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Identification of threshold values for the characterization of sandstorm events Over Saudi Arabia

Essam Mohammed Alghamdi[£¥], Mazen Ebraheem Assiri[¥], and Mohsin Jamil Butt[¥]
[¥]Department of Meteorology, Faculty of Meteorology, Environment and Arid Land Agriculture
King Abdulaziz University
Jeddah, Saudi Arabia

***Abstract*. Sandstorm events are one of the major environmental hazards in the Arabian Peninsula. This study aims to investigate sandstorm events by applying MEDI (Middle East Dust Index) on MODIS (Moderate Resolution Imaging Spectroradiometer) data. For this, twenty sandstorm events over Saudi Arabia are selected. The resultant MEDI sandstorm events are verified by the data from ground-based meteorological stations, MSG (Meteosat Second Generation) satellite data, and Aerosol Optical Depth (AOD) based on dark target-deep blue MODIS Terra product. Accuracy analysis of the method indicates that POFD (Probability Of False positive Detection), POCD (Probability Of Correct positive Detection), and MEDI accuracy for detecting sandstorm event over study area is 29 %, 92 %, and 73 % respectively. The outcomes of the research indicate that MEDI can effectively detect sandstorm events in the study area. It is envisaged that the current endeavor can be very beneficial for the environmentalists, climatologists, and policy makers in order to mitigate sandstorm related issues affecting the society in terms of health and economic conditions.**

Keywords: MEDI, MODIS, AOD, MSG

INTRODUCTION

Sandstorms are frequent phenomena particularly in dry and baren regions in different parts (for example, North China, North Africa, Australia, Middle East) of the world (1). The environmental and climatological issues related with sandstorm events are associated with the interaction of electromagnetic radiation travelling through the atmosphere thereby affecting the clouds microphysics (2–7). Their role in affecting the global warming by indirectly altering the weather system of the globe has been identified by IPCC (8).

The risks associated with sandstorm are devastating that includes but not limited to economy (damaging structures), environment, health (may carry virus spores from source origin and spread related disease in many other places), and daily routine life (9–11). A severe sandstorm can enhance concentration of aerosols in the atmosphere which can interrupt aviation and local transportation due to reduction in visibility. In addition, the high concentration of aerosols can also pollute the local and regional air quality leading to diseases related to respiratory. During the development of sandstorm, the strong wind is responsible of removing fertile soil from an area and depositing it on unwanted places. This process can sometime affect the process of photosynthesis (causing reduction in grain production) if sand and dust are deposited on vegetation. It is therefore very important to monitor sandstorm event in near real time on a regular basis with utmost accuracy so that the required precautionary measurements can be taken in the affected region to minimize their impacts.

When high wind speed uplift loose sand and dust particles from deserts, arid, and dry uncultivated regions into the air and diffusing them into large area due to convection or strong turbulence, sandstorms are formed. These sandstorm can be transported over a long distance in the presence of strong wind in the region (12). Sandstorms have been distributed (suspended sand and dust, blown sand and dust, sandstorm, severe sandstorm) by WMO (World Meteorological Organization) with respect to the extent of their intensity as well as spatial and temporal coverage. In addition, researchers have also classified small scale (covering small area), large scale (covering large area), short lived (stays for few minutes or hours), and long lived (stays for some days) sandstorm events (13).

In the last few decades, one of the main focuses of researchers have been to develop a method that can give near real time accurate detection of sandstorm events. However, the main challenge in the development of efficient technique is the input data (for example, atmospheric pressure, wind speed, surface temperature, soil moisture, humidity) based on ground observation as well as on satellite observation (14). Although, both the data source has their advantages and disadvantages, researchers have been using the input data from both sources in the development of atmospheric models, land surface models, dust emission models, and dust deposition models. The developed models are being used successfully in the sandstorm related research.

Satellite remote sensing due to their large aerial coverage, near real time data availability, and monitoring in the remote and inaccessible area has always attracted researchers in different parts of the world. The freely available satellite data is another reason to compromise on relatively low spatial resolution as compared with ground-based data. Many satellite systems with various payloads have been the source of data required in the development of sandstorm detection methods. For example, data from TOMS (Total Ozone Mapping Spectrometers) onboard Nimbus-7 with a spatial resolution of 50 km, data from AVHRR (Advanced Very High Resolution Radiometer) onboard NOAA (National Oceanic and Atmospheric Administration) with a spatial resolution of 1 km (local mode) and 4 km (global), data from SEVIRI (Spinning Enhanced Visible Infra-Red Imager) onboard MSG (Meteosat Second Generation) with a spatial resolution of 3 km, and data from MODIS (MODerate resolution Imaging Spectroradiometer) onboard both Terra and Aqua satellites with a spatial resolution between 250 m to 1 km (depending on MODIS band).

