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The Impact of Aerosol Optical Depth Impacts on Rainfall in Two Different Monsoon Periods over Madurai, India

Gunaseelan Indira*, B. Vijay Bhaskar, Krishnaswamy Muthuchelian

Department of Bioenergy, School of Energy, Environment and Natural Resources, Madurai Kamaraj University, Madurai-625021, India

ABSTRACT

Aerosols influence the formation and the life cycle of clouds to a significant extent. A wide range of measurements shows that anthropogenic aerosols often alter clouds and their optical properties. The present investigation has revealed the impacts of aerosol optical depth on rainfall for two different monsoon periods (2008–2009), and also estimated trend of aerosol optical depth from 2001 to 2009 over Madurai, India, by using MODIS and TRMM datasets. Annual averages of aerosol optical depth for 2001–2009 varied from 0.23 ± 0.12 to 0.39 ± 0.19. AOD was high in monsoon season, and it was low during winter. Maximum rainfall was recorded during the post-monsoon season, and aerosol optical depth had a significant positive correlation (0.94) with rainfall; during 2008, and a negative one (–0.61) in 2009. The cloud parameters, such as COD and CER, were positively correlated with rainfall during the 2008 post-monsoon season, while they were negatively correlated during the 2009 post-monsoon season. The results of Mann Kendal trend analysis show that there was no significant trend in aerosol optical depth during the study period.

Keywords: Aerosol optical depth; MODIS; Rainfall; Cloud parameters.

INTRODUCTION

Global precipitation is a major component for global water and energy cycle that influence significantly the Earth's climate system (Javanmard *et al.*, 2010). Aerosols are known to impact the formation and the life cycle of clouds. A wide range of measurements shows that anthropogenic aerosol often alter clouds and their optical properties (Ackerman *et al.*, 2000; Rosenfeld, 2000; Ramanathan *et al.*, 2001; Andreae *et al.*, 2004; Kaufman *et al.*, 2005). Aerosols produced from different natural and man-made activities are mixed together and hence each aerosol particle is a composite of different chemical constituents, which determine the refractive index of aerosols (Ranjan *et al.*, 2007). In recent years, among Asian monsoon countries such as China and India, the aerosol problem is becoming increasingly acute, due to the increased loading of atmospheric pollutants associated with the rapid pace of industrialization and modernization especially in large cities and rural areas. Conversely, sustainable development in the Asian monsoon countries depends on the vagaries of the mighty monsoon, which supplies almost all the freshwater required for the region. Uneven distribution of monsoon rain associated with flash flood or prolonged drought has caused major loss of human lives and damages to crops and properties, with devastating societal impacts on Asian countries (Lau *et al.*, 2008). It has been estimated that aerosol may reduce up to 10% of the seasonal mean solar radiation reaching the Earth's surface at various regions of the globe, producing a global cooling effect that masks the global warming (Ramanathan *et al.*, 2001; Chung *et al.*, 2005). Contemporary research findings created more awareness about the potential effects of aerosol radiative forcing on the huge fluctuation in the Indian monsoon rainfall and circulation in recent years which has received more scientific attention since it has considerable impact on agriculture and water resources (Menon *et al.*, 2002; Ramanathan *et al.*, 2005; Lau *et al.*, 2006; Meehl *et al.*, 2008). Previous studies over Madurai showed that the aerosol level (PM_{10}, SPM) is increasing and the same trend will be expected to continue in future (Ramasubramanian *et al.*, 1988; Raja Mohan, 2000; Jeganathan, 2001; Kulandai Samy, 2003; Vijay Bhaskar, 2008). The present study is the new endeavour to this region by using satellite observations to analyze the role of aerosol on the variation in the rainfall during monsoon season for two different years in rapidly emerging mega city.

