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IMPACT OF AEROSOLS OPTICAL DEPTH ON ANGSTROM EXPONENT AND MICROPHYSICAL PROPERTIES OF CLOUDS OVER IRAQ

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ABSTRACT

In this study, spatial and temporal variations of aerosol optical depth (AOD) for selected regions in Iraq, namely, Mosul, Baghdad, Rutbah, and Basrah, were investigated with spatial resolution of 1° × 1° over Iraq (28.5°–38.5°N, 38.5°– 48.25°E); data have been retrieved from January 2003 to December 2015 by Moderate Resolution Imaging Spectroradiometer (MODIS) were analyzed which can lead to modifications in the microphysics of clouds as well. The highest values for mean seasonal AOD were observed in summer and spring, and the maximum recorded AOD values ranged from 0.324 ± 0.191 to 0.378 ± 0.189. By contrast minimum AOD values ranging from 0.195 ± 0.097 to 0.216 ± 0.111 were found in winter and autumn respectively, besides analyzed the relationship between AOD and Ångström exponent (AE) that consider a perfect indicator of the size of an aerosols particles. Furthermore, the relationships between AOD and four cloud parameters, namely, cloud fraction (CF), water vapour (WV), cloud optical depth (COD) and cloud effective radius (CER) have been investigated by employing spatial correlation maps for their data values. The analysis showed a strong negative correlation between AOD and AE particularly in the middle region (Baghdad) and western region (Rutbah). The correlation between AOD and CF showed a weak negative correlation and be close to zero in the western region. The correlation between AOD and WV was positive (~ 0.4) especially in the strip joint between a northern and middle region. AOD showed a negative relationship with COD in the whole of Iraq. AOD and CER presented a positive relation along the arid desert region extended from west northern region to the west southern region passing western region of Iraq. All mentioned correlations performed on the four study regions are based on the large-scale atmospheric variations.

Keywords: aerosols, atmosphere, cloud, modis, Iraq.

INTRODUCTION

Atmospheric aerosols are solid and liquid particles suspended in the atmosphere and their radii range from few nanometers to tens of micrometers. These particles can be emitted directly from anthropogenic sources (e.g. fossil fuel emissions and natural sources (e.g., dust, maritime aerosol, and volcanic ash) or they can be produced from precursor gases (e.g., secondary organic aerosol and sulfates). Aerosols cause most of the environmental problems, such as global warming, photochemical smog, stratospheric ozone depletion and poor air quality (Colbeck, 2014). The relationship between aerosol optical depth (AOD) and cloud parameters has become a research hotspot issue due to the impact of clouds on climate (Alam *et al.*, 2010, Alam *et al.*, 2014). Several studies have investigated the possible modification of cloud properties by the interaction of clouds with atmospheric aerosol particles, because such modification may lead to important changes in Earth's climate. Biomass burning aerosols affect clouds through microphysical and radiative transfer mechanisms (Kaufman and Koren, 2006, Rosenfeld *et al.*, 2008). Biomass burning, including deforestation and annual agricultural burning is the largest anthropogenic source of such particles in southern hemisphere; biomass burning aerosols are hygroscopic and can serve as cloud condensation nuclei (Feingold *et al.*, 2001, Andreae *et al.*, 2004, Ten Hoeve *et al.*, 2010). The present study aimed to investigate the spatial and temporal distributions of AOD over Iraq by using MODIS level-3 data obtained for the last 13 years (2003–2015) and to understand the relationship between AOD and cloud physical properties over Iraq which suffer from a serious shortage of such related studies.

MATERIAL AND METHODOLOGY

Study area and climate situation

The study area is Iraq, which located in western part of Asia and occupies mostly the Mesopotamian Plain, Iraq bordered by Turkey to the north, Islamic Republic of Iran to the east, Arabian Gulf to the southeast, Saudi Arabia and Kuwait to the south, and Jordan and the Syrian Arab Republic to the west. Topographically, Iraq is basin-like and consists of the alluvial plain (Great Mesopotamia) located between the Tigris and Euphrates Rivers. This plain is surrounded to the north and east by mountains, which reaches an altitude of 3550 m above sea level, and to the southern and western regions by desert areas, which forms about 40 percent of the land area (Hasanean, 2004). This study investigated four regions, which represent diverse climate patterns and terrains; these regions include the northern (Mosul), middle (Baghdad), western (Rutbah), and southern (Basrah) regions. The geographical map Iraq is shown in Figure-1. Iraq has a hot and arid subtropical climate. Precipitation is generally low; the maximum rainfall is received during winter months, and

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most places receive less than 250 mm annually, except in the far north of the country, where rainfall is extremely rare during summer. In winter, the ambient temperature rarely exceeds 21 °C with a maximum range of roughly 15 °C to 19 °C in day time and 2 °C to 5 °C at night time. In summer, the average temperature is higher than 40 °C in most parts of the country and frequently exceeds 48 °C. The northern mountainous regions experience cold winters with occasional heavy snow, sometimes causing extensive flooding.

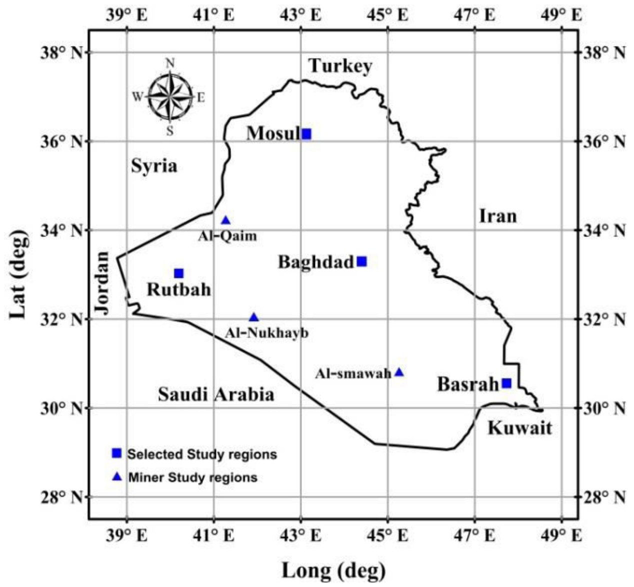

Figure-1. Geographical location of the four studied regions in Iraq.

Acquisition of satellite data

Observation of the earth through remote sensing requires a variety of platforms and instruments ranging from hand-held close-range spectrometers to imagers and sounders on board the satellites flying thousands of kilometers above the Earth. In the present study, aerosols data over study region acquired employing MODIS on board the Terra satellite of NASA, USA earns data at 36 spectral bands to provide information about the atmosphere, ocean and terrestrial (King *et al*., 1992). The mentioned bands range from visible to infrared wavelengths (from 0.4 µm to 14.385 µm), which are very practical to collect and epitomize large statistical and visual influences of aerosols on atmospheric conditions (Ichoku *et al*., 2004). MODIS-Terra data have been employed due to its longer time record. Terra passes the equator from north to south at 10:30 h local time (LT). MODIS gives global coverage every 24 to 48 hours. MODIS instruments are powerful to monitor atmosphere, terrestrial and ocean to observe different changes and collect statistics. The datasets from MODIS are advantageous for collecting several statistics on aerosol characteristics and its effects on cloud formation (Alam *et al*., 2014). For cloud parameters such as water vapor the near infrared retrieval is adopted. The optical and microphysical cloud properties determined by using the visible and near-infrared bands) (Alam *et al.,* 2010). AOD has acquired for the entire period January 2003-December 2015 using long-lat map, time series and correlation maps to generate the data for the study locations. In order to characterize cloud free-pixel, cloud mask algorithm is applied (Hsu *et al*., 2004). The AOD is obtained at 550 nm and the Angstrom exponent (AE470-660) used is for land only by Terra. The cloud parameters though available for daytime, night time and combined and the water vapor were retrieved for clear sky only. More detailed information on algorithms for the retrieval of aerosol and different cloud parameters is available at http://modis-atmos.gsfc.nasa.gov/.

