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Development of Automatic Detection of Dust Storms for MODIS Satellite Images over Iraq Using ArcGIS Model Builder

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Abstract

Geographical Information Systems (GIS) provides a set of instruments and techniques to explain and display different geographical data, and ArcGIS Model Builders consider a very beneficial technique to represent these procedures in a very effective and influential manner. This paper indicates that using the ArcGIS tool Model Builder is the preferred technique to display the flux of procedures, in which the model's design is highly preferable to decrease the time consumed to apply any procedure. One model was used to explain the best methodology to resolve the issue, which deals with dust storm detection over Iraq using MODIS data. This study Facilitate Terra and Aqua MODIS satellite images; the first case was Terra / MODIS during the first half of the day with NDDI and IDDI, while the second case was Aqua/ MODIS during the second half of the day with the three thermal indices MEDI, BTV, TB beside IDDI. This study displays the effectiveness of these indices in two cases to show their validity in detecting dust storms compared to synoptic data over the study area. Besides, it displays ArcGIS Model Builder's importance in applying these Indices more efficiently and smoothly to benefit from it in serving society and the scientific community.

Keywords: ArcGIS, Model Builder, Dust storm, Dust Index, MODIS, Aqua, Terra.

تطوير الكشف التلقائي للعواصف الغبارية لصور القمر الاصطناعي MODIS فوق العراق باستخدام ArcGIS Model Builder

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الخلاصة:

توفر أنظمة المعلومات الجغرافية (GIS) مجموعة من الأدوات والتقنيات لشرح وعرض البيانات الجغرافية المختلفة، ويعتبر ArcGIS Model Builders تقنية مفيدة جدًا لتمثيل هذه الإجراءات بطريقة فعالة ومؤثرة للغاية. تشير هذه الدراسة إلى أن استخدام أداة ArcGIS Model Builder هي التقنية المفضلة لعرض تدفق

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الإجراءات حيث يكون تصميم النماذج مفضلاً للغاية لتقليل الوقت المستهلك لتطبيق أي إجراء. تقديم نموذج واحد لشرح المنهجية الأفضل لحل المشكلة حيث تناول هذا النموذج صلاحية مؤشرات كشف العواصف الترابية فوق العراق باستخدام مرئيات MODIS الفضائية. تتناول هذه الدراسة مرئيات الأقمار الصناعيةMODIS / Terra و Aqua؛ الحالة الأولى كانت MODIS / Terra خلال النصف الأول من اليوم مع NDDI و IDDI، بينما الحالة الثانية كانت MODIS / Aqua خلال النصف الثاني من اليوم مع المؤشرات الحرارية الثلاثة MEDI، BTV، TB بجانب IDDI.تعرض هذه الدراسة مدى فعالية هذه المؤشرات المستخدمة في حالتين تمت دراستها لبيان مدى فعاليتها في الكشف عن العواصف الترابية بعد مقارنتها بالبيانات الساينوبتيكية فوق منطقة الدراسة , بالاضافة الى اظهار دور برنامج ArcGIS Model Builder في تطبيق هذه الموشرات بسرعة وسهولة وبالتالي الاستفادة منها في خدمة المجتمع والوسط العلمي.

1. Introduction

Dust storms have been considered a significant topic during the past few years because of the evidence that has been discovered that affects climate [1, 2]. Dust storms are considered dangerous ecological phenomena in deserts and barren lands [3, 4]. The aerosols will be recognized by remote sensing applications that recognize atmospheric effects more directly, generally small substances that affect the environment and human health [5, 6]. Aerosols are essential as greenhouse gases because of their effect on the atmosphere's chemistry, heat, and radiation balance in the lower part of the atmosphere [7, 8]. Dust storms are classified as naturalistic cases that occur on the ground and affect the ecosystem. It usually happens in desert and arid regions, where it carries and moves large quantities of dust to affect agriculture and communication, lowering visibility and affecting the daily life of mankind. Another effect is decreasing visibility, thus affecting aviation by blocking sun radiation and modulating heat [9, 10].