MODIS data due to its large area coverage, moderate spatial and temporal resolutions, and high spectral resolution has been widely used in the development of sandstorm methods in different parts of the world. For example, NDDI (Normalized Difference Dust Index) developed by Qu et al. (2006), GDDI (Global Dust Detection Index) developed by Samadi et al. (2014), and MEDI (Middle East Dust Index) developed by Karimi et al. (2012) have been applied for the detection of sandstorm over Gobi desert, over Iranian region, and over the Middle East respectively. In the development of NDDI Qu et al. (2006) used the spectral signature of MODIS bands 7 and 3 while in the GDDI Samadi et al. (2014) used the spectral signature of MODIS bands 7 and 4. In the development of MEDI Karimi et al. (2012) used the brightness temperature properties of deserts in MODIS bands 29, 31, and 32.

Satellite remote sensing technique due to an attractive and reliable source of data in sandstorm monitoring has attracted many researchers during the last two decades (18,19,28,20–27). For example, Butt & Mashat (2018) used MODIS data and applied NDDI in the detection of 24 sandstorm events over Saudi Arabia from the year 2002 to 2011. In contrast to the original threshold value (0.26) proposed by Qu *et al.*, (2006) they found lower threshold value (0.23) in the detection of sandstorm over Saudi Arabia. In another study Albugami *et al.*, (2018) determined that NDDI values in the detection of sandstorm event is different between the year 2000 to 2015. Similarly, Alghamdi et al. (2021) used GDDI on MODIS data for the detection of sandstorm event over Saudi Arabia between the year 2000 to 2017. Unlike the Samadi et al. (2014) who did not present any threshold value in the detection of sandstorm events they proposed various threshold values in order to identify different sandstorm related features over the surface and water areas in Saudi Arabia.

Saudi Arabia, which is the study area in this research has been hampered due to frequent sandstorm events almost all year-round. Thus, research on sandstorm detection in Saudi Arabia is very important from climatological and environmental point of view. However, the ground-based meteorological stations, that are the major source of data in the sandstorm related research, are quite sparse in nature. To the best of our knowledge MEDI has never been applied over Saudi Arabia for the detection of sandstorm events. Therefore, in the present study, MEDI is used on MODIS onboard Terra satellite data in order to detect and monitor sandstorm events over Saudi Arabia. MEDI results are validated by utilizing ground-based station data, Meteosat Second Generation (MSG) satellite data, and Aerosol Optical Depth (AOD) based on dark target-deep blue MODIS Terra product (hereinafter called AOD) over the study area.

2 Study Area

Saudi Arabia is an arid, sparsely populated, and largest country in the Middle East. The geographical extent of Saudi Arabia with latitude and longitude as well as location of ground-based meteorological stations in the area are shown in Figure 1. The country has some of the world's major deserts named Ad Dhana, Rub' al Khali, and Al-Nafūd that are the main source of sandstorm activities during all year round. In addition, in the north of Saudi Arabia the barren region of Jordan, Iraq, and Syria are the sources of sandstorms while the arid regions of Iran and United Arab Emirates (UAE) are the main sources of sandstorm in the northeast and east of Saudi Arabia respectively. In the southwest and southeast of Saudi Arabia the African Sahara and Yemen are the main regions that are contributing sandstorm activities from time to time.

Climatologically, the country has been divided into three zones, that is, deserts, western highlands, and highlands (with humid and mild temperature conditions in the north). Cyclonic weather system from Mediterranean Sea moves eastwards to Saudi Arabia in the winter season and sometime reach the eastern and central regions of the country. Similarly, in summer season the monsoon system produces rainfall in the southeast of the country. The lowest temperature (-12 ºC) was recorded in Turaif (north of Saudi Arabia) while the highest temperature (53 ºC) was recorded in Al Ahsa (eastern region of Saudi Arabia) in the year 2015. The average annual rainfall varied between 65 mm in Jeddah to 480 mm in the highlands of Asir. The exceptional case of annual rainfall is however observed in Rub' al Khali which sometime receive 0 mm in a decade.