MATERIALS AND METHOD

Site Description

Madurai

* Corresponding author.
E-mail address: gunaindra17@gmail.com

Madurai (9°54'N, 78°84'E) one of the major cities in South India, which is 100 m above the sea level, popularly known as a city of temples has acquainted with historical, cultural and religious heritage of South India. This is the second largest and most densely populated city in the southern state of Tamil Nadu. It has a surface area of 52.8 km^2 with an estimated population of 3.2 million in 2011. The rapid urbanization, increased industrialization and improved trade and commerce have resulted in augmentation of mushrooming population, vehicular movement and industrial growth, which in total causing an eternal threat to the ambient air environment of the city. Madurai has typical climate of the Deccan plateau and remains hot and humid during most of the year with very bright sun shines during summer season manifested by the temperature ranging from 27°C to 40°C. Therefore, the climate is quite hot during the summer season. Winter starts from December and lasts till February with the temperatures ranging between 20°C and 30°C. The climate remains pleasant during this time, as the temperature rarely falls below 20°C. Rainfall is very frequent in the city and it receives the major share of rainfall between the months of July and October.

Satellite Data

MODerate Resolution Imaging Spectroradiometer (MODIS)

In the present study the data pertaining to the variability of aerosol optical depth (AOD) over Madurai was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument aboard with the Terra and Aqua satellites. The MODIS aerosol retrieval is more accurate wherein albedo is low over land and dark vegetation (Kaufman *et al.*, 1997). The daily mean of aerosol optical depths (AOD), Cloud optical depth (COD) and cloud effective radius (CER) were derived from the MODIS with level 3 and the collection version of 5.1. The grid size was 1° × 1° at 550 nm. These data were further pre-processed in to 0.25° × 0.25° grid resolution. AODs which are above 0 and less than 1.0 are only considered. This limit is imposed on the assumption that AOD value greater than 1.0 would have resulted most likely due to cloud contamination (Chung *et al.*, 2005).

Tropospheric Rainfall Measuring Mission (TRMM)

The Tropical Rainfall Measuring Mission (TRMM) is a joint US-Japan program to measure tropical and subtropical rainfall using Precipitation Radar (PR), TRMM Microwave Imager (TMI), and the Visible and Infrared Scanner (VIRS) instruments (Javanmard *et al.*, 2010). TRMM was launched in 1997 into a unique orbit that maximizes observations of the tropical regions in a ± 40° latitude band (Kummerow *et al.*, 2000). Both a passive microwave sensor (TMI) and an active microwave radar (PR) are located onboard the satellite. Daily TRMM 3B42 version 6 precipitation data has been used in the present study and the output comprises 0.25° × 0.25° grid with spatial extent covering a global belt (−180°W to 180°E) extending from 50°S to 50°N latitude.

NCEP/NCAR Meteorological Data

The daily meteorological data such as temperature, wind speed, outgoing long wave radiation (OLR) and humidity have been retrieved from National Centre for Environmental Prediction (NCEP) Reanalysis data. The NCEP reanalysis provides long time series of gridded atmospheric and surface fields. The most reliable fields such as pressure heights, tropospheric temperature and specific humidity are obtained by atmospheric forecasts with observations. NCEP fields are available from 1948, but since 1979, corresponding to the advent of new generation satellite data streams, the fields are of higher quality (Rawlins *et al.*, 2009).

