required indices type and research purpose. If the indices compromised from both long wave and short wave bands atmospheric correction is inevitable, in this study, it has been used from MODIS Level 1B images that haven’t need to atmospheric correction. MODIS daytime and nighttime images were not georeferenced, so before any process they need to be gesorereferenced. Georeferencing of daytime and nighttime images have been done using ENVI 4.7.0 software.

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1. Normalized Difference Dust Index

2. Iran Meteorological Organization
   (www.weather.ir)
Figure 1- Daytime images of dust occurrence from MODIS. a, b, c and d are daytime images of dust occurrence on 18, 19, 20, 21 April 2008, respectively.
Figure 2: Nighttime images of dust occurrence from MODIS. a, b, c and d are nighttime images of dust occurrence on 18, 19, 20, 21 April 2008, respectively.

Dust Storms Detection
Since many algorithms have been developed for dust storms detection by different scientists, in this study daytime and nighttime images and thermal bands have been used for dust detection. Ackerman index is a useful method for dust detection in thermal bands. Before Ackerman it had been used from Brightness Temperature Method that had limit success in dust detection because of its changes with earth surface emissivity power created some errors in dust detection (Baddaock et al., 2009). Thermal infrared images have some advantages over VNIR data because TIR data can coverage day and night, and can also be used on bright surfaces. For reason of dust emissivity variation and transport nature, Ackerman (1977) used from methods based on Brightness Temperature

1. Visible Near Infrared
Difference (BTD) between two or three wavelength that principally are bands with 11, 12 µm or 8, 11, 12 µm. And concluded that, by increasing dust optical depth the brightness difference (BT8.5- BT11) and (BT11- BT12) will increase, while (BT11-BT12) will become negative. This tri-spectral method is useful for dust storms detection (equation 2).

\[ BTD = BT_{11} - BT_{12} \]  
\[(2)\]

Where, BT11 and BT12 are brightness temperature in 11 and 12 µm wavelengths, respectively.

It should be notice that in this method BTD value is temperature difference between land surface and colder (lower temperate) minerals. Related process did not affect extensively by atmospheric gases.

Besides the dust detection on lands, it can be possible to distinct cloud from dust when they are in the vicinity together. Brightness Temperature Difference between 11 µm and 12 µm wavelengths and also 11 µm wavelength brightness temperatures are intensively controlled with beneath surface temperature (Zhang, 2005). According to assimilation thermal infrared radiation transmission, Ackerman (1997) presented a Tri-Spectral technique with wavelengths 8(band 29), 11 (band 31) and 12 (band 32) µm for dust storm detection on MODIS and NOAA/AVHRR data. In this study, the equation (3) has been used for dust detection which is identified as Ackerman index:

\[ BTD = BT_{31} - BT_{32} \]  
\[(3)\]

Ackerman index threshold value is zero, the values with \(DN^1<0\) supposed as dust and ones equal or greater than zero don’t demonstrate any dust occurrence. Although Ackerman defined the value lower than zero as a dust occurrence, but Darmenov and Sokolike (2005) demonstrated that value is variable when used for dust events on the Ocean. The BTD values for different phenomenon are shown in Table 1 (Zhang et al., 2006).

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2. Digital Number
Table 1 - BTD values of observed targets by satellite (Zhang et al., 2006).

<table>
<thead>
<tr>
<th>Target</th>
<th>Typical value of BTD$_{11-12}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice cloud</td>
<td>Far more than zero</td>
</tr>
<tr>
<td>Water cloud</td>
<td>Around zero or little more than zero</td>
</tr>
<tr>
<td>Bared Land Surface</td>
<td>Around zero or little less than zero</td>
</tr>
<tr>
<td>Sea Surface</td>
<td>Around zero</td>
</tr>
<tr>
<td>Dust Storm</td>
<td>Far less than zero</td>
</tr>
</tbody>
</table>

**Pixel Samples selection**

In order to investigation of the soil type effects on dust detection, it was necessary to establish a correlation between dust and beneath soil. For this object, a geographical correlation between MODIS processed images and their match (comparable) regions on soil maps was needed. So the FAO\(^1\) soil map of Iran were used in this study (Figure 3).

Figure 3. FAO soil map of Iran (2001).

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2. Food and Agriculture Organization of the United Nations
Since developing a geographical coincidence between FAO soil map and images that detected dust phenomenon, in regions with dust occurrences probability, 40 pixels selected for each soil class as ROI points randomly (Figure 4). This pattern repeated for all of 8 daytime and nighttime images and Ackerman index calculated for each of them. Finally all points with their longitude, latitude and Ackerman index value entered and sorted separately in the Excel Software.