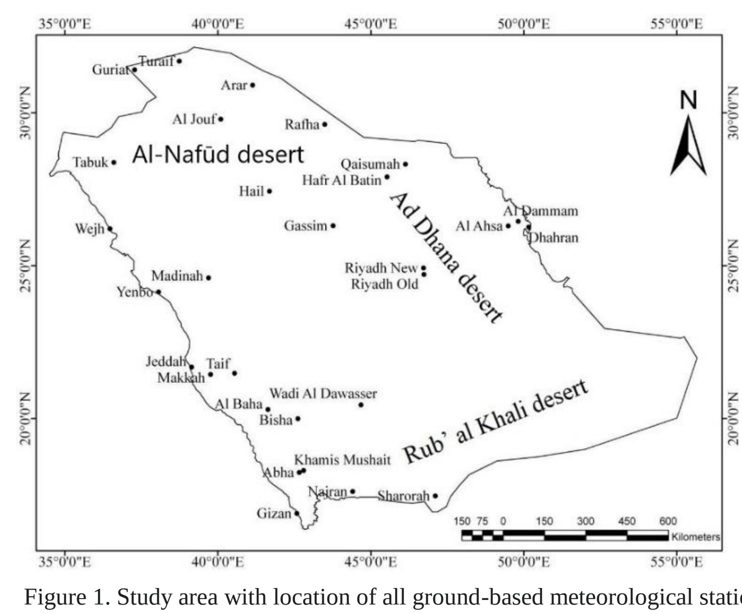

Figure 1. Study area with location of all ground-based meteorological stations.

3 Material and method

MODIS has 36 spectral bands in the range from 0.415 µm to 14.235 µm of wavelength. The spatial resolution of MODIS is band dependent (250 m to 1 km) that makes it very attractive for the environmental studies including sandstorm monitoring. Thus, data from MODIS onboard Terra satellite is used to monitor sandstorm events over the study area. In the present research MODIS (MOD021KM) sandstorm events freely downloaded from https://modis.gsfc.nasa.gov are analyzed over the study area. Table 1 highlights the date of MODIS image for twenty sandstorm events that have been used in the current study. In addition, the names of meteorological stations that have reported the studied events are also given in Table 1.

In Saudi Arabia National Centre for Meteorology (NCM) is the official organization that record, save, and disseminate meteorological data as per WMO standard from ground-based meteorological stations (Figure 1). Thus, ground-based sandstorm data from various stations (as given in Table 1) was retrieved from NCM for the study period.

Once the MODIS data is downloaded (Table 1) MEDI is applied to detect the sandstorm events over the study area. Karimi et al. (2012) modified the method proposed by Ackerman (1997) for the monitoring of sandstorm particularly over the desert regions of Middle East. It was noticed that the technique of Ackerman (1997) that involves brightness temperature values from MODIS bands 31 and 32 gives erroneous results when applied over desert surface. c included MODIS band 29 in order to remove the errors associated with the method of Ackerman (1997) over desert surfaces. Since, Saudi Arabia, which is the largest country in Arabian Peninsula, consists of a large number of small and large deserts MEDI (proposed by Karimi et al., 2012 for sandstorm monitoring over desert regions of Middle East) as given in equation 1 is applied in the current study for the monitoring of sandstorm events.

$$MEDI = \frac{band\ 31 - band\ 29}{band\ 32 - band\ 29} \quad (1)$$

where

band 29 = brightness temperature values of MODIS in the wavelength 8.5 µm

band 31 = brightness temperature values of MODIS in the wavelength 11.01 µm

band 32 = brightness temperature values of MODIS in the wavelength 12.03 µm

One of the main problems in the monitoring of sandstorm events is the misinterpretation due to mineral dust in the atmosphere. Thus, Karimi et al. (2012) introduced a threshold value of 0.6 (dust particles < 0.6 < mineral particles) and successfully differentiated mineral particles from that of the sand and dust particles over the Middle East region. The flow diagram of MEDI is shown in Figure 2.

Table 1. Names of NCM station that reported the sandstorm event and the date of MODIS data used to apply MEDI in the current study.