RESULTS AND DISCUSSION

Aerosol Optical Depth

Annual aerosol optical depth descriptive statistics has been given in the Table 1. Annual mean values of Aerosol optical depth were obtained by taking the daily mean values of AOD from 2001 to 2009. Annual averages of aerosol optical depth were varied from 0.23 ± 0.12 to 0.39 ± 0.19 and the highest value was recorded during 2009 and lowest average was recorded in the 2001 and 2005. Fig. 1 shows the daily variation of aerosol optical depth over Madurai and it was noticed that it was continuously varying over the whole study period since aerosol optical depth is directly proportional to aerosol loading in the atmosphere (Ramachandran and Cherian, 2008). It has been observed that high burden of aerosol mass in polluted regions may resulted in higher AOD (Kaufman *et al.*, 2002). Recent decades witnessed that the rapid population growth in Madurai which is one of the major cities in Tamil Nadu with large number of natural as well as anthropogenic sources for aerosol. Usually small-scale industries, transportation and an elevated rate of combustion of non-renewable fuels for domestic and commercial purposes in the city are found to be the major sources of aerosol in the present investigation. From the diesel exhaust engines NO_x, HC and CO are emitted in to the atmosphere because of the incomplete combustion of fossil fuel. Many small scale and some large scale industries using the diesel exhaust engines for power generation. Besides automobiles, the operation of diesel-powered generators (which are still used in commercial establishments during incessant power failures during summer), emissions from paved roads, and background concentrations from industrial and semi-industrial areas of the city are also contributing particulate load towards the atmosphere. Cooking in houses, schools and commercial establishments, and refuse incineration in houses, public places and municipal incineration in open grounds may also contribute additional load to the overall pollutant load as well as the atmospheric particulate matter concentrations in every Indian city (Salve *et al.*, 2006) and also the sand along the road sides which seems to be dusty in nature and never removed periodically all over the city. Hence, all these factors cumulatively contribute the continuous aerosol loading in the urban atmosphere of the city. Mann Kendal trend analysis was carried out to identify the trend pattern of AOD over Madurai city. Mann Kendal trend analysis is a non-parametric test used to determine the values of a

Table 1. Annual statistics of aerosol optical depth 2001–2009 in Madurai.

Year	Aerosol Optical Depth				
	Min	Max	Mean	SD	CV
2001	0.03	0.84	0.23	0.12	53.38
2002	0.03	0.94	0.27	0.17	62.99
2003	0.04	0.93	0.29	0.16	56.40
2004	0.03	0.86	0.28	0.16	54.77
2005	0.01	0.69	0.23	0.13	58.30
2006	0.02	0.80	0.26	0.16	60.51
2007	0.03	0.97	0.29	0.17	59.91
2008	0.05	0.90	0.31	0.19	61.85
2009	0.02	0.93	0.39	0.19	48.71