RESULTS AND DISCUSSIONS

Spatial and temporal variations of AOD

Table-1 shows the descriptive statistics of annual AOD for selected stations are listed in Table-1, namely, Mosul, Baghdad, Rutbah, and Basrah; The annual mean values of AOD were calculated from the daily mean values obtained from 2003 to 2015, ranged from 0.141 ± 0.051 to 0.640 ± 0.179 in Rutbah and Basrah in 2014 and 2006, respectively. Figure 2 shows the annual mean variation of AOD over the study regions. AOD in all study area except Rutbah continuously changed during the entire duration of the study because of high aerosol loading with high levels of atmospheric aerosols especially in Basrah, which is considered a heavily polluted region, leading to the increased AOD values (Al-Hassen *et al.*, 2015). High aerosol loading is related to anthropogenic activities, which increased during the past 10 years in major cities in Iraq influenced by increase in population growth, increase in the number of vehicles, poor fuel quality, age of vehicles, and emissions of random industrial activities in city centers. The widespread use of civil electricity generators in residential, commercial, and industrial districts which increase the rate of combustion in all cities, contributing to the increase in emission of carbon oxide into the atmosphere as a result of incomplete combustion of fossil fuel. In addition to the effect of pollutants, dust events frequently occur in Iraq (Al-Jumaily and Ibrahim, 2013, Mohammed, 2016, Rezazadeh *et al*., 2013, Al-Dabbas *et al.*, 2012). Figure 3 shows the seasonal AOD values calculated from daily AOD data acquired by MODIS. The seasonal variations in AOD statistics over Iraq are summarized in Table 2. The lowest seasonal mean AOD values (0.195 ± 0.097) were observed in winter as an outcome of the scavenging of high amount of atmospheric aerosols during rainy season. The low AOD value in winter is related to the low temperature of the earth's surface, leading to low production of suspended mineral dust from the surface of the earth (Dey *et al*., 2004). The evident reduction in AOD values during rainy season was caused by fine mode particles, which are non-hygroscopic in nature. Furthermore, the height of boundary layer decreased during winter, resulting in a small volume of pollutant compared with that during summer. By contrast, maximum AOD values were observed during summer and spring with seasonal means of 0.324 ± 0.191 and 0.378 ± 0.189, respectively; this result is due to the increase in wind speed and boundary layer height. The speed of wind initiated and facilitated the movement of copious amounts of soil dust aerosols into the atmosphere from the surface of dry ground of the arid and semiarid regions (Alfaro, 2008).

Table-1. Annual statistics of aerosol optical depth in Mosul, Baghdad, Rutbah, and Basrah.

Year	Aerosol optical depth (Mosul)			
	Mean	Min	max	SD
2003	0.2289	0.1276	0.3907	0.0862
2004	0.1952	0.1072	0.2760	0.0611
2005	0.2538	0.1388	0.3868	0.0911
2006	0.2910	0.1217	0.4499	0.1033
2007	0.3348	0.1568	0.5847	0.1181
2008	0.4859	0.1944	0.7160	0.1804
2009	0.5640	0.3228	0.9317	0.2147
2010	0.4091	0.2131	0.7037	0.1228
2011	0.4193	0.1498	0.7320	0.1809
2012	0.4150	0.1713	0.6707	0.1573
2013	0.2620	0.1164	0.4346	0.0858
2014	0.2225	0.0987	0.3047	0.0669
2015	0.2590	0.1207	0.3498	0.0976

Year	Aerosol optical depth(Baghdad)			
	Mean	Min	max	SD
2003	0.2553	0.1130	0.4150	0.0893
2004	0.2403	0.0970	0.3450	0.0723
2005	0.3234	0.1750	0.6360	0.1615
2006	0.2778	0.1420	0.3910	0.0860
2007	0.3378	0.2340	0.5560	0.1046
2008	0.5599	0.1920	0.9550	0.2542
2009	0.5763	0.2820	1.0000	0.2432
2010	0.4836	0.2290	0.8260	0.2010
2011	0.4672	0.2100	0.7500	0.1845
2012	0.4618	0.1880	1.0400	0.2289
2013	0.2850	0.1040	0.5270	0.1181
2014	0.1820	0.1160	0.2720	0.0557
2015	0.3403	0.1130	0.5360	0.0893

Year	Aerosol optical depth (Rutbah)			
	Mean	Min	max	SD
2003	0.2228	0.0670	0.3960	0.1098
2004	0.2258	0.0630	0.4500	0.1099
2005	0.2033	0.0930	0.3380	0.0805
2006	0.2137	0.0710	0.4180	0.1115
2007	0.2168	0.0590	0.4160	0.1154
2008	0.2605	0.0790	0.4700	0.1362
2009	0.2588	0.1040	0.4660	0.1085
2010	0.2758	0.0770	0.4240	0.1262
2011	0.2683	0.0810	0.5480	0.1377
2012	0.2769	0.0770	0.5450	0.1466
2013	0.2366	0.0830	0.4620	0.1231
2014	0.1419	0.0750	0.2260	0.0517
2015	0.2292	0.0830	0.4470	0.1186

Year	Aerosol optical depth (Basrah)			
	Mean	Min	max	SD
2003	0.2898	0.1780	0.4350	0.0699
2004	0.3799	0.1840	0.6830	0.1256
2005	0.4548	0.2150	0.7620	0.1537
2006	0.6400	0.2690	0.9690	0.1792
2007	0.5554	0.2840	0.7590	0.1399
2008	0.5153	0.1980	0.7730	0.1501
2009	0.5900	0.2640	0.9580	0.1602
2010	0.4813	0.3020	0.5920	0.0681
2011	0.4289	0.2350	0.5740	0.0896
2012	0.3894	0.2580	0.4760	0.0556
2013	0.2578	0.1940	0.3240	0.0423
2014	0.2805	0.1800	0.4220	0.0756
2015	0.2898	0.1780	0.4350	0.0699

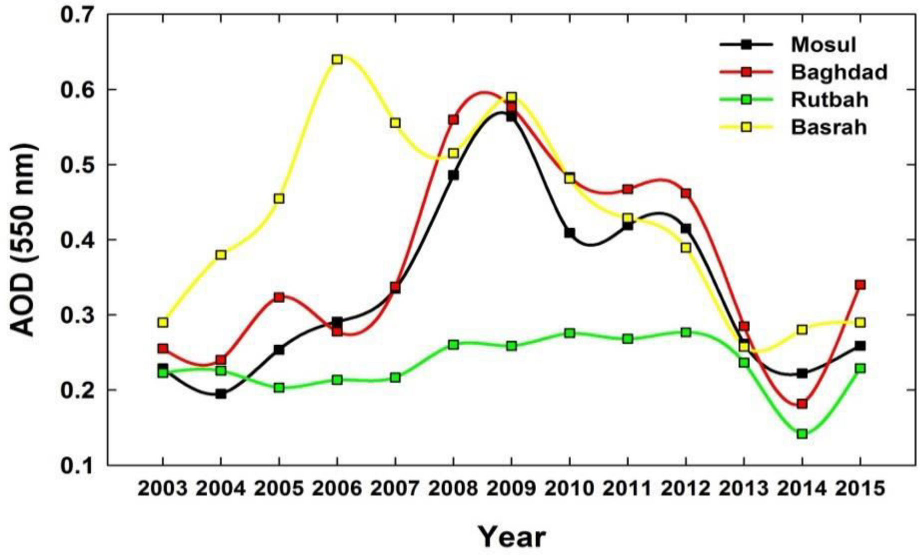

Figure-2. Time series of the annual mean AOD for the period 2003–2015.