1. Region of Interest
Figure 4- MODIS selected pixels for one image (a), selected pixels for each soil type (b). Four soil types in FAO soil map have correlation with regions that have dust occurrence on the MODIS images, presented in table 2. These soil types are particularly in arid and, semi-arid and wilderness regions.

Table 2. Soil types that have correlation with regions by dust occurrence on MODIS images.

<table>
<thead>
<tr>
<th>Number</th>
<th>Soil Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lithosols (I)</td>
</tr>
<tr>
<td>2</td>
<td>Calcaric Regosols (Rc)</td>
</tr>
<tr>
<td>3</td>
<td>Calcic Yermosols (Yk)</td>
</tr>
<tr>
<td>4</td>
<td>Orthic Solonchaks (Zo)</td>
</tr>
</tbody>
</table>

Red, green, blue and yellow pixels in figure 4-b are Lithosols, Calcaric Regosols, Calcic Yermosols and Orthic Solonchaks soil samples, respectively. These pixel samples derived from each daytime and nighttime image separately. These soils are composed from different minerals with different thermal characteristics and best thermal properties of their minerals can be distinguished in 4-18µm wavelength range. This range of thermal infrared wavelength have coincidence with absorption properties of some soil compromising material such as Carbonates, Silicates, Oxides, Phosphates, Sulphates, Nitrates and etc. Carbonates have high absorption property in thermal infrared ranges because of high mobility of the carbonate ions. Sulphate and Phosphate absorption properties are distinct in 9 and 16µm and 9.25-10.3 µm wavelengths, respectively.

Litosols are shallow soils with high content of stone and gravel which formed from unconsolidated and continues stones parent materials. Calcaric Regosols are regosol soils that have calcic materials and have 2 or more than 2 percent calcium carbonate. These soil have low development and have been extended in eroded lands and arid and semiarid regions.

Calcic Yermosols are Yermosols that have Calcic horizon with distributed secondary calcium carbonates. These soils also existed in regions with arid climate. Orthic Solonchaks are soils with high concentration of dissolved salts and developed on arid, semi arid and beach regions.

As mentioned above all of the studied soils were particularly developed in regions with arid and semi arid climate. Calcite, Gypsum and dissolved salts that are main materials in these soils may affect on dust detection process. After collecting dust pixel samples and soil data statistical analysis were conducted to determination the most effective soil on dust detection.

RESULTS AND DISCUSSION

Since dust detection on daytime and nighttime images, in order to determination of dust affected regions, the FAO soil map of Iran were overlayed on the images using ENVI 4.07 software.

Dust detection on these images showed that dust event mainly focused in south and southwest regions of Iran. Dust detection results
on daytime and nighttime images have been showed in figures 5 and 6, respectively.

Figure 5. Dust detection results on daytime images a, b, c, d are 18, 19, 20, 21 April daytime images.
Figure 6. Dust detection results on nighttime images a, b, c, d are 18, 19, 20, 21 April nighttime images.

Pixel samples that derived from MODIS nighttime and daytime images were analyzed statistically for each studied soil types. Statistical analyses were carried out using completely randomized design (CRD) and mean comparison test was done using Duncan’s test. These analyses created 160 samples for each soil types and after sorting them in Excel software from smallest value to largest, the daytime and nighttime images graphs were drew separately. The pixel sample numbers are showed against the brightness temperature difference in daytime and nighttime images in Figure 7 and 8, respectively. In these graphs X axis is samples number and Y axis is BTD value in bands 31 and 32 of MODIS sensor.
Figures (7 and 8) illustrated that BTD (BT31-BT32) values for daytime are greater than nighttime images because BTD values for dust particles in day are greater than night. Pixel sample graphs of daytime images showed that Calcaric Regosols and Calcic Yermosols, calcareous soils, are in downer position (level) comparing two other soils and consequently they have the highest BTD value. Orthic Solonchaks, and Saline soils are situated at the next level and have relatively high BTD but its value is lower than two calcareous soils. Lithosol which is a shallow soil with abundant gravel content is also placed in uppermost position. In the nighttime images, the graphs in quick view are very close together as one couldn’t certainly declared what graph is related to soil with higher BTD, but the Calcaric Regosols soil graph have higher BTD proportion than other soils and is almost situated below the other graphs.