Many dust storms might remain suspended in the air for several days while others shift and transfer away from their creation region by wind. In the last few years, some researchers have noticed that severe dust storms might affect the creation of tornadoes [11, 12]. Generally, dust storms are registered in arid and desert regions [13, 14]. Dust consists of many substances shifted by the wind, such as salt, bacteria, and significant metals, to move it to another area [15, 16]. The Arabian Peninsula is classified as an arid environment [17, 18], which is recognized as containing extensive deserts. This classification indicates that dust storms are defined as natural hazards to people in this region [19, 20]. The study area is between dust storm paths [21, 22]. The ground wind is recognized and treated as the primary cause affecting dust movement [23]. Dust storms affect the speed of the air and the terrain [24]. Iraq is exposed to many dust storms that bring out drought and lack of green regions because of global warming, which eventually causes an increase in these dust events [25]. Remote sensing is essential for detecting dust storms, especially in arid and semi-arid regions that are hard to reach and detect [26]. Many researchers applied methods to detect dust storms using MODIS for several benefits provided by these satellite images. Qu et al. [27] used the normalized difference dust index (NDDI) to detect dust storms. The advantage of NDDI is its sensitivity to humidity. [28, 29]. [27] defines the influence of dust storms on human health. Dust storms nowadays have environmental effects, and in the last decade, they have roughly transformed into the worst phenomena in East Asia. NDDI is used to detect over-radiative grounds. [30] displays the detection of dust storms (DS) by utilizing MODIS. The researcher depends on MODIS Surface Reflectance Daily to apply (NDDI) index. The study exposes good consistency between satellite and in-situ data. [31] In his study, he expressed the importance of DS on the environment and ecosystem because it influenced the global range. The researcher processed dust storms over KSA using MODIS and discovered that multisource data is essential to detect dust storm phenomena. [32] shows that observation time is crucial in detecting dust storms. The study tests the outcome visually with MODIS true color images, quantitative analysis, and Ozone Monitoring Instrument (OMI). [33] used (NDDI) and (BTV) to detect dust storms; the researcher concluded that NDDI helps detect DS during the day while BTV is used to detect DS during the night, and this relies upon the difference in temperature brightness for aerosol particles in the atmosphere. [34] suggested that NDDI is a suitable index to detect dust storms over Iraq, while the MEDI index had a weakness in detecting DS over Iraq. This study aims to survey and examine Dust Storms to find the best way to detect them by utilizing MODIS to clarify the existence of DS by utilizing various indices besides using a new index for Iraq (IDDI) Iraq Dust Detection Index to inspect NDDI, MEDI, BTV automatically using ArcGIS Model Builder to detect DS over Iraq.

2. Materials and Methods

2-1 Study Area

Iraq is located in the Middle East and shares a border with six countries: Kuwait, Iran, Turkey, Syria, Jordan, and Saudi Arabia. From Figure (1), it can be seen that Iraq is located in semi-tropical latitude in the northern hemisphere between latitude (29.5°-37.5°N) and longitude (38.45°-48.45°E) [35]. Because of the location, the Mediterranean Sea and Arabian Gulf influence Iraq's climate most [36]. Iraq has a hot, dry climate characterized by long, hot, dry summers and short, cool winters [37]. A significant variance in temperature characterizes Iraq during the day and between the seasons. This significant difference is mainly defining the case of continental climates [38]. Iraq's climate is characterized by desertification and dust storms, which are caused by the lack of rainfall, particularly during winter, with a rise in evaporation because of the amount of solar radiation incident upon the ground, which leads to more desertification [39,40]. The 192.03 mm/year computed by the Thiessen method was considered a reliable mean annual rainfall value for Iraq [41]. At the same time, the average annual wind speed over Iraq was 3.6 m/s [42].