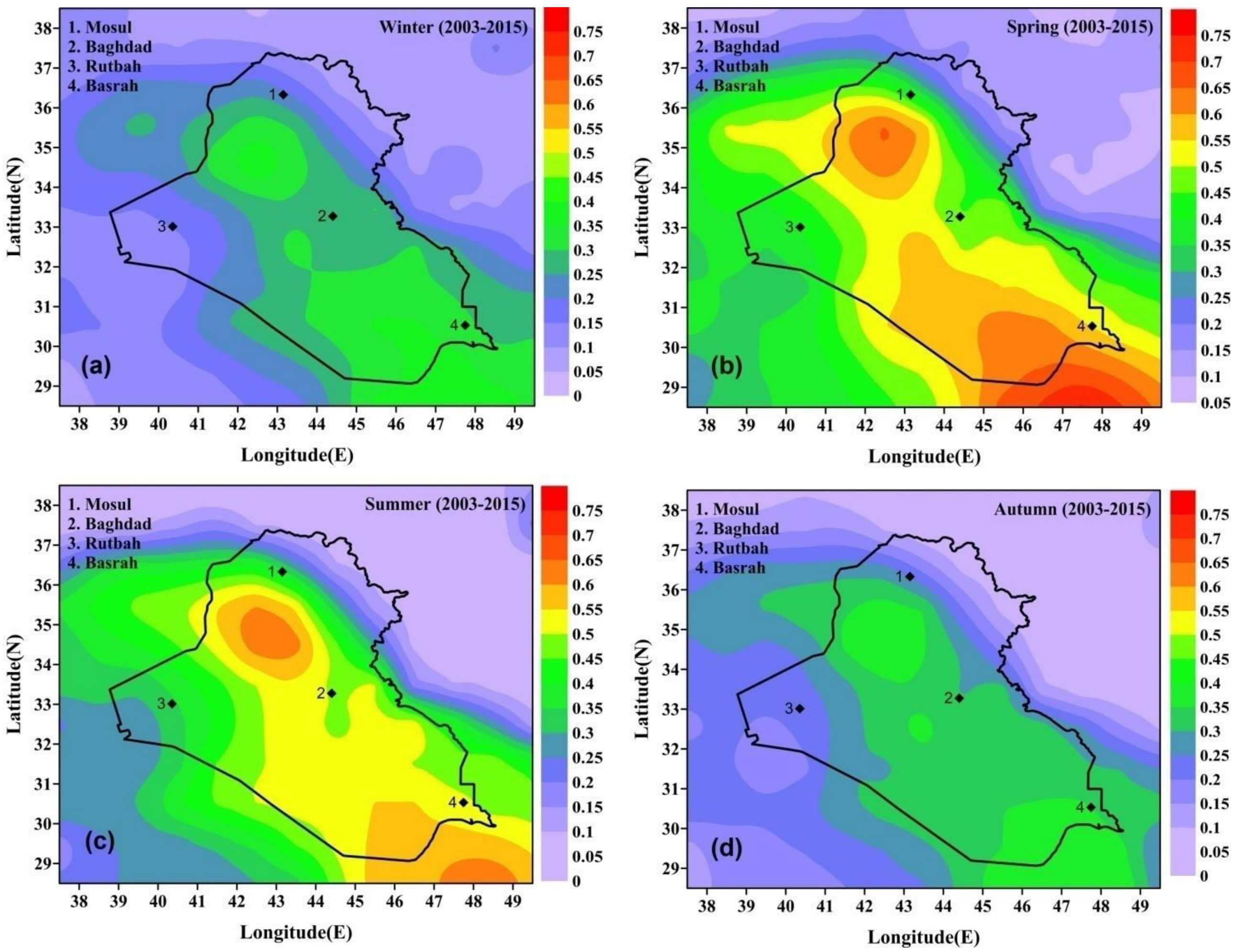

Figure-3. Seasonal mean AOD retrieved from MODIS-Terra for (a) winter, (b) spring, (c) summer and (d) autumn for the period 2003–2015 over the entire Iraq.

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Relationship between AOD and AE

AE is a characteristics indicator of aerosols dependency on wavelength and determines the size of aerosols. It is large (small) for fine (coarse) mode particles size as suggested by Angstrom. (Ångström, 1964). AE can be given approximately by the relation:

$$AE = \log \frac{\tau_{\lambda_1}}{\tau_{\lambda_2}} / \log \frac{\lambda_1}{\lambda_2} \quad (1)$$

Where: $\tau_{\lambda 1}$ and $\tau_{\lambda 1}$ are optical thickness at two different wave lengths λ_1 and λ_2 respectively. The AE have a several application such as; Earth Radiation Budget Study and Radiative Transfer Model. Regional AOD was strongly negatively correlated with AE over the entire Iraq (Figure-4a). Iraq has 10 dust storm sources, covering 16% of the total area of Iraq, particularly the northwestern region of Iraq near the Iraqi-Syrian borders and Samawah desert in Muthanna Province (Cao *et al.*, 2015). This section of present paper analyzes the inverse relationship between AOD and AE ranges from (- 0.87 to - 0.70) in Rutbah and Mosul respectively (Table-3); a strong inverse relationship between AOD and AE was observed in most regions of Iraq because of high aerosol loading during spring and summer, except in northern areas that include mountain ranges which have lowest aerosols loading activities whole of Iraq. In the Basrah region, which is overlooking the Arabian Gulf, the aerosol loading consists of coarse mode (sea salt and mineral dust) and fine mode aerosols associated with pollutants that originated from emissions from petroleum industry; fine mode aerosols are dominated by sulfates (very hygroscopic) that can grew in size, increasing the AOD of fine mode aerosols under high humidity conditions. The temporal correlation between AOD and AE in Mosul, Baghdad, Rutbah, and Basrah shows opposite behaviors and trend through most months of the year as shown in Figure-4(b). The high negative correlation over most regions may be associated with dust loading activities, except Basrah overlooking on gulf, where sea salt aerosols are dominant.

Table-2. Seasonal statistics of AOD for the period 2003–2015 over the entire Iraq.

Season	Seasonal AOD (2003–2015)			
	Mean	SD	Min	Max
Winter	0.195	0.097	0.034	0.385
Summer	0.324	0.191	0.035	0.641
Autumn	0.216	0.111	0.041	0.396
Spring	0.378	0.189	0.081	0.744
Average	0.278	0.147	0.047	0.541

Table-3. Correlation between aerosol optical depth (AOD) versus Angstrom exponent (AE) and cloud parameters.

Region	AOD versus				
	AE	CF	WV	COD	CER
Mosul	- 0.70	- 0.19	0.39	- 0.32	0.12
Baghdad	- 0.84	- 0.27	0.39	- 0.26	- 0.15
Rutbah	- 0.87	- 0.16	0.33	- 0.22	0.47
Basrah	- 0.78	- 0.24	0.13	- 0.26	0.32

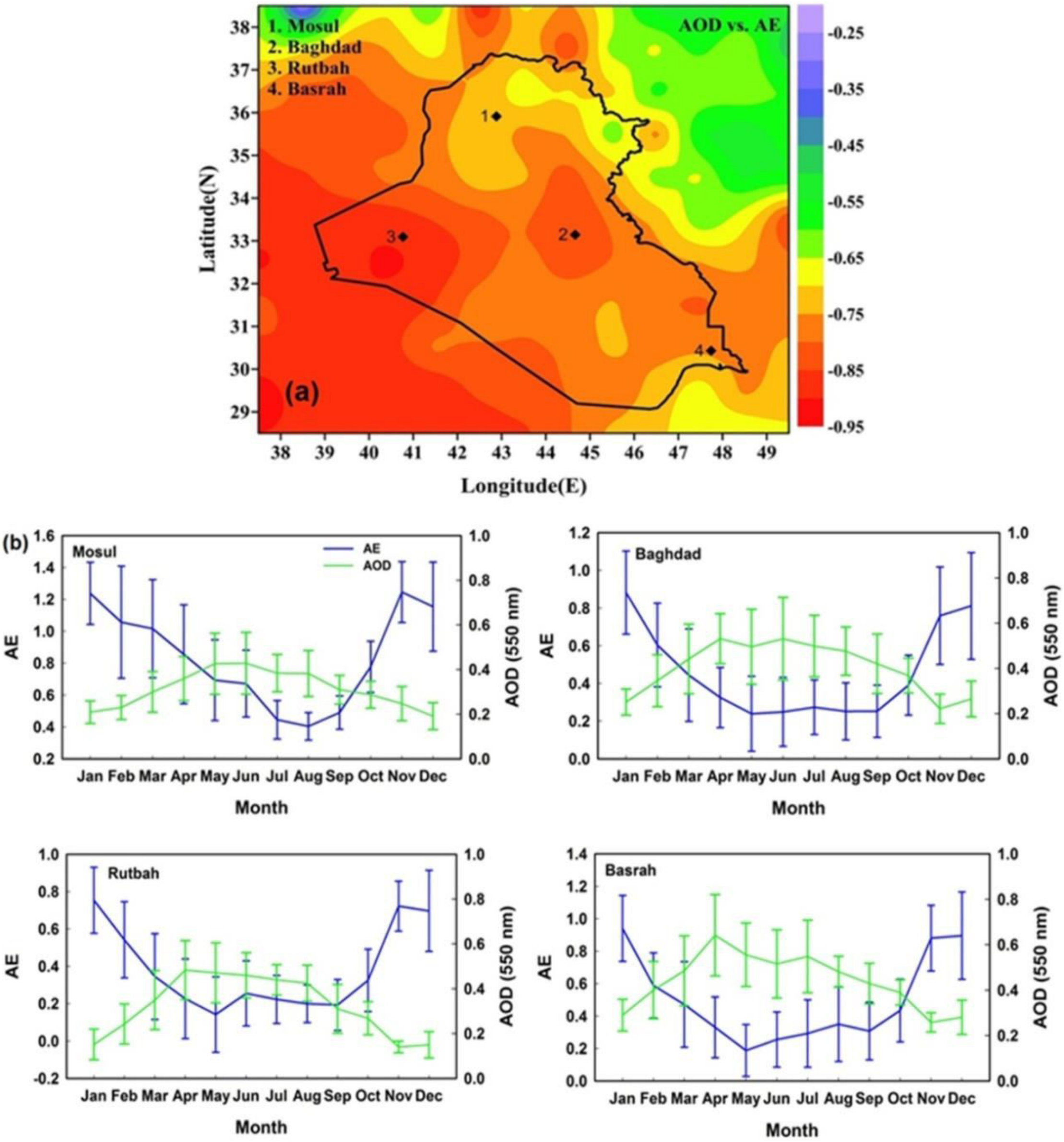

Figure-4. (a) Spatial correlation map and (b) time series plots of average AOD and AE values with standard deviation over the four locations in Iraq for the study period 2003-2015.

Interactions between AOD and cloud parameters

In order understand the role of aerosols in cloud modification, the spatial correlation between AOD and cloud parameters which denoted by CF, WV, COD, and CER have been studied by using MODIS-Terra satellite data.

Relationship between AOD and CF

Figure-5 (a) shows the spatial correlation between AOD and CF for whole of Iraq. The employed data for present analysis was that of MODIS-Terra day and night combined data for the period 2003 -2015. The negative relationship between AOD and CF dominant over the whole of Iraq with relatively higher negative values in urban regions, such as Mosul, Baghdad, and Basrah, the lowest correlation is found in desert regions (Rutbah). In the whole areas, negative correlation ranging from - 0.16 to - 0.27 was found. All of the mentioned regions, except Rutbah, the existence biomass, and dust aerosols showed a marked increase in inverse correlation. Moreover, Table-3 presents that the relative sensitivity of the relationship between AOD and CF increased in regions with high aerosol and pollutant loading caused by urbanization and local anthropogenic activities, such as electricity generation by local civil generators. In polluted regions, aerosols cause indirect effect, in which clouds tends to contain increased number of small droplets that can reflect increased amount of solar radiation into space, consequently cooling the Earth surface (Rosenfeld, 2000). Junior cloud droplets tend to minimize droplet outgrowth rate through collision-coalescence, which increases the lifetime of the cloud (Twomey, 1977). The increased

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amount of fine particles is likely to produce a massive number of cloud condensation nuclei, which effectively reduce the radii of cloud droplets. Based on Kelvin effect, cloud droplets with small radius tends to evaporate, further repressing cloud formation and ultimately leading to minimal cloud cover levels (Andreae and Rosenfeld, 2008). The time series plots depicted in Figure-5b showed the comparable behavior of CF with a maximum value in late autumn, winter, and early spring, and the CF values rapidly decrease in summer until early autumn in all study sites.

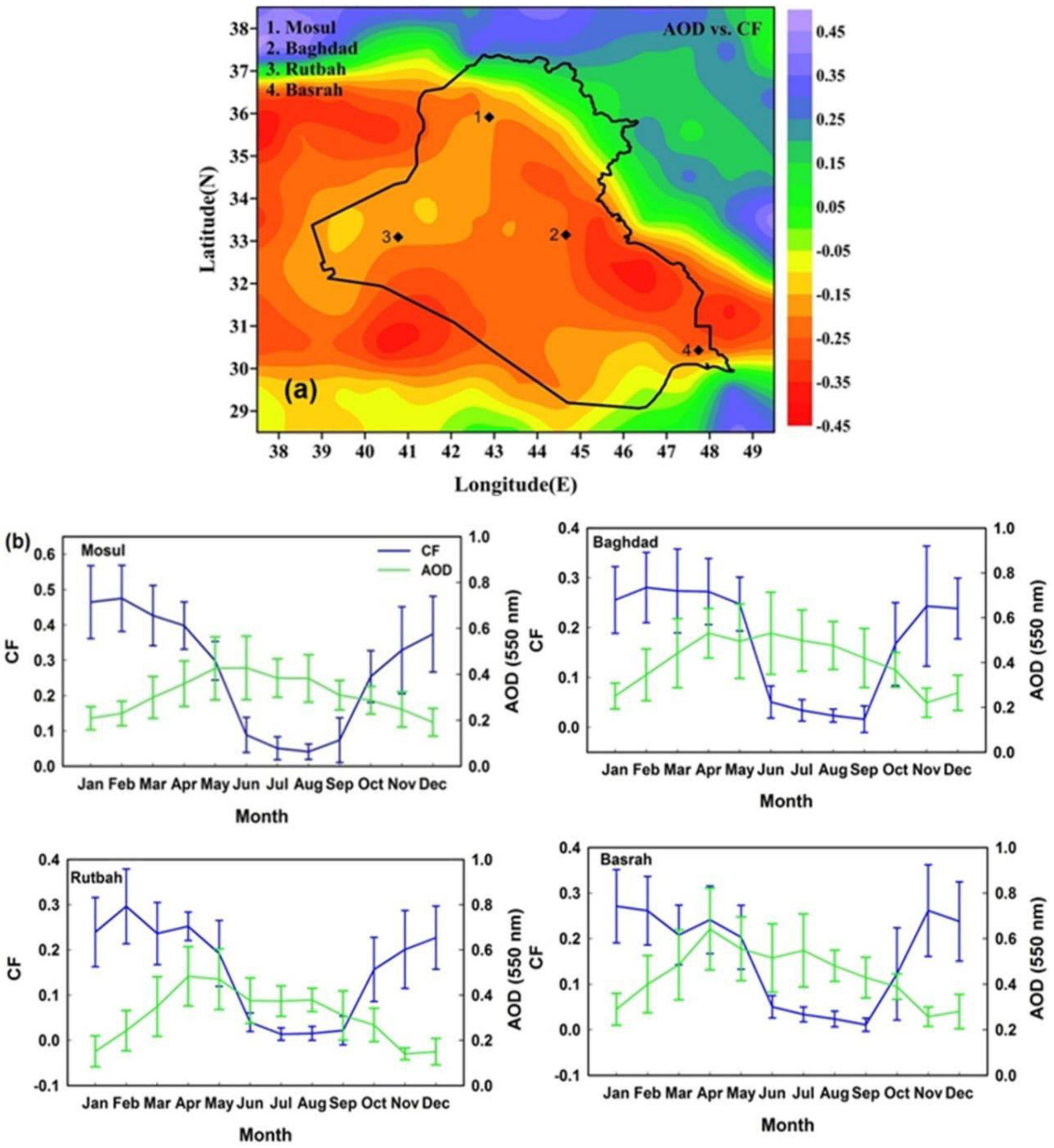

Figure-5. (a) Spatial correlation map and (b) time series plots of average AOD and CF values with standard deviation over the four locations in Iraq for the study period 2003–2015.

Relationship between AOD and WV

The variation in WV in relation to aerosols was investigated to provide an insight into the effect of aerosol on hydrological cycle (Myhre et al., 2007). MODIS-Terra retrieval separately reveals the outcomes for WV in the clear sky and above the clouds. This study determined the spatial correlation between AOD and WV over Iraq for the period 2003–2015 (Figure. 6a). To better understand the impact of aerosol on clouds, the relationship of aerosol with WV has been investigated. Figure 6a shows the positive correlation between AOD and WV unevenly distributed over Iraq. Positive correlation was found in the belt where the northeastern region along Iraqi-Syrian borders passing through Mosul meets the middle region of Iraq represented by Baghdad; gives maximum correlation in these regions was 0.39. In the western region of the

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country (Rutbah), the correlation was 0.33, and a lower correlation value (0.13) was found in the southern region (Basrah) (Table-3). Figure-6 b shows the time series plot for AOD and WV. Generally, WV increased during summer in all selected regions, and this phenomenon was observed because the monsoon low-pressure system dominated accompanied by humid air masses.

AOD and WV show the same trends throughout the year in all regions. Basrah, which is overlooking the Arabian Gulf, showed the highest AOD levels caused by the coated fine aerosols emitted from oil refineries and by the abundance of coarse mode aerosols represented by sea salt and mineral dust particles, which existed in low correlation (0.13). In addition, the relationship between AOD and WV was inconsistent over Basrah, where the relationship is poor. The water-absorbing ability of aerosols depends on aerosol types. This phenomenon is influenced by the aerosol's solubility, which varies among aerosol types according to Shi et al (Shi *et al.*, 2008) found that coarse mode particles are mostly insoluble but can become hygroscopic once coated with sulfate; such aerosol includes mineral dust. Moreover, the hygroscopic nature of aerosols depends on the mixing of particular types of aerosol and on meteorological parameters, such as humidity, wind speed, wind direction, and temperature (Aloysius et al., 2009). Moreover, water uptake of atmospheric aerosols is important as it can result in a number of outcomes; for instance, it can change the size and chemical composition of particles and consequently alter their optical properties (Müller *et al*., 2011).

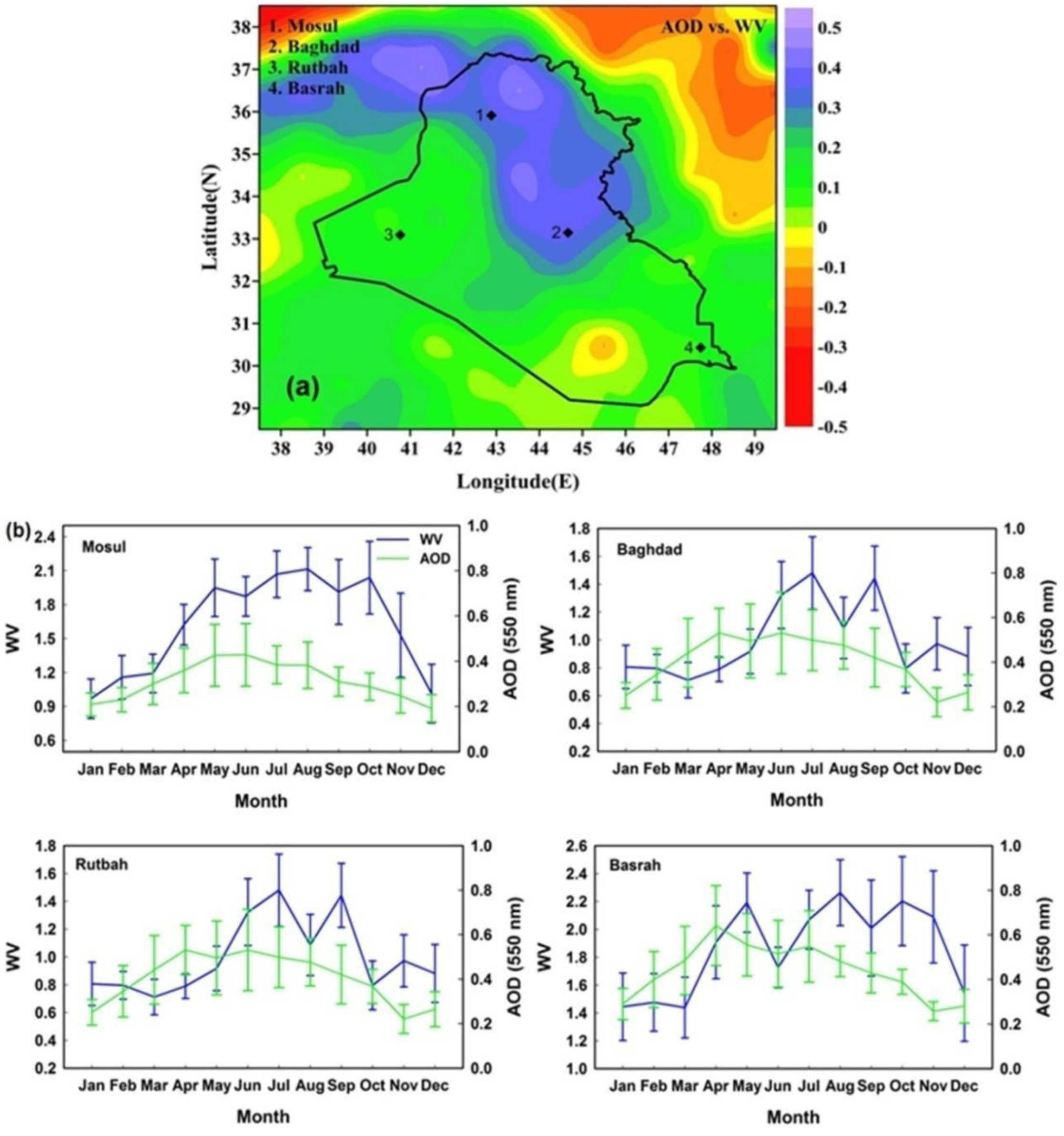

Figure-6. (a) Spatial correlation map and (b) time series plots of average AOD and WV values with standard deviation over the four locations in Iraq for the study period 2003–2015.

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Relationship between AOD and COD

COD is a measure of the attenuation of solar radiation passing through the atmosphere; this attenuation is caused by the scattering and absorption of light by cloud droplets. COD has numerous applications in radiative transfer and climate change, as well as in computing the Earth's radiation budget (Prasad et al., 2004, Nakajima and King, 1990). Figure-7a shows the spatial correlation between AOD and COD over the selected regions of Iraq as revealed by the 13-year study. Negative correlation values, which are close to one another, was observed (Figure-7a); the highest negative correlation was found in Mosul (− 0.32), whereas the lowest negative correlation was found in Rutbah (-0.22). Baghdad and Basrah showed the same correlation (- 0.26). AOD is normally positively correlated with COD (Adesina *et al*., 2016, Andreae, 2009) by contrast, in this study COD increased with decreasing AOD in all study regions as a result of the impact of aerosol particles on cloud microphysics, consistent with the findings of Twomey (Twomey, 1977). Reduction in COD with increasing AOD levels up to approximately more than 0.3 (Figure-7b) can be interpreted by the combination of physical processes and satellite retrieval artifacts. Physically, the aerosols absorption of solar radiation causes a partial evaporation of cloud and making it thinner (Lohmann and Feichter, 2005). Moreover, satellite retrieval artifacts can play a role; carbonaceous aerosols within or above clouds or sub pixel holes that show a dark surface beneath the clouds reduce the visible reflectance received by satellite; this phenomenon is indicated by retrieval of low COD (Kaufman and Nakajima, 1993). A physical–artificial feedback can be initiated, in which an aerosol begins to thin clouds via radiative processes, revealing more holes that introduce dark visible reflectance to the satellite measurements. The microphysical effect dominates at low AODs, whereas the physical and artificial effects that reduce COD with aerosol loading will dominate at high AOD. This phenomenon is possibly caused by environmental and radiative factors (soot absorption and heating rates) that cause some areas to display high aerosol loading and low COD (Tao *et al*., 2012).

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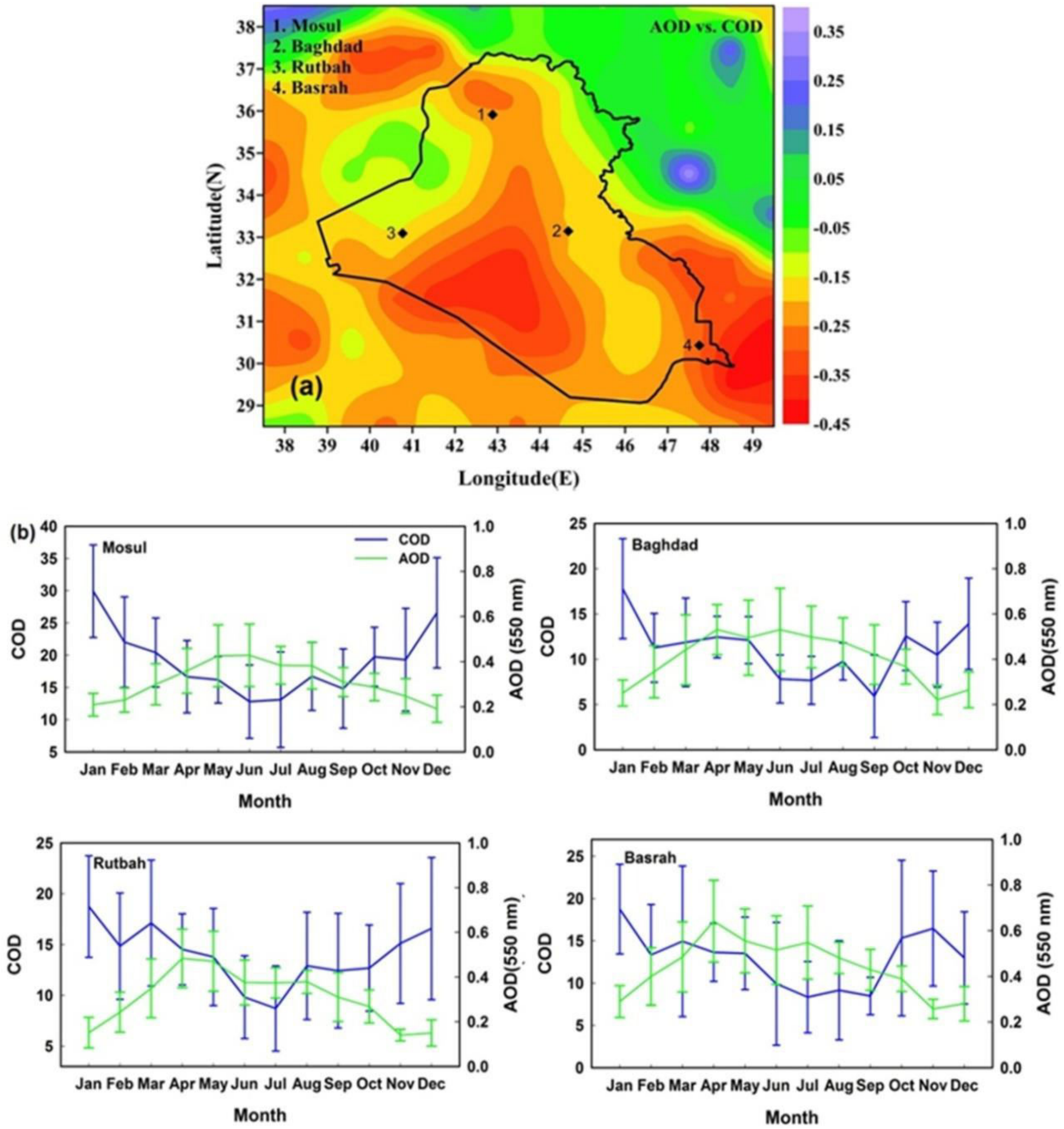

Figure-7. (a) Spatial correlation map and (b) time series plots of average AOD and COD values with standard deviation over the four locations in Iraq for the study period 2003-2015.

Relationship between AOD and CER

CER is the ratio of the third moment to the second moment of cloud droplet size distribution. It considers as a key parameter for estimating liquid water content of clouds Radiative characteristics (Kaufman *et al.*, 2005, Han *et al.*, 1994). In most cases, it's inversely proportional with AOD but some special cases positively correlated with AOD as found by Yuan et al (Yuan *et al.*, 2008). Figure-8a shows the spatial correlation between AOD and CER of entire Iraq for the study period 2003-2015. A maximum positive correlation not exceeding 0.45 to 0.32 between these two parameters was observed over the western to south passing through the southwestern regions along the Iraqi-Saudi border, whereas the north and middle regions show a weak negative correlation ranging from - 0.12 to - 0.15 . Figure-8b shows the monthly mean AOD and CER for each selected region. Over the urban regions, including Mosul, Baghdad, and Basrah, the AOD values peaked in late spring and summer. CER values corresponded to AOD behavior in all months of the year, except in June, July, August, and September, in which CER showed the lowest values.

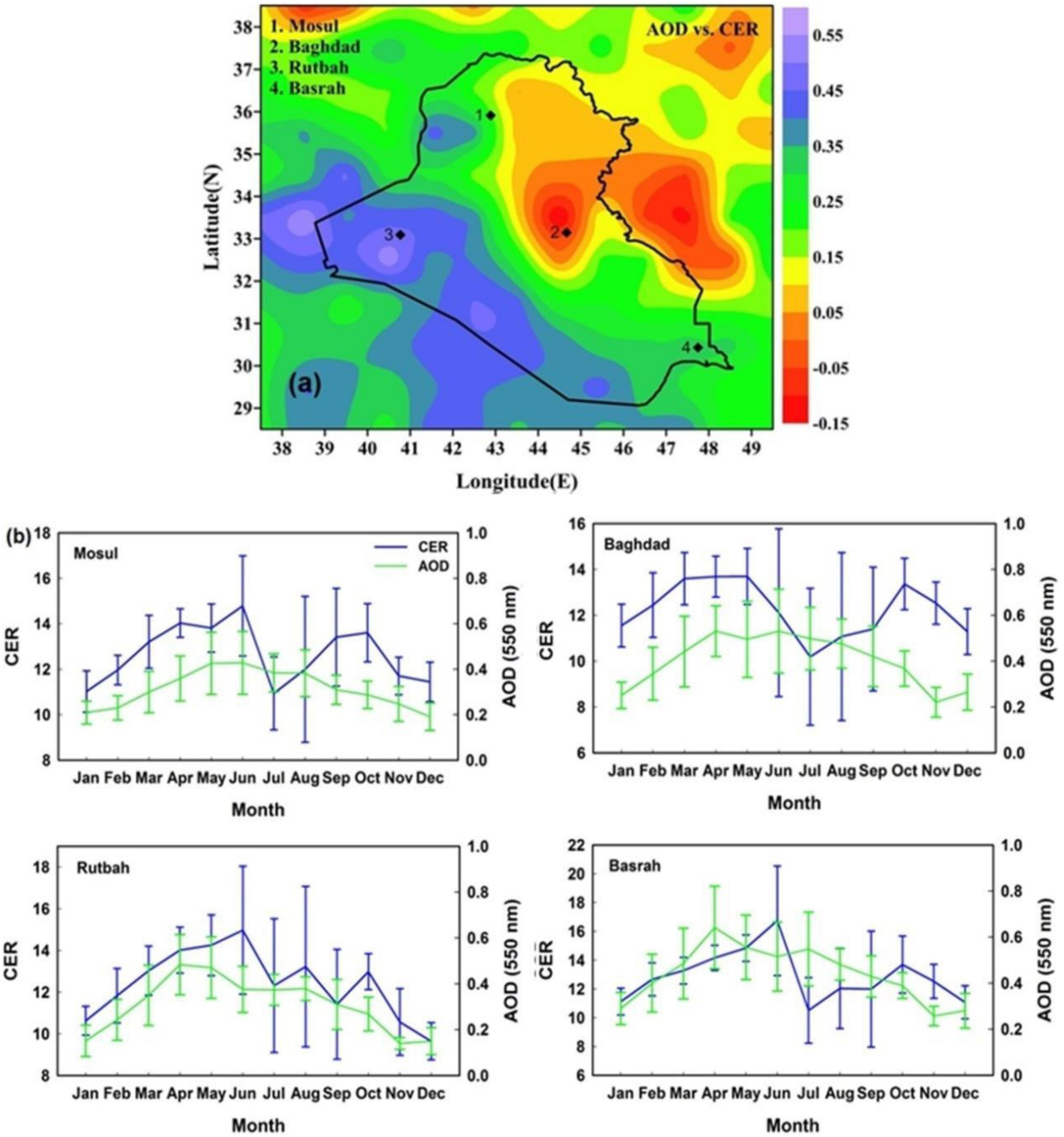

Figure-8. (a) Spatial correlation map and (b) time series plots of average AOD and CER values with standard deviation over the four locations in Iraq for the study period 2003-2015.

CONCLUSIONS

Aerosols characteristic over Iraq not studied well. In order to improve our understanding of aerosols spatiotemporal variations, so this is the first attempt to analyze and investigate aerosol feature over this region. AOD spatial and temporal variations were analyzed by employing of the MODIS-Terra satellite data, furthermore, the relation between aerosol and cloud parameters has been investigated to increase in our knowledge of aerosol-cloud interaction studies. In spite of the study did not include specifics of the aerosol types and their source regions, It can be concluded the following findings : The AOD is relatively high over Iraq with spatial average value reaches to 0.278, the maximum seasonal average AOD was (0.744), which was observed over northwest and southeast regions of Iraq in the spring. By contrast, the minimum AOD values of approximately (0.034) were observed over western and northeastern mountainous region of Iraq in the winter.

The AE and AOD correlate with a high negative correlation for all selected study regions. AOD and CF showed a negative correlation over urban, desert, and coastal regions of Iraq, except in areas with high terrain relative to the sea level. These areas include northeastern Iraq with mountain chains; in this region, the correlation was close to zero, especially when AOD values dropped below 0.25. AOD and WV showed a positive relationship in all regions of Iraq, but unevenly saluting be a correlation between positive limits (greater than 0.35) in the region, where northwest Mosul meets Baghdad, which is part of central Iraq; this region is located toward the north. By contrast, the remaining part of the country toward the south and southwestern region, which is dominated by semi-arid desert environment showed a correlation of less than 0.15. AOD and COD negatively correlated in all regions of Iraq, as a result of aerosol absorption of solar radiation, which causes partial cloud evaporation and making clouds to be thinner. AOD and CER are negatively correlated over Baghdad and northeastern regions and positively correlated for regions located along the stretch of Al-Qaim city towards Al-Nukhayb desert through the desert of Samawa, adjacent to the border toward Saudi Arabia down to Basrah City which may be attributed to the existence of slightly soluble organic particles and massive cloud condensation nuclei.

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REFERENCES

Adesina A. J., Kumar K. R. & Sivakumar V. 2016. Aerosol-Cloud-Precipitation Interactions over Major Cities in South Africa: Impact on Regional Environment and Climate Change. Aerosol and Air Quality Research. 16: 195-211.

Al-Dabbas M. A., Abbas M. A. & Al-Khafaji R. M. 2012. Dust storms loads analyses-Iraq. Arabian Journal of Geosciences. 5: 121-131.

Al-Hassen S. I., Sultan A. W. A., Ateek A. A., Al-Saad H. T., Mahdi S. & Alhello A. A. 2015. Spatial Analysis on the Concentrations of Air Pollutants in Basra Province (Southern Iraq). Open Journal of Air Pollution. 4: 139.

Al-Jumaily K. J. & Ibrahim M. K. 2013. Analysis of synoptic situation for dust storms in Iraq. Int J Energy Environ. 4: 851-858.

Alam K., Iqbal M. J., Blaschke T., Qureshi S. & Khan G. 2010. Monitoring spatio-temporal variations in aerosols and aerosol–cloud interactions over Pakistan using MODIS data. Advances in Space Research. 46: 1162-1176.

Alam K., Khan R., Blaschke T. & Mukhtiar A. 2014. Variability of aerosol optical depth and their impact on cloud properties in Pakistan. Journal of Atmospheric and Solar-Terrestrial Physics. 107: 104-112.

Alfaro S. C. 2008. Influence of soil texture on the binding energies of fine mineral dust particles potentially released by wind erosion. Geomorphology. 93: 157-167.

Aloysius M., Mohan M., Suresh Babu S., Parameswaran K. & Krishna Moorthy K. 2009. Validation of MODIS derived aerosol optical depth and an investigation on aerosol transport over the South East Arabian Sea during ARMEX-II. Annales Geophysicae. Copernicus GmbH. pp. 2285-2296.

Andreae M. & Rosenfeld D. 2008. Aerosol-cloud-precipitation interactions. Part 1. The nature and sources of cloud-active aerosols. Earth-Science Reviews. 89: 13-41.

Andreae M. O. 2009. Correlation between cloud condensation nuclei concentration and aerosol optical thickness in remote and polluted regions. Atmospheric Chemistry and Physics. 9: 543-556.

Andreae M. O., Rosenfeld D., Artaxo P., Costa A., Frank G., Longo K. & Silva-Dias M. 2004. Smoking rain clouds over the Amazon. Science. 303: 1337-1342.

Ångström A. 1964. The parameters of atmospheric turbidity. Tellus. 16: 64-75.

Cao H., Amiraslani F., Liu J. & Zhou N. 2015. Identification of dust storm source areas in West Asia using multiple environmental datasets. Science of the Total Environment. 502: 224-235.

Colbeck I. 2014. Aerosol Science: Technology and Applications, John Wiley & Sons.

Dey S., Tripathi S. N., Singh R. P. & Holben B. 2004. Influence of dust storms on the aerosol optical properties over the Indo-Gangetic basin. Journal of Geophysical Research: Atmospheres. p.109.

Feingold G., Remer L. A., Ramaprasad J. & Kaufman Y. J. 2001. Analysis of smoke impact on clouds in Brazilian biomass burning regions: An extension of Twomey's approach. Journal of Geophysical Research: Atmospheres. 106: 22907-22922.

Han Q., Rossow W. B. & Lacis A. A. 1994. Near-global survey of effective droplet radii in liquid water clouds using ISCCP data. Journal of Climate. 7: 465-497.

Hasanean H. 2004. Middle east meteorology. Avaliable online: http://www. eolss. net/(accessed on 7 August 2015).

Hsu N. C., Tsay S.-C., King M. D. & Herman J. R. 2004. Aerosol properties over bright-reflecting source regions. IEEE Transactions on Geoscience and Remote Sensing. 42: 557-569.

Ichoku C., Kaufman Y. J., Remer L. A. & Levy R. 2004. Global aerosol remote sensing from MODIS. Advances in Space Research. 34: 820-827.

Kaufman Y. J. & Koren I. 2006. Smoke and pollution aerosol effect on cloud cover. Science. 313: 655-658.

Kaufman Y. J., Koren I., Remer L. A., Rosenfeld D. & Rudich Y. 2005. The effect of smoke, dust, and pollution aerosol on shallow cloud development over the Atlantic Ocean. Proceedings of the National Academy of Sciences of the United States of America. 102: 11207-11212.

Kaufman Y. J. & Nakajima T. 1993. Effect of Amazon smoke on cloud microphysics and albedo-analysis from satellite imagery. Journal of Applied Meteorology. 32: 729-744.

King M. D., Kaufman Y. J., Menzel W. P. & Tanre D. 1992. Remote sensing of cloud, aerosol, and water vapor properties from the Moderate Resolution Imaging Spectrometer (MODIS). IEEE Transactions on Geoscience and Remote Sensing. 30: 2-27.

Lohmann U. & Feichter J. 2005. Global indirect aerosol effects: a review. Atmospheric Chemistry and Physics. 5: 715-737.

Mohammed S. K. 2016. Analyzing the synoptic patterns associated to dust events over west Asia during summer months - Case Studies. Ph.D, Al-Mustansiriyah University.

Muller T., Henzing J., De Leeuw G., Wiedensohler A., Alastuey A., Angelov H., Bizjak M., Coen M. C., Engström J. & Gruening C. 2011. Characterization and intercom parison of aerosol absorption photometers: result of two intercom parison workshops.

Myhre G., Stordal F., Johnsrud M., Kaufman Y., Rosenfeld D., Storelvmo T., Kristjansson J. E., Berntsen T. K., Myhre A. & Isaksen I. S. 2007. Aerosol-cloud interaction inferred from MODIS satellite data and global aerosol models. Atmospheric Chemistry and Physics. 7: 3081-3101.

Nakajima T. & King M. D. 1990. Determination of the optical thickness and effective particle radius of clouds from reflected solar radiation measurements. Part I: Theory. Journal of the atmospheric sciences. 47: 1878-1893.

Prasad A. K., Singh R. P. & Singh A. 2004. Variability of aerosol optical depth over Indian subcontinent using MODIS data. Journal of the Indian Society of Remote Sensing. 32: 313-316.

Rezazadeh M., Irannejad P. & Shao Y. 2013. Climatology of the Middle East dust events. Aeolian Research. 10: 103-109.

Rosenfeld D. 2000. Suppression of rain and snow by urban and industrial air pollution. Science. 287: 1793-1796.

Rosenfeld D., Lohmann U., Raga G. B., O'dowd C. D., Kulmala M., Fuzzi S., Reissell A. & Andreae M. O. 2008. Flood or drought: how do aerosols affect precipitation? Science. 321: 1309-1313.

Shi Z., Zhang D., Hayashi M., Ogata H., Ji H. & Fujiie W. 2008. Influences of sulfate and nitrate on the hygroscopic behaviour of coarse dust particles. Atmospheric Environment. 42: 822-827.

Tao W. K., Chen J. P., Li Z., Wang C. & Zhang C. 2012. Impact of aerosols on convective clouds and precipitation. Reviews of Geophysics. p. 50.

Ten Hoeve J., Remer L. & Jacobson M. 2010. Impacts of water vapor/aerosol loading trends and land cover on aerosol microphysical and radiative effects on clouds during the Amazon biomass burning season. Atmospheric Chemistry and Physics Discussions. 10: 24919-24960.

Twomey S. 1977. The influence of pollution on the shortwave albedo of clouds. Journal of the atmospheric sciences. 34: 1149-1152.

Yuan T., Li Z., Zhang R. & Fan J. 2008. Increase of cloud droplet size with aerosol optical depth: An observation and modeling study. Journal of Geophysical Research: Atmospheres. p. 113.