S.NO	Names of NCM Stations that reported sandstorm event	Total NCM stations	MODIS Image
1	Al Ahsa, Al Dammam, Hafr Al Batin, Riyadh, Qaisumah, Rafha, Yenbo	7	24 March, 2000
2	Al Ahsa, Arar, Dhahran, Al Dammam, Guriat, Hafr Al Batin, Al Jouf, Qaisumah, Rafha, Sharorah,Turaif	11	26 March, 2003
3	Al Ahsa, Dhahran, Al Dammam, Hafr Al Batin, Al Jouf	5	15 Feb, 2004
4	Arar, Guriat, Hail, Al Jouf, Rafha.	5	29 April, 2004
5	Al Baha, Bisha, Rafha, Sharorah, Wadi Al Dawasser	5	28 April, 2005
6	Gassim, Hail, Hafr Al Batin, Jeddah, Madinah, Qaisumah	6	3 Feb, 2006
7	Al Ahsa, Bisha, Al Dammam, Qaisumah, Tabuk	5	29 March, 2006
8	Arar, Gassim, Hail, Al Jouf, Rafha, Wadi Dawaser	6	23 April, 2006
9	Al Ahsa, Al Dammam, Riyadh, Qaisumah, Wadi Dawaser	5	5 May, 2006
10	Al Ahsa, Hail, Hafr Al Batin, Riyadh, Qaisumah	5	10 April, 2007
11	Al Ahsa, Al Dammam, Hafr Al Batin, Wadi Dawaser	4	28 May, 2007
12	Al Ahsa, Dhahran, Al Dammam, Hafr Al Batin, Al Jouf, Qaisumah, Turaif	7	11 Feb, 2009
13	Al Ahsa, Al Dammam, Hafr Al Batin, Riyadh, Qaisumah	5	10 March, 2009
14	Al Ahsa, Al Dammam, Rafha	3	4 March, 2010
15	Al Ahsa, Dhahran, Al Dammam, Hafr Al Batin, Riyadh, Rafha	6	25 March, 2011
16	Al Dammam, Riyadh, Qaisumah, Rafha, Yenbo	5	30 April, 2011
17	Al Ahsa, Dhahran, Al Dammam, Jeddah, Yenbo	5	18 March, 2012
18	Al Ahsa, Dhahran, Hafr Al Batin	3	6 April, 2013
19	Al Ahsa, Arar, Qaisumah	3	24 April, 2015
20	Hail, Al Jouf, Riyadh, Rafha	4	19 March, 2017

In the past, researchers have applied MEDI over the Middle East for different kind of studies. For example, Moridnejad et al. (2015) successfully highlighted the desertification from the year 2001 to the year 2012 in the Middle East by applying MEDI on MODIS data. Similarly, in another study Bin Abdulwahed et al. (2019) investigated three sandstorm events in the year 2007 over the Middle East region. They used MODIS data and applied MEDI for the detection of sandstorm and concluded that the detection accuracy of the method is around 85 % over the Middle East region. Thus, in the current study we have applied the MEDI over

Saudi Arabia for the twenty sandstorm cases between the years 2000 to 2017.

In the current study, sandstorm days were selected using ground-based meteorological data retrieved from NCM. MODIS image for the sandstorm days is retrieved and MEDI (equation 1) is applied in order to detect sandstorm event from satellite data. In the selection of sandstorm events, we used the criteria and include the event reported by at least 3 or more ground-based NCM meteorological stations as given in Table 1. The hourly sandstorm ground-based data retrieved from NCM meteorological stations was tested using Grubbs method.

For the validation of the MEDI results, apart from NCM ground-based sandstorm data, we have also used AOD product, and data from Meteosat satellite. The AOD product over Saudi Arabia was obtained from Giovani website (https://giovanni.gsfc.nasa.gov). Similarly, SEVIRI data onboard MSG was obtained from EUMETSAT (European Organization for the Exploitation of Meteorological Satellites) website (http://eumetsat.int/viewer). The AOD data product is in NetCDF format that can be processed by using Grads software. Thus, average monthly (for the month of sandstorm event) and three days average (±1 day from sandstorm event) maps are prepared from AOD data product. These maps are very useful in the validation process as it gives the average monthly aerosols conditions as well as three days aerosols conditions during the sandstorm event over the study area.