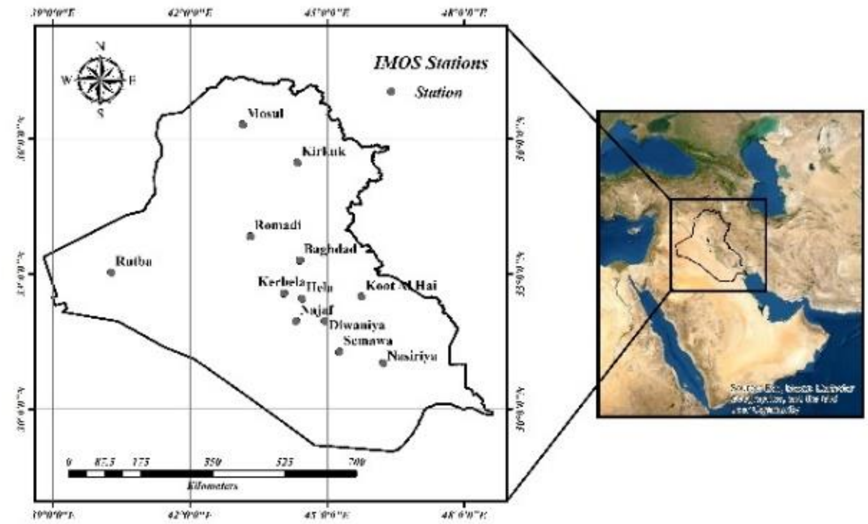

Figure 1: The meteorological station sites over Iraq

2-2 Data from MODIS

MODIS has primary tools attached to Aqua and Terra. The significant advantage is that it offers enormous scope for spectral bands. MODIS has 36 spectral bands ranging from 0.41 to 14.24 µm and can cover visible range and near Infrared with thermal scope for the electromagnetic spectrum [39,40]. MODIS data was downloaded every day and was used in this study. Data chose spectra from different materials categorized within thermal and reflectance bands [41]. Mainly, the reflectance of dust ascent linkage with wavelength 0.4 and 2.5 µm, and the minimum in MODIS band 3 (0.469 µm) and the highest rate in MODIS band 7 (2.13 µm) [27].

3. Indices Used for Dust Storm Detection

a. Normalized Difference Dust Index (NDDI)

NDDI was utilized in several previous studies [42,43,44], where this index deals with MODIS solar reflectance bands (7,3) (equation 1). Those two bands have 500m spatial resolution and are characterized by wavelengths of 459 to 479 µm (2105 to 2155) µm to the bands 3 and 7, respectively. These bands were commonly utilized with land surfaces to detect aerosols, besides obtaining information about optical cloud thickness, phase, and effective radius.

$$NDDI = \frac{Band7 - Band3}{Band7 + Band3} \tag{1}$$

b. Middle East Dust Index (MEDI)

This index deals with band 31 and band 32, which have problems detaching between dust in the air and the dust on the ground; the Index method has a threshold with a value less than 0.6 to refer to the dust in that specific region [45, 46]. Besides, this index relies on Ackerman's dust detection method, which included band twenty-nine. Finally, MEDI was used in band 29, which has a wavelength of 8.40 to 8.70 µm, 31 (10.78-11.28) µm and 32 (11.77-12.27) µm as displayed in equation 2, with 1000 m for spatial resolution, which has a specific purpose to distinguish between dust in the air and dust on the surfaces.

$$MEDI = \frac{Band\ 31 - Band\ 29}{Band\ 32 - Band29} \tag{2}$$

c. Brightness Temperature Variance (BTV)

Since the NDDI index has ineffective results during nighttime, Thermal infrared radiation can be utilized to detect dust. Bands 32(12 µm) and 31(11 µm) were applied as fine collection for dust storm detection. The indexing algorithm uses (31,32) bands that vary through the dust storm. The equation for detecting dust storms is Eq. 3, [47].

$$\Delta T = \{Band32 - Band31(Band32 - Band31) \geq 1K\} \tag{3}$$

ΔT provides a dust area that includes more than 1 k, while other substances ΔT have a value lower than 1k. Thus, the 1 k threshold was adjusted to distinguish between the dust and other substances [47].

d. Temperature Brightness (TB)

The TB technique used different thermal emissive bands, which were applied and obtained great results in many areas [44]. The thermal emissive band B31 is usually the most used band with a wavelength range of 10.78-11.78 µm and a spatial resolution of 1000m. TB distinguishes between dust in the air and dust in [48,49].

e. IRAQ DUST DETECTION INDEX (IDDI)

The equation used to create the new index was gathered between bands one and thirty-one. Band one depends on surface reflection with a spatial resolution (500m) and spectral reflection (21.8 Wm^{-2} μm^{-1}) with bandwidth (41.8 nm) and Band range of 0.620-0.670 with central wavelength (0.659 µm) and the primary use of this band is with land/cloud/ aerosols boundaries and to obtain information on the clouds optical thickness, phase, and effective radius, while band 31 is a thermal band with primary use for surface and cloud temperature with a spatial resolution of 1000m and spectral reflection (9.55 (300K) Wm^{-2} μm^{-1}) with bandwidth (510.3 nm) and band range of 10.78-11.28 um with central wavelength of 11.030 µm. The equation for this index formed as band 1 – band 31, but this equation was applied not before applying an image process for both bands (1 and 31). Since these two bands have different spatial and spectral resolutions, they were united and then georeferenced with the original product MODIS satellite image. The next step is using the map algebra in ArcGIS to examine the results from the new formula concerning the meteorological station that has already indicated its location on the boundary of the study area. The examination and validation of the new index IDDI with the in-situ observation of the selected station over Iraq were done by extracting the values of the IDDI with the stations through a threshold to separate between the dust and non-dust events in the image. It is worth noting that IDDI was applied, and its results were obtained over land, not water or oceans, as the results and accuracy of the first process were more challenging to obtain with high accuracy and reliability than over water bodies.

4. Dust Storm Indices Model

This model calculates Dust storm indices value for an area depending on MODIS images, and this was done by adding the MODIS images in the ArcGIS and extracting the study area from it. The equation for each Dust storm index was entered into the "Raster Calculator" to obtain the value of this Dust storm index.

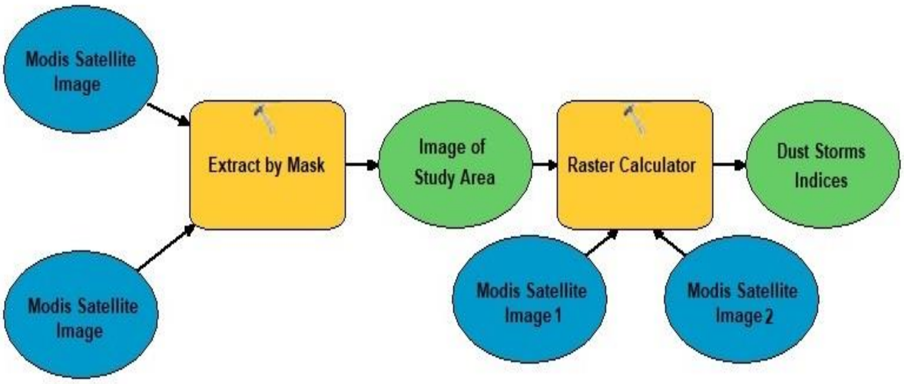

Figure 2: The model was designed to compute the dust storm indices value in ArcGIS.

3. Creating tools of Dust Storms indices with Model Builder

Generally, the model contains three minimum elements: input, output, and geoprocessing tools. Steps of building a model of NDDI in Model Builder. Step 1. Opening map document Start ArcMap. On the ArcMap - Getting Started dialog box, click Existing Maps
> Browse for more. The Open ArcMap Document dialog box appears.
Step 2. Add and open Model Builder

To add Toolbox, click Arc Toolbox to begin generating the model. The model Builder window will appear to insert the user's geoprocessing tools. Figures (3).

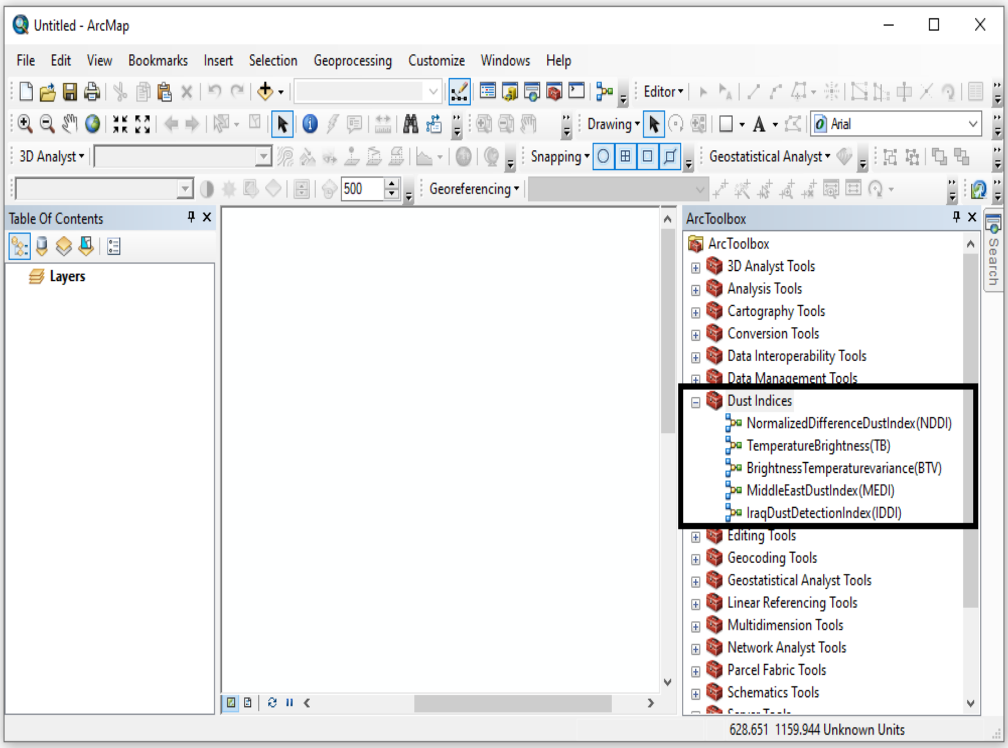

Figure 3: Creating Models Builder of Normalized Difference Dust Index (NDDI), Brightness Temperature Variance (BTV), Temperature Brightness (TB), Middle East Dust Index (MEDI), and Iraq Dust Detection Index (IDDI).

Step 3. Changing model parameter order

In Normalized Difference Dust Index (NDDI), start by clicking Model Properties, right-click on the model diagram, and click on Model Properties.

Click the Parameters tab. Choose a parameter, move its placement by user demand up or down, and click OK.

At this stage, giving a simple description of each green cover indicator and information on contacting the programmed person is possible.

Figure (4) shows the cod description of the Normalized Difference Dust Index (NDDI):

NDDI was applied to calculate and Detect dust utilizing reflective solar bands 3 and 7 of MODIS / Terra. The spatial resolution of 500m of these bands is characterized by spectral reflectance at wavelength range 459-479 µm for band 3 and 2105-2155 µm for band 7 [42, 43].

Those bands are usually applied with land surface studies to detect aerosols and acquire data on clouds' optical thickness, phase, and effective radius to detect dust over the study area [44].

NDDI=(B7 – B3) / (B7 + B3)

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Other indicators can also be described and coded using the definition above for MEDI BTV IDDI.
Step 4. Create variables in the NDDI Model.
Double click on NDVI Model, choose Raster Dataset to create a variable
Step 5 Add images to the layer.
Double-click on every tool (Raster Dataset), then insert inputs and outputs.
Step 6. Enter tool parameters
Double-click on every tool (Raster Calculator), then insert the code
Float("%Band_7%" - "%Band_3%") / Float("%Band_7%" + "%Band_3%").

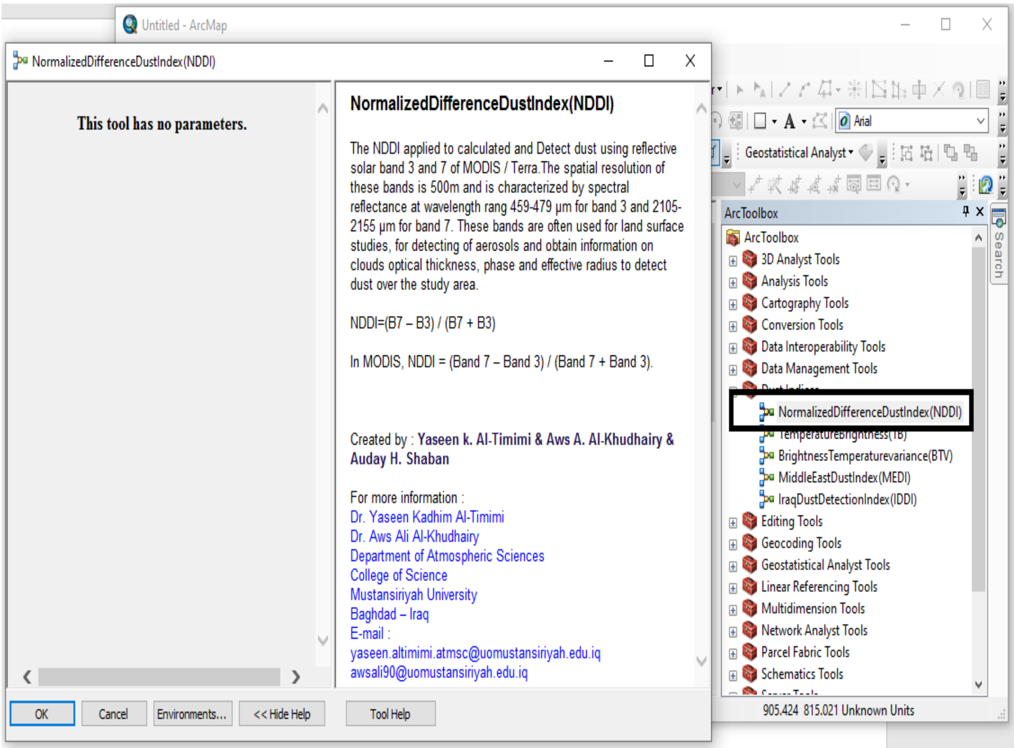


Figure 4: The file result of the Normalized Difference Dust Index (NDDI)

Step 7. Running the Model
the previous step was to build the model to generate and obtain a report; then, the model needed to be run. This happens when You click on the „Play" button. Figure (5).

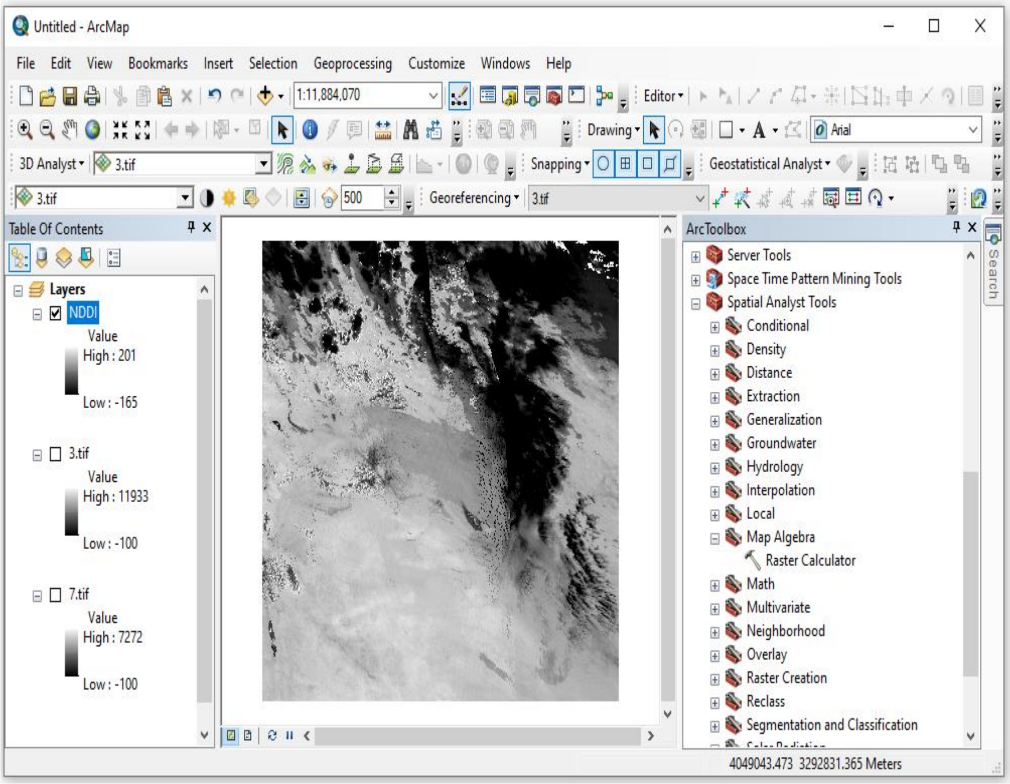


Figure 5: The Final result for the Normalized Difference Dust Index (NDDI) model

RESULTS AND DISCUSSIONS

After applying the model builder, the dust detection results were obtained using the threshold values determined. The dust detection results and in_situ data were noticed and processed to verify the validation of indices and their threshold for dust detection. The outcome validation, NDDI, MEDI, TB, and BTV Indices methods reveal a refined ability to detect dust and then distinguish dust among different regions, where expressed the results of In-situ observation with the mentioned indices above beside the new index IDDI. Initially, the meteorological data obtained from the Iraq Meteorological Organization and Seismology (IMOS) was arranged, and since it was hourly data, the data was filtered and selected for the cases shown in the tables below. Those four cases between day and night were chosen after many classifications were used, in the first place, based on the existence and observation of the dust storms by IMOS stations. The ones with the highest number of stations registered were chosen, whether they were slight/ Moderate or severe, and the period of each event during these dust events; the ones with the longest occurred that were registered by IMOS stations on this classification in conjunction with the MODIS satellite data product were chosen, which also existed with no errors or black dots during this dust event. By these standards, 4 cases were chosen. It is worth noting that the new indicator IDDI works during the day and night, as it deals with the first band and the 31 bands of the MODIS satellite, with conditions that the dust is continuous between the day and night and as long as it last longer will be finer in order to obtain results with greater precise and more stability.

Figures (6) show the results obtained from NDDI and IDDI indices on 22 May 2012. The outcome of dust indices presented as shapefiles of 12 stations over Iraq were overlayed over dust indices raster. From this figure, noticing that in case 1, IDDI almost covered all of Iraq except the north region, while the NDDI index seems to cover the west and the north of the study area only. Dust storm detection validation was accomplished by comparing in-situ data and MODIS satellite images. The outcome of the dust storms in Iraq on 22 May 2012 was analyzed and summarized more precisely as case 1 in Table (2). Table (1) shows the registration of Dust storms in IMOS stations on cases one and two depending on Standards WMO Classification and the Dust storm category, whether it was slight / Moderate or severe at the time it occurred in Greentech Meantime and the dust storm period in an hour. Table 2 displays the validation of Indices used with In-situ observation in the previous table over 12 stations.

By comparing and examining the results of D.S indices with in_situ, the Effectiveness of these indices for separating and distinguishing the dust storm was applied. Table 2 displays the dust detection outcome using each index's threshold values. The dust detection results were examined with the in_situ data to verify the indices' validation to detect dust storms. For the first case, results reveal that the IDDI index can detect dust storms and then recognize dust in different regions with a percent of validation 92 matching with In-situ observation. Twelve cases (4 non-dust and eight dust) were analyzed, and 11 stations were identical between IDDI and in-situ. At the same time, NDDI has less validation with in_situ, only 67% matching with IMOS observation.

Figure (7) shows the outcome obtained from the dust storm by utilizing MEDI, TB, BTV, and IDDI indices on 12 May 2014. The outcome of the dust storm utilizing these dust indices presented as a shapefile of 12 stations was overlayed over the dust indices raster. The Indices validation for detecting D.S was accomplished by comparing in-situ IMOS data with MODIS satellite images. From Figure (7), noticing that for case 2, the MEDI, BTV, and IDDI indices have the same validation percent with IMOS synoptic data, but IDDI is more precise in the detection the dust storms compared with the other two indices MEDI, BTV even so they have the same percentage as shown in Table 2 more specifically, while TB has lower validation percentage. From the figure, in case 2, the BTV index did not detect dust almost all over the study area, while the MEDI index detected dust in the western and middle regions of the study area, the same as TB. Examining the outcome of dust storms from in_situ data with MODIS satellite images shows the effectiveness of the threshold applied to detect dust storms.

Table 1: Dust storm observing over the IMOS stations (Case 1,2)

Date	D.S Category	No. of station	Name of station	Dust storm Observation in Hour	Observation Time UTC
(Case 1) 22 May 2012	Slight Or	650	Baghdad	3	13
	Moderate	676	Nasiriya	3	10
		657	Hela	2	5
		645	Romadi	5	2
		670	Najaf	4	5
		672	Diwaniya	2	13
		674	Semawa	3	15
	Sever	650	Baghdad	6	7
		656	Kerbela	6	5
		657	Hela	2	6
		670	Najaf	3	6
		672	Diwaniya	6	7
		674	Semawa	4	8
(Case 2) 12 May 2014	Slight	656	Kerbela	2	22
	Or	670	Najaf	2	22
	Moderate	672	Diwaniya	1	23
		674	Semawa	1	23

Table 2: The Validation of Indices with In-situ data over 12 stations (Case 1,2)

STATIONS		Case One			Case Two				
Name	Number	In-Situ	NDDI	IDDI	In-Situ	MEDI	TB	BTV	IDDI
Baghdad	650	√	Not Match	Match	×	Not Match	Not Match	Match	Not Match
Mosul	608	×	Match	Match	×	Match	Match	Match	Not Match
Kirkuk	621	×	Not Match	Match	×	Match	Not Match	Match	Not Match
Hela	657	√	Not Match	Match	×	Not Match	Not Match	Match	Match
Kerbela	656	√	Match	Match	√	Match	Match	Not Match	Match
Najaf	670	√	Not Match	Match	√	Match	Match	Not Match	Match
Koot Al Hai	665	×	Match	Not Match	×	Not Match	Not Match	Not Match	Match
Semawa	674	√	Not Match	Match	√	Not Match	Not Match	Not Match	Match
Diwaniya	672	√	Not Match	Match	√	Match	Match	Match	Match
Nasiriya	676	√	Not Match	Match	×	Match	Match	Not Match	Not Match
Romadi	645	√	Not Match	Match	×	Match	Match	Match	Not Match
Rutba	642	×	Not Match	Match	×	Not Match	Not Match	Match	Match
Percent of Validation	Matching		**25**	**92**		**58**	**50**	**58**	**58**
	Not Matching		**75**	**8**		**42**	**50**	**42**	**42**

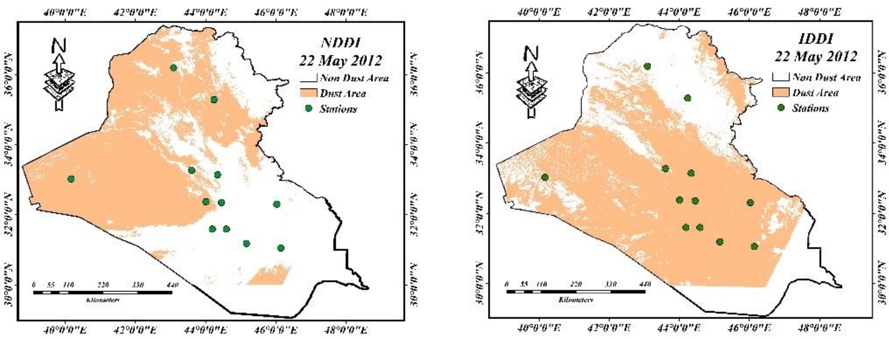
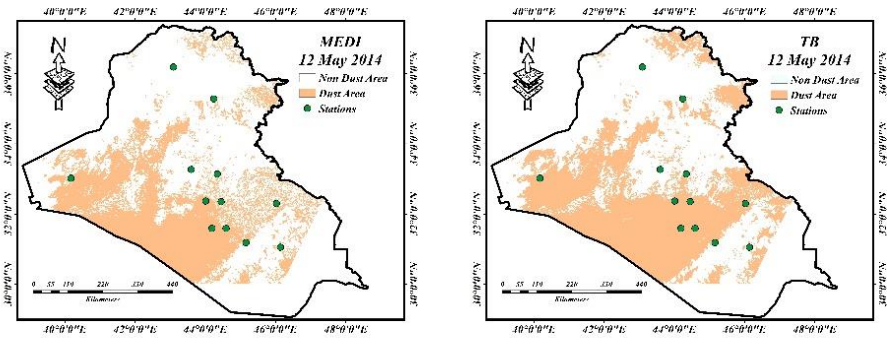


Figure 6: Dust indices of MODIS Aqua/Terra monitoring display the dust storm over Iraq in case one



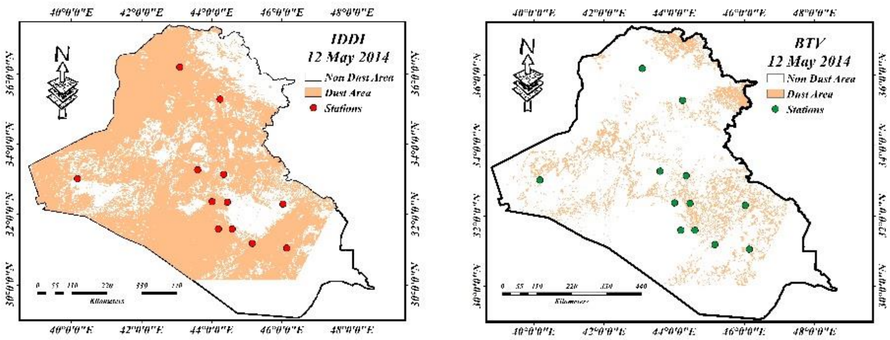


Figure 7: Dust indices of MODIS Aqua/Terra monitoring display the dust storm over Iraq in case two

Conclusion

The features of utilizing GIS models illustrated in this paper to Dust storm detection as techniques for providing decision-makers to distinguish convenient regions for the required investment, select then quantify the effect of dust storms on agriculture, human health, and the economic even, few procedures were not automated such as the collection of the data or choosing them. The model built for Iraq provided an integration of a large amount of information and data to activate the automatic geoprocessing outflow of the work to provide quantified, georeferenced, and visionary outcomes. Besides that, the model presents a simplified and easily comprehensible method related to dust storm detection. Arc Model Builder provides a simple tool to generate, modulate, run, and re-run models. Also, models may be replaced and applied to different regions and investment targets. It is worth noting that this index (IDDI) was applied, and it is considered the ultimate useful MODIS index for dust storm detection in different regions. Also, IDDI is the suitable index for separating and recognizing dust away from non-dust in vast areas. The validation results reveal that the NDDI and thermal indices (MEDI, BTV) index have limitations in distinguishing dust compared to IDDI. The results were obtained over land, not water or oceans, as the results and accuracy of the first process are more difficult to obtain with high accuracy and reliability than over water bodies because of the variation of the surface and its terrain. The difference in this terrain, in turn, affects the index results when applied. However, the results from the index were more than satisfactory among all the applied indices on MODIS data to detect dust storms over Iraq.

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