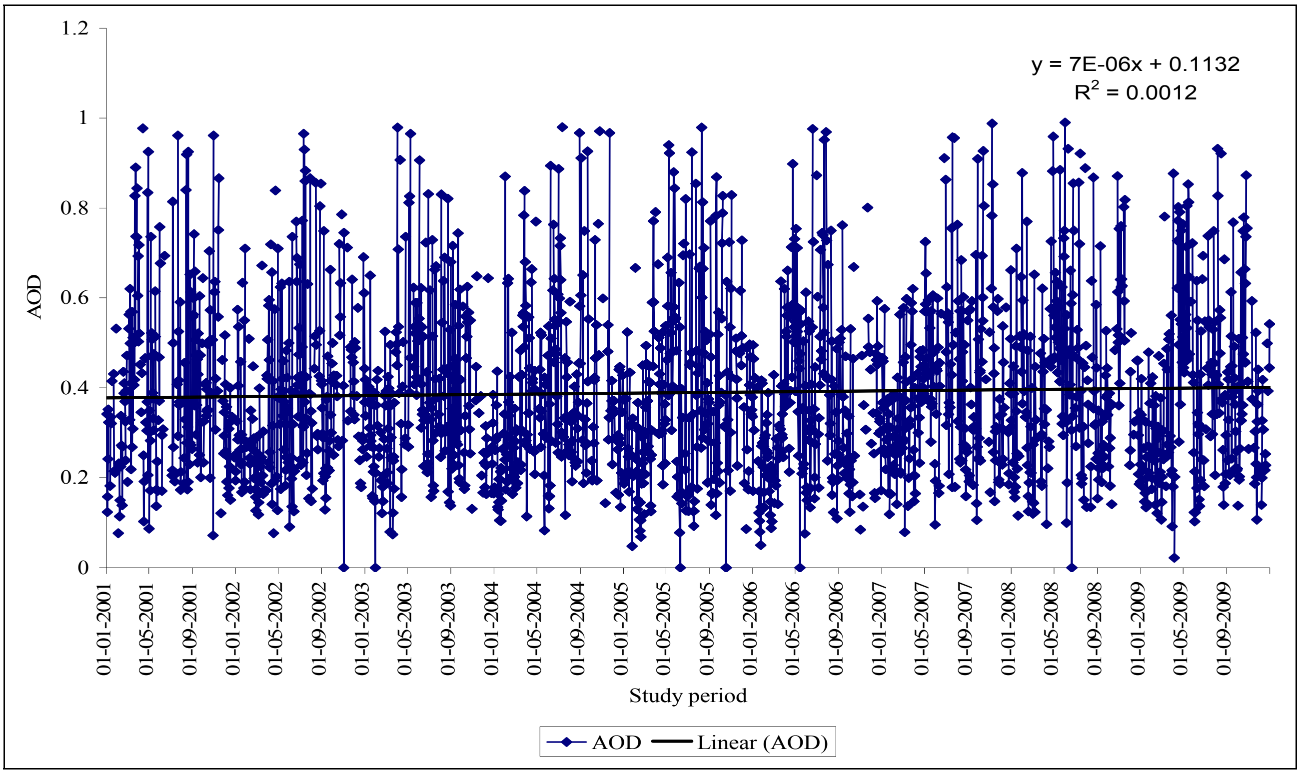

Fig. 1. Daily time series of AOD over Madurai city 2001–2009.

random variable generally increase or decrease over some period of time in statistical terms (Helsel and Hirsch, 1992). Kendal tau value, S value, P value and alpha values were calculated and they are 0.42, 12.00, 0.17 and 0.05 respectively.

Daily data were classified into seasonal data following the Indian Meteorological Department (IMD) classification. Table 2 shows that the seasonal variations of AOD over Madurai. Aerosol optical depth was maximum throughout the monsoon because the numbers of data points were very few, because of the prevalence of overcast conditions (cloudy in nature) during most of the days. In addition, the increase in AODs can occur because of hygroscopic growth of water soluble aerosols and transport of larger sized aerosols (dust and sea salt) during favourable wind conditions (Ramachandran and Cherian, 2008). However, winter season shows much low levels of aerosol optical depth as a result of monsoon rainfall and the post monsoon rainfall washes out most of the aerosol particles in the atmosphere. Atmospheric aerosols could be trapped by poor ventilation during the fall and winter, considering the relatively stable atmospheric conditions (Kim *et al.*, 2011). Moreover winter season manifested reversal of spatial gradient of aerosol loading and during this period spatial gradient of aerosol shows comparatively much low levels over entire Indian peninsula.

During winter the boundary layer is shallow and holds the pollutants in a smaller volume when compared to the hot summer as a result of confinement of aerosols. An increasing trend of aerosol optical depth was observed during summer season rather than at winter. This is due to the two reasons such as an increase in wind speed and boundary layer height. During pre-monsoon season large quantities of soil derived dust aerosol to get lifted in to the

Table 2. Seasonal variations of aerosol optical depth in Madurai.

Year	Aerosol Optical Depth (2001–2009)							
	Winter		Summer		Monsoon		Post Monsoon	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2001	0.21	0.04	0.23	0.04	0.41	0.33	0.20	0.04
2002	0.26	0.03	0.33	0.04	0.52	0.19	0.21	0.03
2003	0.24	0.04	0.31	0.05	0.49	0.07	0.26	0.04
2004	0.19	0.02	0.32	0.13	0.49	0.12	0.28	0.06
2005	0.20	0.04	0.22	0.04	0.28	0.20	0.22	0.03
2006	0.19	0.01	0.27	0.03	0.37	0.30	0.24	0.05
2007	0.26	0.01	0.26	0.04	0.66	0.28	0.26	0.03
2008	0.25	0.03	0.35	0.05	0.51	0.26	0.28	0.01
2009	026	0.09	0.47	0.21	0.39	0.19	0.39	0.18