Similarly, SEVIRI data which is onboard on MSG is also in NetCDF format that can be processed with script written in Python language. The processed data is used to prepare the dust product in RGB (Red Green Blue) in order to validate MEDI results. To prepare the RGB dust product band 9 is subtracted from band 10 and resultant values are displayed in red color, band 7 is subtracted from band 9 and resultant values are displayed in green color while band 9 is displayed in blue color. Finally, the performance of MEDI results is tested with statistical methods of POCD (equation 2), POFD (equation 3) and accuracy (equation 4).

$$POCD = \frac{a}{a+c} \times 100 \quad (2)$$

$$POFD = \frac{b}{a+b} \times 100 \quad (3)$$

$$Accuracy = \frac{a+d}{a+b+c+d} \times 100 \quad (4)$$

where

ɑ = total cases when both NCM and MEDI show sandstorm (called true positives)

b = total cases when NCM shows no sandstorm, but MEDI predicts sandstorm event (called false positives)

c = total cases when NCM shows sandstorm and MEDI predicts no sandstorm event (called false negatives)

d = total cases when both NCM and MEDI show no sandstorm event (called true negatives)

4 Results and Discussion

Application of MEDI for the monitoring of sandstorm event over Saudi Arabia has been conducted in this study. For this, twenty sandstorm events are analyzed between the year 2000 to 2017 using MODIS data onboard Terra satellite. The MEDI results are investigated with the help of equation 2, 3, and 4 that gives, POCD, POFD, and accuracy of the used method respectively. In the calculation of POCD, POFD, and accuracy we have used all the 20 sandstorm events reported by NCM ground based meteorological stations as well as MEDI based results applied on MODIS images for the identification of same sandstorm events. Our results indicate that the POCD, POFD, and accuracy of MEDI with NCM ground based meteorological station data is 92 %, 29 %, and 73 % respectively. However, in order to keep the brevity and preciseness two case studies, that is, sandstorm events of 30 April 2011 and 19 March 2017 are discussed in detail in the current research.

The sandstorm event of 30 April 2011 was reported by five (Al Dammam, Riyadh, Qaisumah, Rafha, Yenbo) ground-based NCM meteorological stations (Table 1) in the study area. Out of five NCM ground-based meteorological stations, Qaisumah and Rafha are in the northern region, Al Dammam is in the eastern region, Riyadh is in the central region, and Yenbo is in the western region of Saudi Arabia. It was surprised to note that three ground stations (Dhahran, Al Ahsa, Hafr Al Batin) which are in close vicinity did not report sandstorm event. On further examining the reason it was observed that these three stations have reported isolated dust in the atmosphere. It is believed that either the observer has misinterpreted the sandstorm or it was observed at the time when sandstorm was in the weakening stage. The MEDI results applied on 30 April 2011 sandstorm event is shown in Figure 3a. It is evident from Figure 3a that MEDI values for the 30 April 2011 sandstorm events are in the range between 0.4 to 2.8. After analyzing the index values in the ERDAS imagine image processing software we noticed that the threshold value of sandstorm event is slightly different from that proposed (less than 0.6) by Karimi et al. (2012).

In the current research, we have identified three main features (Figure 3a) in the MEDI based results with a range of threshold values. The threshold value of MEDI for sandstorm features is less than 0.8 (dark brown color features in Figure 3a), threshold value of MEDI greater than 0.8 but less than 2.0 is for surface area (light brown color features in Figure 3a), and threshold value of MEDI greater than 2.0 is for cloud features (cream color features in Figure 3a) over the study area. Based on the threshold values it is evident from Figure 3a that sandstorm event with cloud features are present in the northern and central parts of study area for the 30 April 2011 case study.

We have validated our results with the NCM ground-based meteorological data that shows that Qaisumah, Rafha (ground stations in the northern region), and Riyadh (ground station in the center of the country) have reported sandstorm event with cloud cover over Saudi Arabia on the day of sandstorm event. Unfortunately, the MODIS image did not show the station situated in the west (Yenbo) while only a small portion of Al Dammam (ground station in the east) is visible. Therefore, we did not include Yenbo station in our discussion of validation using NCM ground-based meteorological data for 30 April 2011 sandstorm event over study region.

As part of validation of MEDI results we have also used MSG data in the current research. Thus, MSG based RGB dust product is prepared for the 30 April 2011 sandstorm event as shown in Figure 3b. The sandstorm features in the MSG image are highlighted with pink color while clouds are represented with dark brown color in Figure 3b. It is pertinent to mention here that for the 30 April 2011 sandstorm event the scanning time difference between retrieved MODIS Tera and MSG scene was approximately one hour. It is evident from Figure 3b that intense sandstorm along with some traces of clouds are visible in the northern region of the study area (reported by Qaisumah and Rafha stations in north) while moderate sandstorm traces with heavy clouds are apparent over Riyadh (central Saudi Arabia) and Al Dammam (east of Saudi Arabia). However, local traces of dust are apparent over the Yenbo (west of Saudi Arabia) region which might have been misclassified by the ground observer as sandstorm event at the time of observation.

In the current study we have also used AOD product over the study area in order to validate MEDI results. Thus, average monthly (April) and three days (±1 day from sandstorm event) average AOD product are represented in Figure 3c and 3d respectively. In both these figures the green color represent low concentration of aerosols, yellow and orange colors are designated for moderate aerosol concentration while red and pink colors are for intense aerosol concentration in the atmosphere. It is evident from Figure 3c that the northern and eastern regions of the Saudi Arabia are under high aerosols concentration while the remaining parts of the country are under moderate aerosols concentration during the month of April. Similarly, it is evident from Figure 3d that the concentration of aerosols is very intense in the eastern, northern, and central region of Saudi Arabia while small portion of western region also witnessed intense aerosols. This agrees with MEDI sandstorm monitoring results (for eastern, northern, and central regions) of 30 April 2011 as well as with the ground-based NCM meteorological data and MSG based RGB dust product over the study area.

Similarly, the sandstorm event of 19 March 2017 was reported by four (Hail, Al Jouf, Riyadh, Rafha) ground-based NCM meteorological stations (Table 1) in the study area. Out of four NCM ground-based meteorological stations Hail, Al Jouf, and Rafha are in the north while Riyadh is in the center of Saudi Arabia. Once again, it was noted that a number of ground stations which are in close vicinity did not report sandstorm event. Further analyses of the data indicate that 23 NCM ground-based meteorological stations have reported 6-9 WMO codes on 19 March 2017 over Saudi Arabia. These codes are used to represent suspended dust in the atmosphere not raised by wind (code 6), suspended dust in the atmosphere raised by wind (code 7), whirled dust in the atmosphere but no sign of sandstorm event (code 8), and whirled dust in the atmosphere with sign of development of sandstorm event (code 9). It is believed that either the observer has misinterpreted the sandstorm or it was observed at the time when sandstorm was in the weakening stage. The results of MEDI applied on 19 March 2017 sandstorm event is shown in Figure 4a. It is evident from Figure 4a that MEDI values for the 19 March 2017 sandstorm events are also in the range of 0.4 to 2.8. Once again, we analyzed the index values in the ERDAS imagine image processing software and identified similar three features (sandstorm, surface features, clouds) with same threshold values (less than 0.8 with dark brown color for sandstorm, greater than 0.8 but less than 2.0 with light brown color for surface area, and greater than 2.0 with cream color for cloud in Figure 4a) as that of 30 April 2011 sandstorm event. Based on the threshold values it is evident from Figure 4a that sandstorm event is present in the northern and central parts of Saudi Arabia for the 19 March 2017 case study.

The results of MEDI method on 19 March 2017 sandstorm event are validated by using the NCM ground-based meteorological data. Our analyses indicate that all four NCM ground-based meteorological stations (Hail, Al Jouf, and Rafha in the north and Riyadh in the center of Saudi Arabia) have reported sandstorm event over the study area. Further validation of MEDI results is achieved by applying MSG data in the current research. The MSG based RGB dust product is prepared for the 19 March 2017 sandstorm event and is shown in Figure 4b. The sandstorm features in the MSG image are highlighted with pink color while clouds are represented with dark brown color in Figure 4b. Once again there was a scanning time difference (around one hour) between retrieved MODIS Tera and MSG scene over the study area. Some heavy clouds are also apparent over the study area as evident from Figure 4b.

In the present research we have also used AOD product over the study area in order to validate MEDI results. Thus, average monthly (March) and three days (±1 day from sandstorm event) average AOD product are represented in Figure 4c and 4d respectively. In both these figures the green color represent low aerosol concentration, yellow and orange colors are designated for moderate aerosol concentration while red and pink colors are for intense aerosol concentration in the atmosphere. It is evident from Figure 4c that the concentration of aerosols is from moderate to high over entire Saudi Arabia during the month of March. Once again these results are in agreements with the findings of other scientists who reported that the spring season witnessed the highest number of sandstorm events thereby resulting in intense concentration of aerosols in the atmosphere over Saudi Arabia (29,30,35–37).

Similarly, it is evident from Figure 4d that the concentration of aerosols is from high to intense in the northern and central regions of Saudi Arabia which is in agreement with the MEDI sandstorm monitoring results of 19 March 2017 as well as with the ground-based NCM meteorological data and MSG based RGB dust product for the study area. Considering the time duration of three days (±1 day from sandstorm event which means 18, 19, and 20 March 2017) average AOD product the intense concentration of aerosol evident in Figure 4d is plausible.

5 Conclusion

The applicability of MEDI for the detection of sandstorm events in Saudi Arabia has been examined in the current study. Saudi Arabia is considered as arid land with some contrasting relief and irregular topography. The desert areas within the country as well as in the vicinity are the major factors in the development of sandstorms and in the increase of concentration of aerosols in the atmosphere. These factors along with local and regional climatological affects made Saudi Arabia very vulnerable from sandstorm point of view.

The main finding of the current research is the identification of three main features based on threshold values (which are different from the one proposed by Karimi et al. 2012) in the MODIS data by using MEDI method over the study area. The MEDI values are in the range between 0.4 to 2.8 and the threshold value for the detection of sandstorm events is higher from that proposed by Karimi et al. (2012). In addition, the threshold values are distributed into three categories, that is, sandstorm (if less than 0.8), surface area (between 0.8 and 2.0), and clouds (greater than 2.0). The MEDI threshold values proposed in the current research are validated by using MSG data based RGB dust product, AOD product, and NCM ground-based meteorological data. Furthermore, the accuracy of MEDI results is also evaluated in current research. These findings indicate that MEDI can be successfully applied in Saudi Arabia for the detection of sandstorm events by using proposed threshold values.

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Declaration

No funding was received for conducting this study. The authors

declare no competing financial interests.

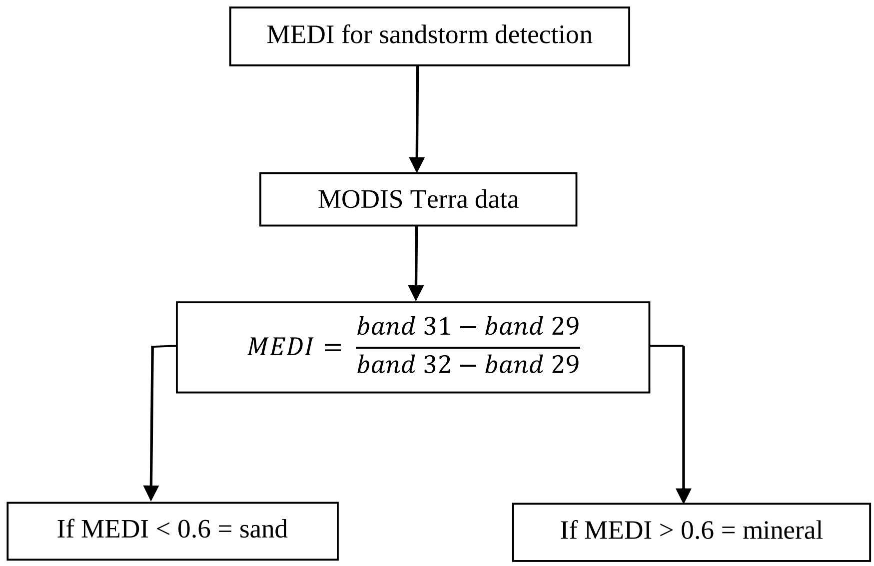

Figure 2. MEDI flow diagram used in the current study.

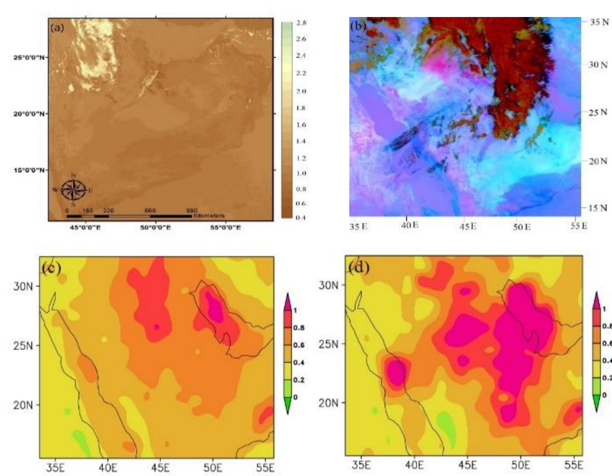

Figure 3. Sandstorm event of 30 April 2011 over Saudi Arabia (a) detection by MEDI method, (b) MSG RGB dust product, (c) average AOD product for the month of April, and (d) average AOD product for three days (±1 day from sandstorm event)

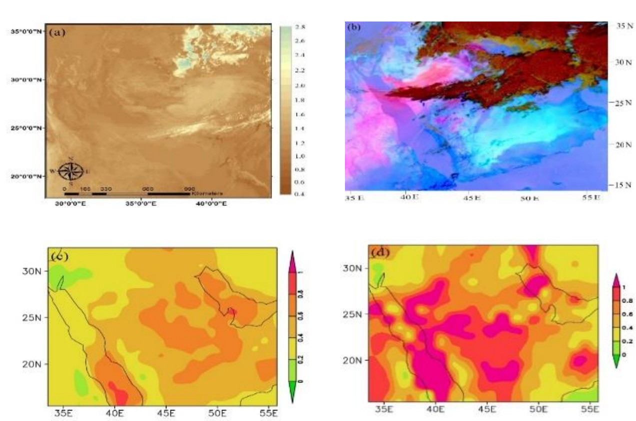

Figure 4. Sandstorm event of 19 March 2017 over Saudi Arabia (a) detection by MEDI method, (b) MSG RGB dust product, (c) average AOD product for the month of April, and (d) average AOD product for three days (±1 day from sandstorm event)

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تحديد قيم محددات مؤشرات العواصف الترابية فوق المملكة العربية السعودية.

عصام بن محمد الغامدي و مازن بن إبراهيم عسيري و جميل محسن

قسم زراعة المناطق الجافة، كلية الأرصاد والبيئة

وزراعة المناطق الجافة، جامعة الملك عبد العزيز، جدة، المملكة العربية السعودية

مستخلص. تعتبر العواصف الترابية من أكبر المخاطر البيئية في شبة الجزيرة العربية حيث تشكل المملكة العربية السعودية الجزء الأكبر من شبة الجزيرة العربية. وتهدف هذه الدراسة إلى التحقق من حدوث ظاهرة العواصف الترابية بتطبيق مؤشر غبار الشرق الأوسط (MEDI) باستخدام بيانات مقياس الطيف (MODIS). لهذا الغرض تم تحديد (٢٠) عاصفة ترابية حدثت فوق المملكة العربية السعودية، واستخدام بيانات محطات الأرصاد الجوية من المركز الوطني للأرصاد وبيانات الأقمار الصناعية للجيل الثاني من أقمار الأرصاد الأوروبية (Meteosat - MSG)، وبيانات العمق البصري للهباء الجوي (AOD) من منتجات قمر موديس (MODIS). وأظهرت النتائج إلى أن مؤشر غبار الشرق الأوسط (MEDI) يمكن أن يكتشف ويحدد بشكل فعال حدوث العواصف الترابية فوق المملكة حيث أن تحليل الدقة أوضح أن احتمالية الخطأ في النتائج الإيجابية هي ٢٩% واحتمالية الصح في النتائج الإيجابية هي ٩٢% ودقة مؤشر غبار الشرق الأوسط هي ٧٣% لتقصي حدوث العواصف الترابية فوق منطقة الدراسة. وبالتالي فإن الدراسة أظهرت فعالية مؤشر غبار الشرق الأوسط جيدة لتقصي حدوث العواصف الترابية، وعلى ضوء ذلك يستنتج بأن بيانات المؤشر مفيدة لعلماء البيئة والمناخ وللمساهمة في اتخاذ قرارات خطط التخفيف الخاصة بالقضايا المتعلقة بالعواصف الترابية التي بدورها تؤثر على المجتمع صحيًا واقتصاديًا.

الكلمات المفتاحية: MEDI, MODIS, AOD, MSG