Statistical analysis
In order to determine the soil with maximum brightness temperature difference and most effect on dust detection, Statistical analyses such as analysis of variance and mean comparison test conducted in SPSS software (Table 3 and 4).
Tables 3 and 4 presented that Calcaric Regosols and Calcic Yermosols have higher BTD mean value in daytime images and have more effect on dust detection. Calcic Yermosols in nighttime image have most BTD and more effect on dust detection.

Table 5 showed that mean value of these four soil types at both daytime and nighttime have difference. To determination of the most effective soil on dust detection, Mean comparison was necessary and it was conducted by Duncan’s test. The results of the Duncan’s test in daytime and nighttime images are presented in Table 6 and 7, respectively.

Table 6. Duncan’s test results for daytime data.

<table>
<thead>
<tr>
<th>Treat</th>
<th>Subset</th>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>160</td>
<td>-1.2462</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>160</td>
<td>-1.2112</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
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<tr>
<td>1</td>
<td>160</td>
<td>-</td>
<td>-</td>
<td>-0.8177</td>
<td></td>
</tr>
</tbody>
</table>

1. Standard Deviation  
2. Coefficient of variation  
3. Mean Square
Table 7. Duncan’s test results for nighttime data.

<table>
<thead>
<tr>
<th>Treat</th>
<th>N</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>160</td>
<td>-0.7916</td>
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<td>3</td>
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<td>-</td>
<td>-0.7058</td>
</tr>
<tr>
<td>4</td>
<td>160</td>
<td>-</td>
<td>-0.6562</td>
</tr>
<tr>
<td>1</td>
<td>160</td>
<td>-</td>
<td>-0.6460</td>
</tr>
</tbody>
</table>

Numbers 2 and 3 are Calcaric Regosols and Calcic Yermosols and both of them have same subgroup and they have significant difference with other soil types. Number 4 is soil with another subgroup that has significant difference with Lithosol. It can be concluded that in Calcaric Regosols and Calcic Yermosols BTD parameter rather than other soils have more significant difference, then the effect of these soils on dust detection is higher than other soils. Calcaric Regosol soils had more significant difference in comparison with 3 other soils and situated in one subgroup, but other 3 soils had not any significant difference and situated in next subgroup.

CONCLUSION

This paper investigated dust storm detection with multiple MODIS thermal IR (infrared) bands by analyzing data for major dust events over Iran during April, 2009. Results showed that in daytime images, regions with calcareous soil type because of their more heat absorption about thermal infrared wavelengths range and consequently having maximum BTD comparing to other soil types have a significant effect on dust detection. In addition, similar results could be seen in nighttime images, but only one of two calcareous soils have significant difference by other soil types, thus could not certainly extrapolated this result for nighttime images, other studies results also was showed the capability of Brightness Temperature Differences (BTD) in bands 31 and 32 of MODIS daytime and nighttime images in dust storm detection (Shenk and Curran, 1974; Ackerman, 1997). One type of saline soils in daytime images data also had relatively high BTD but less than that of calcareous soils and in nighttime data had not considerable difference. Accordingly, it was concluded that salt had no effect on dust detection in nighttime images. As a result, surfaces with high contents of Lime had a drastic effect on dust BTD values and subsequently on dust detection, because Calcium Carbonate had a high potential for heat absorption in thermal infrared wavelengths. Although similar result had been seen in nighttime images, but it can’t be extrapolated certainly. The BTD11 − 12 and BT11 for the dust storm are strongly controlled by the underlying surface temperature, Dust aerosol loading, particle size distribution of dust aerosol and the refractive index of dust aerosol. The unknown surface emissivity also has considerable influence on the forward and retrieval process. These factors will decrease the reliability of retrieval results (Zhang et al., 2006). Different soil types that cover land surfaces have different effect on dust detection by used of satellite images. As mentioned above lime (Calcite) have high BTD values for its more heat absorption and more absorption ability in thermal infrared wavelengths that is useful parameter for dust determination. Generally lands with light color surface materials such as Gypsum, Salt (Halite) and specially Calcite (Lime) due to their more heat absorption properties about thermal infrared wavelength range had high BTD values and this parameter can be applied to determine dust beneath surface type. Indeed, if dust concentration was so high in the satellite image, it’s beneath surface probably had noticeable contents of Calcite, Gypsum or Salt.

REFERENCES


Baddock MC, Bullard JE, Bryant RG (2009) Dust source identification using MODIS:


