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Spatio-Temporal Analysis of Dust/Sand Storms in Iraq Using MODIS Images

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ABSTRACT

The Sand Dust Storms (SDS) phenomenon has become one of the climate variability phenomena that has an essential impact on human life in various sectors. Studying these phenomena has become of a special priority for many countries that suffer from climate change impacts. In this study, a long-term spatiotemporal analysis is conducted on SDS events in Iraq, which is known as one of the Middle Eastern countries suffering from these environmental phenomena. Middle East Dust Index (MEDI) values retrieved from forty MODIS-satellite data and climatological datasets for twelve synoptic stations from 2005 to 2019 are used to determine the main relationships controlling Iraq. Three factors are found to affect increasing SDSs: wind speed, temperature, and precipitation. The interpreted relationships between these factors show positively correlated relationships of wind speed, temperature, and MEDI (+ 0.68, + 0.81, +0.7) respectively with Sand Dust Storm Frequency (SDSF), while precipitation has shown negatively correlated relationship of SDSF equals (- 0.23). The findings of this study have proven that some parts of Iraq were exposed to massive SDS impacts, especially in the western and southern regions as a result of the proposed long-term spatiotemporal analysis.

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التحليل الزمكاني للعواصف الغبارية/الرملية في العراق باستخدام بيانات القمر الصناعي MODIS

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الملخص

اصبحت ظواهر العواصف الرملية والترابية (SDS) أحد أشكال التقلبات المناخية التي لها تأثير أساسي على حياة الإنسان في مختلف القطاعات. أصبحت لدراسة هذه الظواهر أولوية خاصة للعديد من البلدان التي تعاني من آثار تغير المناخ. في هذه الدراسة، تم إجراء تحليل زماني ومكاني طويل المدى على أحداث هذه الظواهر في العراق المعروف بانه بات يعاني من هذه الظواهر البيئية. تم استخدام قيم مؤشر الغبار في الشرق الأوسط (MEDI) والمشتقة من أربعين مرئية قضائية من بيانات MODIS ومجموعة البيانات المناخية لاثنتي عشرة محطة انواء جوية وللفترة من 2005 إلى 2019 وذلك لتحديد العلاقات الرئيسة التي تتحكم في العواصف الترابية. تم تحديد ثلاثة عوامل تؤثر على زيادة SDSs حيث تم تحديدها على أنها سرعة الرياح ودرجة الحرارة وهطول الأمطار. تُظهر العلاقات المفسرة بين هذه العوامل علاقات ارتباط موجبة بين سرعة الرياح ودرجة الحرارة وMEDI مع تردد عواصف الغبار الرملية (SDSF)، بينما أظهرت بيانات هطول الأمطار علاقات مرتبطة سلبًا بـ SDSF. أثبتت نتائج هذه الدراسة أن بعض أجزاء العراق خاصة المناطق الغربية والجنوبية قد تأثرت وسوف تتأثر بمرور الزمن نتيجة تردد هذه العواصف على هذه المناطق، وقد اثبت ذلك في هذه الدراسة وفقا للتحليل الزمكاني طويل المدى لهذه الظواهر.

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Introduction

Sand-Dust Storms (SDS) are natural disastrous impacts, which can occur on a global or regional scale due to climate change, and they occur in arid and semi-arid regions. The mechanism of these events is defined by the ability to blow wind that moves up/upwards. The SDS materials separate into the atmosphere from the original source and then deposit far away from the SDS origin sources. Many variables affect SDS formation such as lack of precipitation, anomaly increasing of temperature, soil degradation, ground surface warming, and wind speed besides the factors caused by human activities like unregulated migration and wars (Sissakian et al., 2003; Yahya and Seker, 2019; Khusfi et al., 2020). Many studies have indicated that there are huge activities of the SDSs in the Middle East region that consists of many countries (e.g., Syria, Iraq, Iran, and Kuwait, etc.), where a large quantity of sand-dust materials emits into the atmosphere cussing different problems (Middleton, 1986; Alghamdi et al., 2015; Al-Dabbas et al., 2020; Khidher, 2024). There are many previous studies on the impact of SDS on Iraq, where the researchers of these studies were able to analyze the characteristics of these storms and their impact on Iraqi society using many modern techniques. Here the following studies are reviewed. Iraq is one of the countries that suffer greatly from the regular occurrence of dust storms. In the year 2019, Albarakat and Lakshmi reported that one of the worst dust storm events in history took place between June 29 and July 8, 2009, and thus many Iraqis experienced health problems. They utilized MODIS data for monitoring, mapping, and assessing the spread and development of dust storms over the semi-arid and arid regions of Iraq. In 2021, Halos and Mahdi studied two spring SDS events that took place in Iraq in two different years (2012 and 2018). Iraq may experience two different types of wind in the spring, one brought on by north winds (Shamal), a dust storm that has traditionally affected Iraq. The maximum dust surface concentration occurred during the 2012 dust storm, which was more powerful than the 2018 sand/dust storm. The study conducted by Ghazal (2020) stated that studying SDS using remote sensing data is important to devote SDS and their detection. It is challenging to discern between such storms and desert regions, but the presented work has shown that SDS could be detected in semi-arid areas. Two remote sensing approaches, the Brightness Temperature Variation (BTV) and Normalized Difference Dust Index (NDDI) could be used to distinguish between SDS pixels in the image and those not including dust storms. Numerous issues pertaining to the life sectors including human health, ecosystems, and socioeconomic issues have been linked to SDS. For instance, in the health sector, infectious diseases, eye infections, respiratory problems, and cardiovascular problems are the most SDS effects that threaten human life as a result of inhalation of contaminated air with dust microorganisms which range in size from very fine materials to larger materials (Arora et al., 2022). Moreover, SDS can create economic crises as mentioned by Al-Hemoud et al. (2020), where they showed that SDS in Kuwait occurred from 2001 to 2014 have caused total damage equal to 28,180 $ per day to the oil export sector.

It is necessary to gather and evaluate data on a number of crucial variables including meteorological data, land use/cover, dust and sand concentration, and air quality data in order to analyze the spatiotemporal aspects of SDS in Iraq. It could be possible to spot trends and patterns in the incidence of sand-dust storms by tracking the above factors over time and coming up with plans to reduce their effects (Hamzeh et al., 2021; Halos et al., 2021). Climate change impact is more noticeable throughout the last ten years in the Middle East region by the increased frequency and intensity of SDS. The Arab Forum for Environment and Development (Jafari et al., 2020) reported that the SDS events will become intense and frequent due to huge emissions of sand, dust, and other materials to the atmosphere that caused an increase in annual temperature in many desert regions and that stated in a study conducted in Iraq by AFAD (2009), where they found that the SDS events are increasing continuously from the last decade. The SDSs events have been classified according to different scopes of studies like formation sources studies, SDS detection studies, atmosphere studies, and climate change studies, etc. (Sun et al., 2019; Moneer et al., 2022; Furman, 2003).

Remote sensing can help in detection, quantification, monitoring, and effect assessment while studying and analyzing SDS (Al-Daghastani et al., 2020). Since year 2000, NASA has enhanced the spatial, spectral, geometric, and radiometric quality characteristics of earth observation data through using the Moderate Resolution Imaging Spectro-radiometer (MODIS) instruments onboard the EOS-Aqua and EOS-Terra satellites (Abbas et al., 2019). The detection and monitoring of SDS utilizing satellite-based sensors and ground-based measurements heavily relies on remote sensing. Normalized Difference Dust Index (NDDI), Brightness Temperature Difference (BTD) and the Middle East Dust Index (MEDI) are adopted to detect and extract the SDS over Mideast and North Africa using different supplementary data like ground meteorological data (Moridnejad et al., 2015; Bin Abdulwahed et al., 2020). In this study, several articles are reviewed to highlight some of those studies which adopted SDS as scientific research in specific environmental or social aspects; for instance, the visibility reduction in the Middle East due to SDS occurrence is studied by analyzing the SDSs sources area and some spatiotemporal characteristics. The main objective of this study is to analyze the long-term spatiotemporal factors that control the SDS in Iraq as well as model the spatial distribution of all involved datasets. This analysis is conducted on several dataset types represented by the recorded meteorological variables' datasets (wind, temperature, and precipitation) that belong to twelve Iraqi meteorological stations from 2000 to 2018 and remote sensing data represented by MODIS product.

Materials and Methods

Study area description

Iraq as a country in the Middle East is bordered by six countries (Jordan, Syria, Turkey, Saudi Arabia, Kuwait, Iran), and a small portion of the Arab Gulf. As shown in Figure (1), Iraq is divided into 18 Governorates, with Baghdad serving as the nation's capital. Iraq's climate is classified as subtropical and continental semi-arid, with a Mediterranean climate found in the country's northeastern and northern mountainous regions (Al-Mukhtar and Qasim, 2019). The south and center of Iraq experience warm winters and scorching summers due to their desert climate. The northern mountains experience a climate that is bright and warm in summer and rainy (or snowy) and cold in winter, with nights that are cooler because of their high altitude. The northern region is dominated by a semi-desert environment with relatively chilly winters.

Iraq experiences a wide range of monthly average temperature being 28.5 C. July and August have temperatures above 48 C, while January has temperature below zero. With an average wind speed of no more than 3 m/sec, the projected yearly rainfall is 216 mm (Yu et al., 2016). The terrain, varying human activity, and the changing global climate, all constitute extremely complicated physical elements that affect SDSs in Iraq. The high daily and annual temperature range and strong winds in the south and southwest of Iraq, which are indicative of the country's continental climate feature, contribute to the frequent occurrence of SDS. Generally speaking, there are two prevailing wind kinds in Iraq (locally called Haboob and Shamal). Those two wind types are mostly responsible for storm formation, which has a detrimental effect on the country's form of life (Yahya and Seker, 2019). Furman (2003) found that while the most common dust storms are regular in western Iraq and usually continue into the spring, the most frequent sand/dust storms occur in summer, particularly in northeastern Iraq. Shamal storms are classified as local sandstorms that are typically caused by northwest winds collecting dust in the atmosphere in the lower Tigris and Euphrates River valleys in Iraq, whereas haboob storms strike quickly forming a wall of dust that quickly turns daytime into complete darkness (Sissakian et al., 2003; Yahya and Seker, 2019).

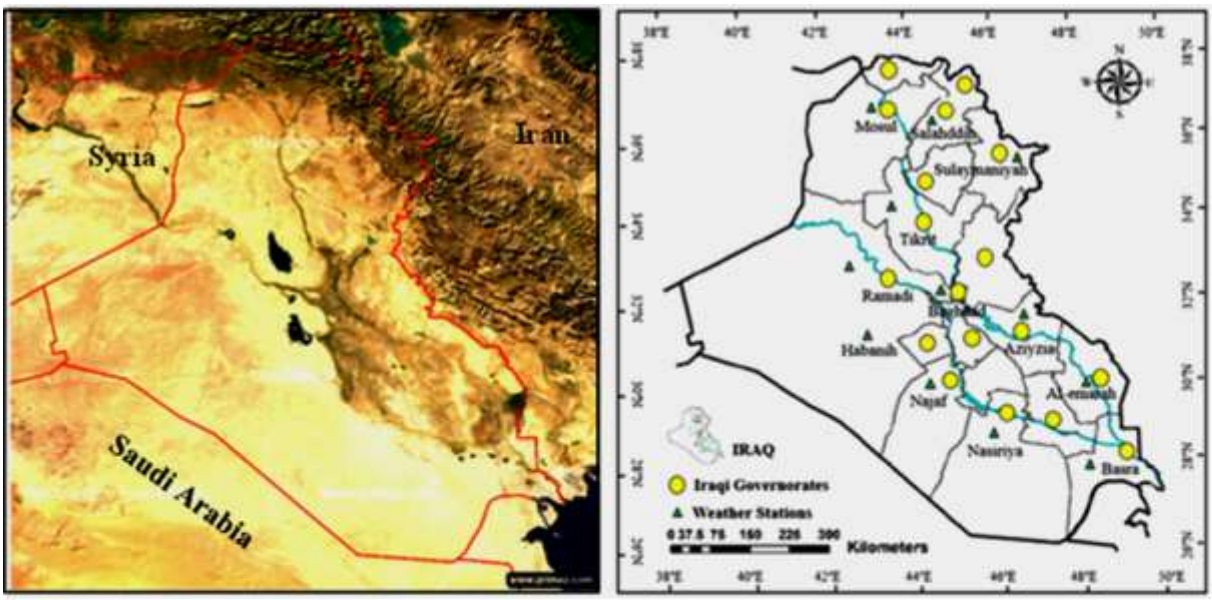

Fig. 1. General view of Iraq (the study area).

Data used

Large areas of Iraq have been exposed to SDS in the last two decades. To study this phenomenon, two kinds of data; first, forty satellite images type MODIS L1B products captured by MODIS on Aqua and Terra satellites representing the occurred??? SDS events from 2005 to 2019 as seen in Table (1).

Table 1: Sand dust storm events images information

Year	Images date	Year	Images date
2005	17-April-2005 13-May-2005 7-September-2005 8- September-2005 9- September-2005	2012	7-July-2012 13-August-2012
2006	21-January-2006 12-May-2006	2013	24-March-2013 31-Jun-2013
2007	13-October-2007 20-December-2007	2014	3-April-2014 16-July-2014
2008	1-July-2008 18-September-2008 16-October-2008	2015	2- July-2015 2- September-2015 15-November-2015
2009	13-April-2009 5-Jun-2009 5-July -2009	2016	16-May-2016 4-Jun-2016
2010	22-February-2010 7-Jun-2010 22-Jun-2010 30-Jun-2010 21-July-2010	2017	18-February-2017 31-March-2017 31-October-2017
2011	3-March-2011 2-Jun-2011 2-August-2011 7-August-2011 20-September-2011	2018	24-March-2018 25-March-2018
		2019	29- April- 2019

These events were mentioned in various Iraqi media as harmful environmental events that had several negative implications for society and public health. The MODIS L1B products were used for retrieving the Middle East Dust Index (MEDI) images and preparing a threshold index for each adopted meteorological station; second, from Iraqi Meteorological Organization and Seismology (IMOS), SDS information occurred???? during the period from 2000 to 2019 was adopted; these datasets contained frequency, horizontal visibility, and acquiring time records. The Sand Dust Storms Frequency (SDSF) values are calculated from the available SDS information by averaging the total occurrence days for the adoptive twelve meteorological observation stations distributed over the whole of Iraq. Furthermore, meteorological data reports that consist of rainfall, temperature, and wind (speed and direction) records belonging to these stations are used to complete the objective of this study as seen in Figure (1), which illustrates the geographical location of these stations. The meteorological data have been organized in a suitable format to be handled by the Arc GIS environment.

Used methodologies

GIS environment represented by Arc view v. 10.4 software is used by adopting a widely famous analysis called geo-statistical analysis using Radial Basis Functions (RBF) as deterministic techniques' interpolation method (Wu et al., 2019; Ul Mustafa et al., 2019) to produce spatial distribution maps for SDS events, precipitation, temperature, wind, and MEDI values. This ability in the GIS environment gave an efficient procedure to detect the spatial distribution of any feature or phenomena over time with the ability to integrate many variables or other statistical results with different variables.

Correlation analysis methods are important to many fields of science, where the correlation doesn’t mean causation of all cases; it’s often the first step to understanding the true relationship between all variables involved in a specific study and can give a valuable hint that there is a causal relationship somewhere. For investigating the potential existence regarding significant relations between Sand Dust Storms Frequency (SDSF) as a quantitative dataset, selected meteorological data (wind speed, temperature, and precipitation), MEDI values, and the studied period (Time in years), a Pearson correlation analysis (r) as a measure of the strength between two association variables, temporal variation analysis, linear trend analysis, and Spearman’s rank correlation are employed in this study (Akoglu, 2018).

In Pearson correlation analysis there is a basic rule for interpreting or classifying the strength of correlation based on Pearson correlation coefficient (r) values as seen in Table (2) that classified r-values into four levels (weak, very weak, moderate and strong), where the relation between two variables is commonly considered strong in the case when their r value is larger than 0.7 (Obilor and Amadi, 2018). The variables' dataset has been first standardized depending on the mean and standard deviation, resulting in a standard distribution with a mean of 0 and a variance of 1. Through such analyses, remarkable behaviors are found, and SPSS software is used as an effective statistical platform. The results after that are simulated as maps and charts of spatial distribution.

Table 2: Strength relationships classification according to r- values

r- Values	Relationship Strength
$r < 0.3$	very weak (VW)
$0.3 < r < 0.5$	Weak (W)
$0.5 < r < 0.7$	Moderate (M)
$r > 0.7$	Strong (S)

The importance of these analyses is demonstrated for finding clear correlations between the variables involved in this study, where the analysis shows that there are increasing and decreasing correlation relationships between the involved variables. According to El-ossta et al. (2013), the dust detection technique named the Middle East Dust Index (MEDI) is used as a remotely sensed classification method of distinguishing SDSs airborne materials from other land use/cover classes. This index is applied over Middle East regions and it gave very accurate results for monitoring or extracting SDS events from remote sensing data (Boloorani et al., 2020). MEDI depends on the MODIS reflective solar bands (B29, B 31, and B32) that have wavelengths ranging between (8.40–8.70 μm) for band 29 to (11.77–12.27 μm) for band 32 at a spatial resolution of 1000 m. The MEDI is illustrated mathematically in equation (1) (El-Ossta et al., 2013).

$$MEDI\ model = (BT31–BT29) / (BT32–BT29) \quad \text{........ (1)}$$

Where, BT29 represents one of MODIS bands number 29 that classified clouds properties and BT32 represents MODIS band number 32 that classified clouds and temperature.

Based on MEDI values, SDSF, and time (study period), the spatial distribution of MEDI values is mapped. Also, the influence of meteorological variables and MEDI on SDSF is discussed in the context of explaining the complex relationships between multiple factors.

Results and Discussions

According to the SDS event records gathered from twelve meteorological stations from 2000 to 2018 in Iraq. The study period (2000-2018) is divided into two periods (2000 to 2009 and 2009 to 2018). The analysis of SDS data for the first period shows high SDSF values concentrated in western of Iraq, specifically in Ramadi, Habaniah, Najaf, and Nasiriya stations, where these values range from 11 to 16 days per year. Furthermore, these values are decreasing to the east parts of Iraq by a range of 0 to 11 days per year according to the rest of the stations as illustrated in Figure (2 a) which shows the spatiotemporal pattern of SDSs in the first period over Iraq.The second-period analysis shows that SDSF values increased to the south and southwestern parts where SDSF became more than 11 days per year. Moreover, it seems that there is an increase in the SDSF values of the center parts of Iraq such as Tikrit and Baghdad stations as illustrated in Figure (2 b) which shows the spatiotemporal pattern of SDS in the second period over Iraq. This analysis shows that Iraq has been exposed to increasing SDS events when the two-study periods are compared, where it has been noticed that the regions in the south and southwest suffer from the heavy impact of SDSF reaching to (SDSF 16-20 days/year), especially in Ramadi, Habaniah, Najaf, Nasiriya and Basra stations.

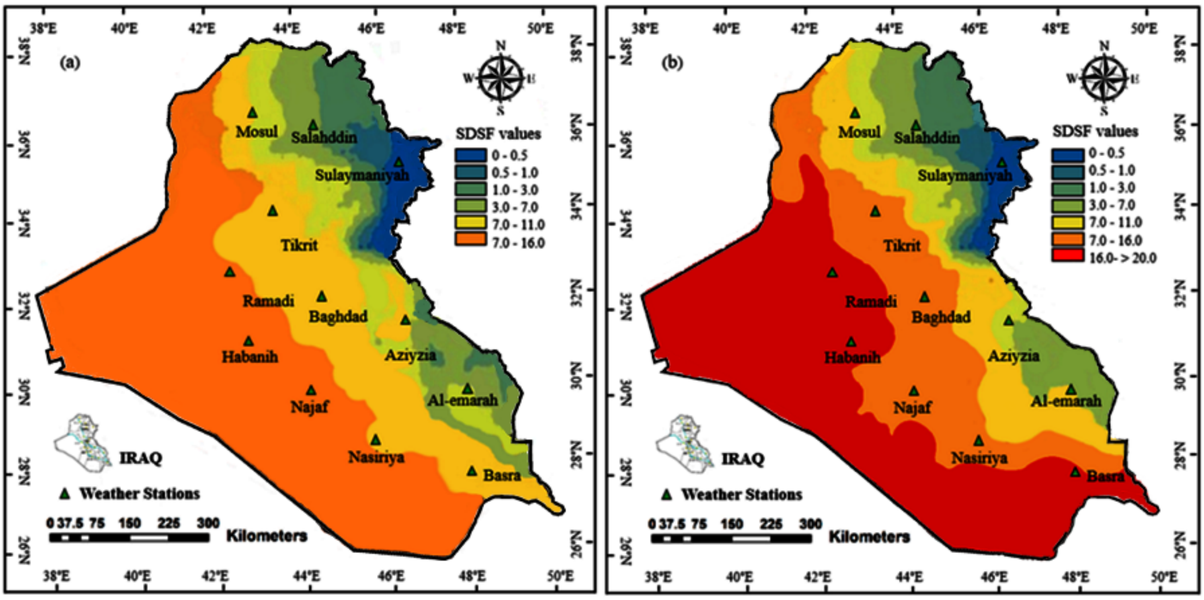

Fig. 2. The Spatiotemporal pattern of SDSF values in two periods over Iraq a- the first period (2000 to 2009) b- the second period (2009 to 2018)

When the Pearson correlation analysis (r) is conducted between SDSF as a quantitative dataset and the studied period (time in years), the gained results show that the spatial distribution of the SDS in large parts of Iraq tends to transfer from low-frequency regions (SDSF <7 days/year) ($r = 0.41$, $p < 0.05$) to moderate-frequency regions (SDSF > 11 days/year) ($r = 0.62$, $p < 0.05$) especially in Mosul, Tikrit, and Baghdad stations, where the SDS exposed area had been changed by 10.6 % when a comparison is made between the two study periods. While stations of Ramadi, Habaniah, Najaf, Nasiriya and Basra show high – frequency-increase (SDSF 16- 20 days / year) ($r = 0.76$, $p < 0.05$) as illustrated in Figure (3 a). A long-term temporal variation on SDS analysis is conducted using the maximum number of SDS days in each studied year and the Pearson correlation coefficient of SDSF in each station as seen in Figure (3 b). From this analysis, the regions that suffer from increased SDS frequency can be monitored easily.

As a result of this analysis, Nasiriya and Basra regions are the most regions sufferred from increasing SDS. The overall situations of the SDS distribution of the study area are illustrated in Figure (3 c), which represents the SDS year variation curve, where the SDS events show a transient increasing trend with time reaching a peak of SDS in the year 2018 (SDSF 22 day/year). Many studies that analyzed the SDS events in Iraq reported that the main factors that influence SDS are the wind activity that generates, transmits, and deposits the SDS; the anomaly changes in temperature and precipitation due to climate change activity. The relationships between the above factors that influence the SDS events and the MEDI index as a remote sensing technique for monitoring the SDS in the Middle East are examined and evaluated as follows:

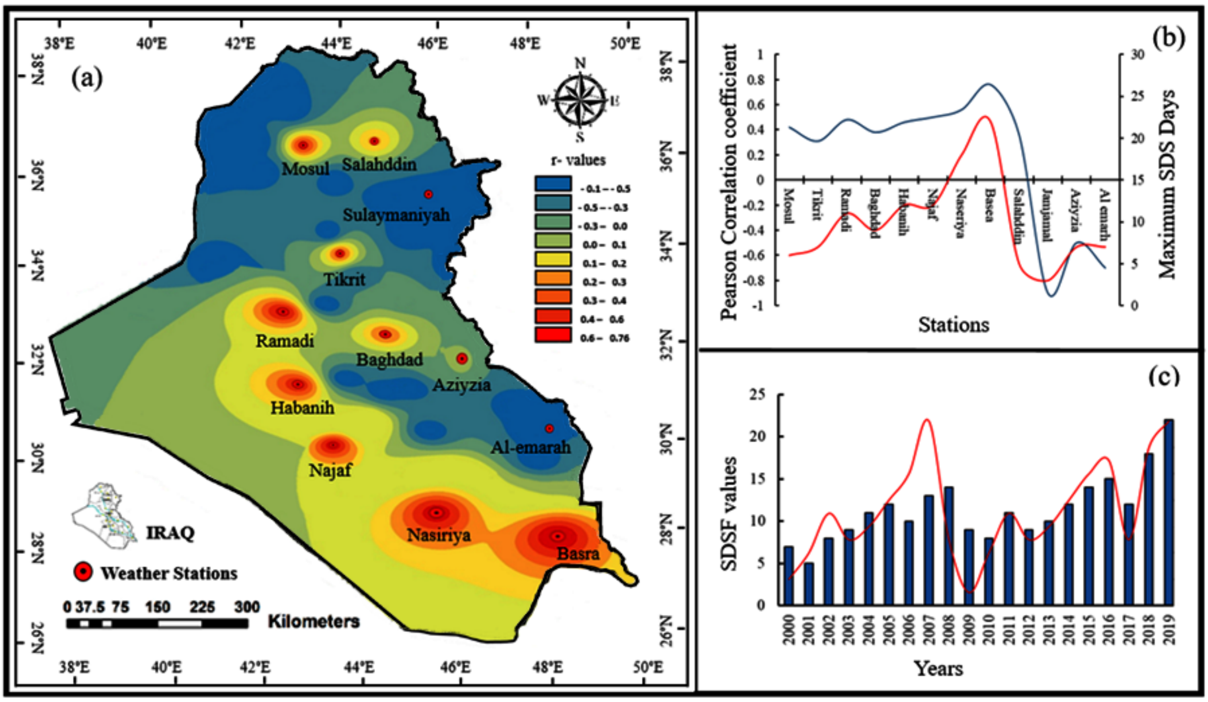

Fig.3. (a) SDSF spatiotemporal variation; (b) Correlation coefficients between SDS and stations; (c) SDSF year variation

1- SDS and Average Wind Speed (AWS) relationship

SDS is directly related to wind speed; when wind speed exceeds 3.6 m/sec, the susceptibility of wind to transfer the sand and dust materials will increase, where this situation will increase the opportunity to generate SDS events (Bilal, 2019). There are two types of winds that dominated in Iraq. First, the entire country of Iraq is impacted by the Shamal wind, a consistent summer wind that blows from the north and west. It brings with it very dry air, which means that very few clouds form, and the sun heats the ground surface intensely. Second, in the early summer and early winter, the Haboob wind originates in the southeast and south. According to the available wind data, the estimated annual average wind speed in Iraq equal 2.8 m/sec fluctuated between 1.4 m/sec in Mosul station and 4.2 m/sec in Basra station. Simple statistical analysis is made for estimating the wind behavior in Iraq that can be described as (1–5 m/sec) prevailing wind speed with an AWS of 2.8 m/sec, a prevailing west wind of 12.8%, and a prevailing south wind of 14.7%. The spatial distribution analysis shows that wind speed decreases northward due to the influence of mountains, while wind speed increases southward due to two factors (ground flatness and high temperature) compared to the northern part of Iraq as seen in Figure (4 a). According to Pearson correlation coefficient analysis, a positive value is detected between AWS and SDSF ranging from moderate to strong correlation relationship, where the moderate correlation relationship appears in the northern-, central- and eastern parts of Iraq in Baghdad, Mosul, Salahuddin, Sulaimanieah, Tikrit, Aziyzia, and Al-Emarah regions, while the strong correlation relationship appears in south and west of Iraq in Ramadi, Habaniah, Najaf, Nasiriya, and Basra regions.

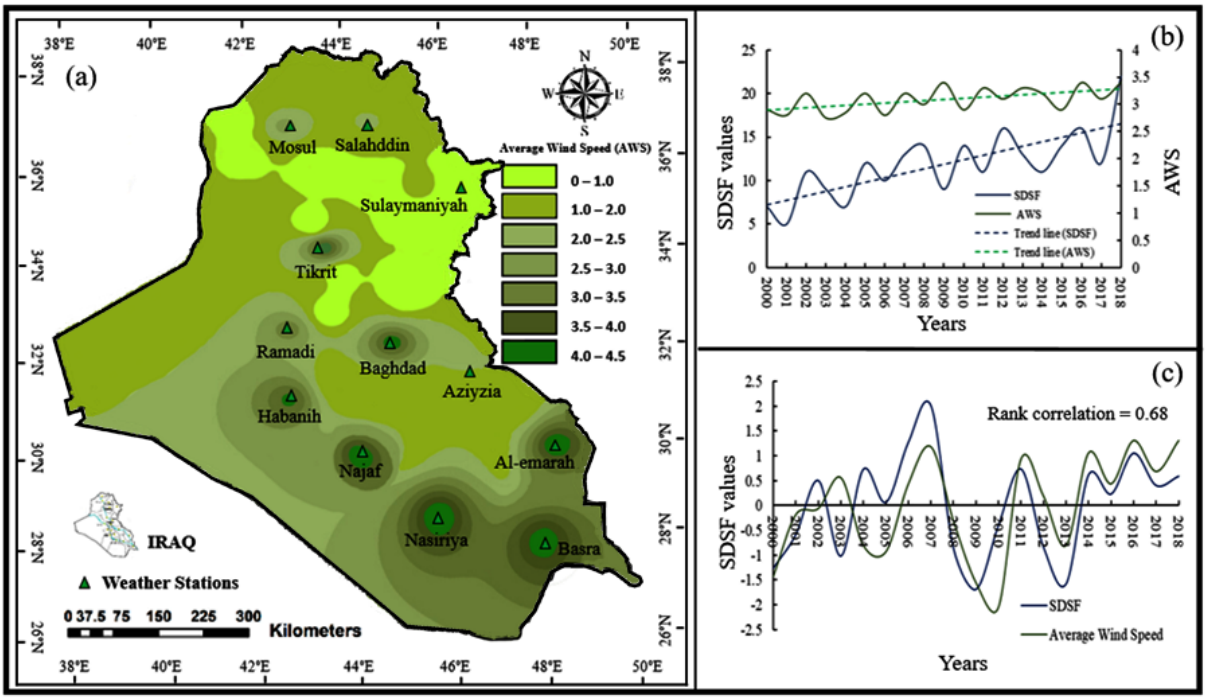

Fig.4. (a) Wind speed spatiotemporal variation; (b) Linear trend analysis AWS and SDSF; (c) Rank correlation between AWS and SDSF

The trend analysis reveals a linear direct association between SDSF and AWS with an increase in SDS seen in the case when AWS exceeded the average as illustrated in Figure (4 b). The strength of the relationship between AWS and SDSF (either negative or positive) is summarized using Spearman's rank correlation approach. As can be observed in Figure (4 c), the rank correlation results demonstrate a positive correlation between SDSF and AWS equal to +0.68 supporting the finding from the Pearson correlation analysis that points to the function of wind as a direct factor influencing the SDS in Iraq.

2- SDS and Average Temperature (AT) relationship

In Iraq, the average yearly temperature is 28.5° C with monthly temperatures ranging from above 48° C in July and August to below than zero in January. The average temperature values were spatially distributed over Iraq for the period from 2000 to 2018, where the southern and southwestern regions (Ramadi, Najaf, Nasiriya, and Basra) are considered the highest temperature regions compared with the other regions with an average ranging between 27° C in Ramadi and 31° C in Basra as seen in Figure (5 a) that represents the spatiotemporal variation of average temperature all over Iraq. The variation analysis between AT and SDSF shows a positive correlation relationship, where according to Pearson correlation coefficient analysis, a positively correlated relationship is detected between AWS and SDSF ranging from weak, moderate to strong correlation relationship, where the weak and moderate correlation relationships appear in the northern and eastern parts of Iraq at Mosul, Salahuddin, Sulaimanieah, and Aziyzia regions, while the strong correlation relationship appears in southern and southwestern regions of Iraq.

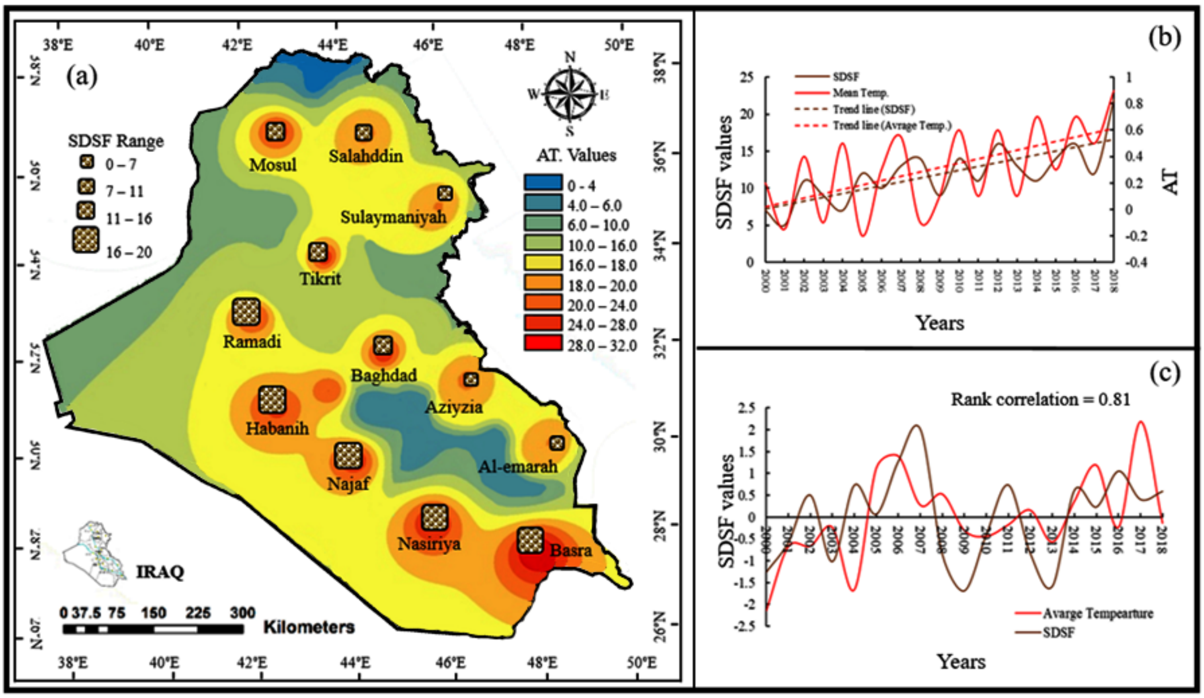

Fig.5. (a) AT spatiotemporal variation; (b) Correlation coefficients between AT and SDSF; (c) Rank correlation between AT and SDSF.

In some studied period, years, the results of the correlation coefficient values were observed to range from (- 0.7 to 0.3), which means the number of SDS events are decreased in these years as a result of decreasing the average temperature degree in these years like in 2001, 2003, and 2005 as an example. So, it can be said that the relationship between AT and SDSF is positive in general, but it is somewhat complicated and needs extensive studies. According to the linear trend analysis, a linear direct relation has been discovered between AT and SDSF when the AT increased over the average the SDS increase as illustrated in Figure (5 b). The results gained from Spearman's rank are (+ 0.81) correlation and linear trend analysis. Generally, these analysis results indicate that the average temperature can be considered as another factor that has a great influence on increasing SDS in Iraq similar to the wind factor as illustrated in Figure (5 c).

3- SDS and Average Precipitation (AP) relationship

The spatiotemporal analysis of precipitation within Iraq shows gradual decrease from southeast to northeast, where the mean precipitation in Iraq was estimated as 460 mm as seen in Figure (6 a).

The variation analysis of AP and SDSF values shows a weak negative Pearson's correlation, where it appears in all parts of Iraq with an average value equal to - 0.23; that means when precipitation falls below the mean value, the possibility of SDS events increase due to a kind of inverse relationship between them as illustrated in Figure (6 b) that shows the trend lines of AP and SDSF.

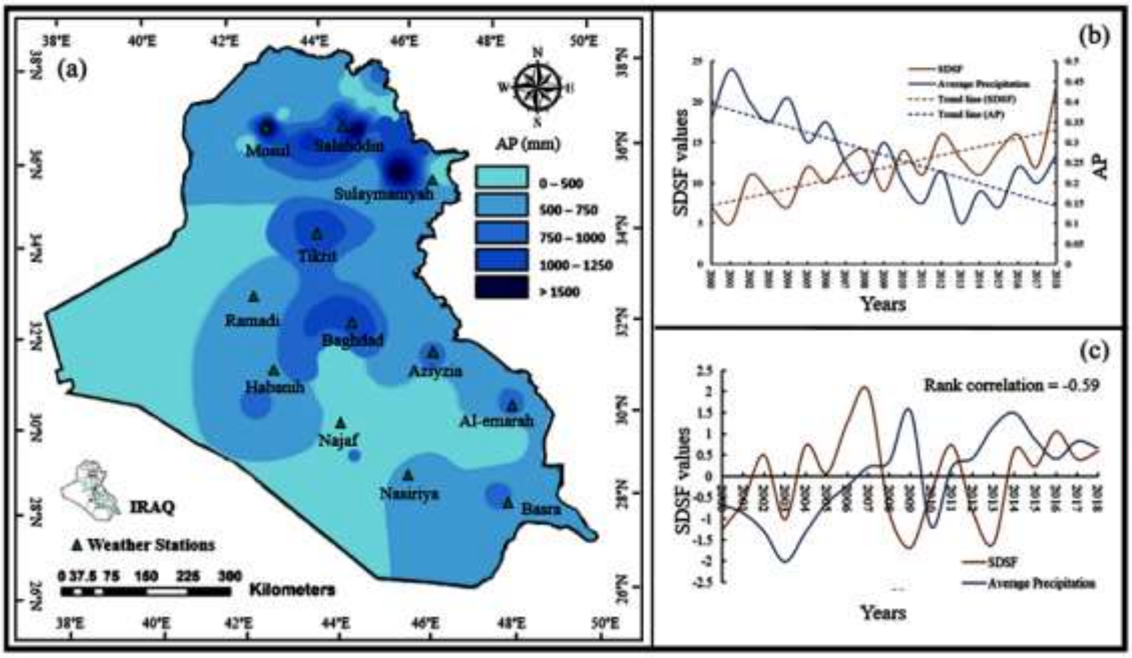

Fig. 6. (a) AP spatiotemporal variation; (b) Correlation coefficients between AP and SDSF; (c) Rank correlation between AP and SDSF.

As shown in Figure (6 c), the same situation between AP and SDSF is also noted when Spearman's rank correlation analysis is employed where this analysis shows a negative correlation equal to -0.59. Furthermore, this analysis shows that the SDS events in Iraq were increased in the last five years due to decreasing precipitation values compared with the first five years of the study period.

4- SDS and MEDI relationship

MEDI model is used for extracting the SDS events from forty MODIS data as illustrated in Table (1). A value of less than 0.08 is a reasonable threshold value for extracting water bodies and clouds, while the values ($0.08 < MEDI \leq 0.98$) are reasonable for extracting SDS events. The estimated MEDI values of the forty SDS events are spatially distributed. The long-term average analysis of MEDI shows that the SDS events were concentrated or highly occurred???? in the southwestern and southern regions of Iraq comparable with other regions due to the increased activity of SDS in these regions as seen in Figure (7 a). Variation analysis of MEDI and SDSF in each adopted station is conducted, where the correlation coefficient shows an average high value equal to 0.77 as seen in Figure (7 b), which shows the spatiotemporal variation of MEDI in Iraq. This analysis shows, in general, an increasing trend of MEDI values for Nasiriya and Basra stations, that means there is a high activity of SDS in these regions. As shown in Figure (7 c), Spearman's rank correlation analysis employed between MEDI and SDSF shows a positive correlation equal to 0.73 and that means that the MEDI index values are a good indicator for studying the SDS events in Iraq.

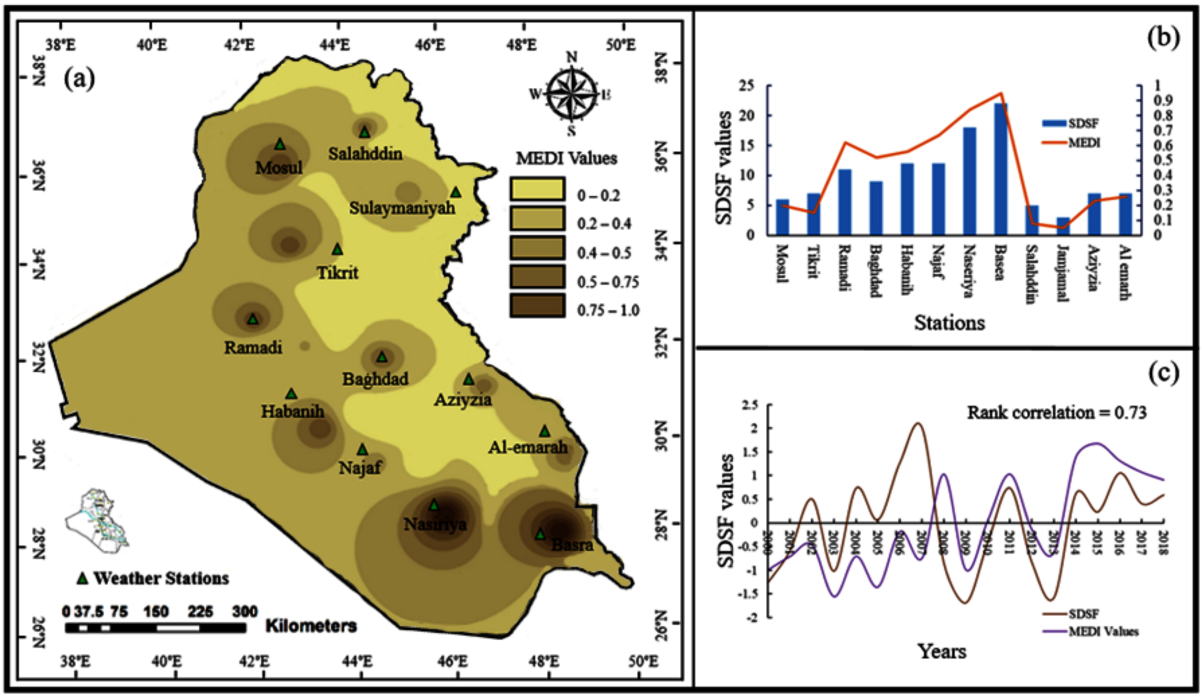

Fig. 7. (a) MEDI values spatiotemporal variation; (b) Correlation coefficients between MEDI and SDSF values; (c) Rank correlation between MEDI and SDSF values

Conclusion

Due to climate change's impact on Iraq and surrounding countries, SDS events has been increased rapidly in the last two decades causing different environmental and social problems like increasing desertified lands at the expense of arable lands; i.e., the desertification area. There are no much researches done on the effects of weather factors (such as temperature, wind, and precipitation) on the incidence of SDS, and the extent of SDSs throughout Iraq is still unknown. In this study, a long-term spatiotemporal analysis is conducted on SDS events occurred in Iraq from 2000 to 2018 to define which parts of Iraq that were exposed to any changes in SDSs activity. Ramadi, Najaf, Nasiriya, and Basra regions show increasing SDS activity, but the highest activity has been detected in Nasiriya and Basra, where the SDSF reaches over 20 days/year. The employed methodology in this study shows that meteorological variables like wind, temperature, and precipitation besides the remotely sensed products are necessary to understand the climate variability in Iraq in any period (past, present, or even future). The study results show that the three dominant factors that can affect SDS events in Iraq are wind speed, temperature, and precipitation. The statistical analysis procedures have proven that these factors have complex correlated relationships with SDS events ranging between positive and negative. Careful studies of the complex relationship between climate change and SDS occurrences are necessary to mitigate or lessen the impact of SDS events in Iraq. The Government needs to take various actions, starting with creating a knowledge foundation as well as conducting climate studies as a necessary first step in addressing the difficulties posed by SDS occurrences. Secondly, creating proactive methods such as windbreak cultivation, which include placing rows of specific fast-growing tree species in areas that align with the prevailing winds. These windbreaks are intended to slow the movement regarding sand dunes and lessen the likelihood of sandstorms and dust, particularly in south and west of Iraq.

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Conflict of Interest

The authors declare there is no conflict of interest.

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