atmosphere from the dry lands of semiarid region. Boundary layer height or the mixed layer thickness showed an increasing trend starting from winter to pre-monsoon season. This will provide adequate opportunity to all kinds of natural and anthropogenic aerosols to get accommodated into it (Ganguly *et al.*, 2006). During summer and monsoon seasons, the air mass brings dry dust particles from the surrounding areas, conversely during post monsoon and in winter months the winds are from the north while the northwest brings finer and continental aerosols. Winter season shows much low levels of AOD as a result of monsoon rainfall and post monsoon rainfall washes out most of the aerosol particle in the atmosphere (Dey *et al.*, 2004). The low value of AOD in winter is caused by the low surface temperature which results in the weak production of soil derived mineral dust from the surface. The slight reduction in alpha during rainy season is a result of the fine mode particles which are non-hygroscopic in nature.

Rainfall

Goswami *et al.* (2006) classified the rainfall events between 5 and 100 mm/day as moderate rainfall events. Rainfall events ranging from 100–150 mm/day as heavy rain events and rainfall events equal or greater than 150 mm/day are considered as very heavy rainfall measures. Rainfall shows considerable variations, the daily rainfall were ranged from 0.01 to 151.74 mm/day and the same aerosol optical depth trend was observed in the case of monthly rainfall values manifested by a continuous variation throughout the year. During the study period only four times the daily rainfall has crossed the level of 100 mm/day and it was observed thrice during the post monsoon period and once in summer season. Fig. 2 shows the TRMM monthly cumulative rainfall variations over Madurai for the period of 2001–2009. Monthly rainfall was recorded as maximum during October and November and it was found to be minimum in February. The southwest monsoon (SWM) generally delivers major component of annual rainfall in India, but in this study area, post monsoon season contributes more annual rainfall. During this post monsoon season about 50–60% of rainfall was received by the state of Tamilnadu. Rainfall seasonal variations were low during winter months of January and February. Conversely, an increasing trend in the rainfall was observed from March to June subsequently it showed a decreasing trend during July and August. The rainfall was found utmost during the months of September to November in a constant increasing manner. Annual cumulative rainfall was ranged between 856.95 mm to 1443.96 mm. The highest cumulative rainfall was noticed during the year 2008 and the lowest cumulative rainfall was recorded in 2009. As far as the trend is concerned Mann Kendal trend analysis was carried out and it was noted that the computed P value is greater than the significant level of alpha and no trend was observed. Kendal tau = 0.07, S = 2.00, P = 0.90 and alpha = 0.05 and it was noticed that the observed P value is greater than the alpha value and hence no trend in annual rainfall data was observed. The annual percentage of increase and decrease in values for the years (2001–2009) are 3.8%, 1.9%, 42.9%, –6.9%, –36.1%, 49.6%, 12.6% and 34.1% respectively and it was ranged from –36.1 to 49.6%. Frequency distribution analysis has been carried to understand the normality of rainfall data. It was observed that the skewness varied from 3.65 to 6.83 and kurtosis also varied from 15.94 to 62.20. Rainfall data is not normally distributed since the skewness and kurtosis values are varied from their normal distribution values of skewness of 0.03 and the kurtosis value of 3.0.

Aerosol and Rainfall Interaction in 2008–2009

For aerosol and rainfall interaction study, solitary active monsoon year (2008) and another drought year (2009) were selected as per Climate Profile of India for 2010. This study was mainly focused on two successive monsoon seasons (monsoon and post monsoon) of the year 2008 and 2009. Because India receives its major rainfall in the monsoon season and Tamil nadu receives its major rainfall during the post monsoon period especially in the October and November months. Fig. 3 shows the monthly variations of aerosol index for 2008 and 2009. It was observed that the minimum monthly aerosol index was in November and maximum was in May for the year 2008. As far as 2009, maximum was found in May and minimum was found in January. The lowest seasonal averages of aerosol index for the year 2008 and 2009 were observed during the post monsoon and winter season respectively. On the other hand, the highest seasonal average of AI was noticed during the summer seasons of both the years 2008 and 2009. The

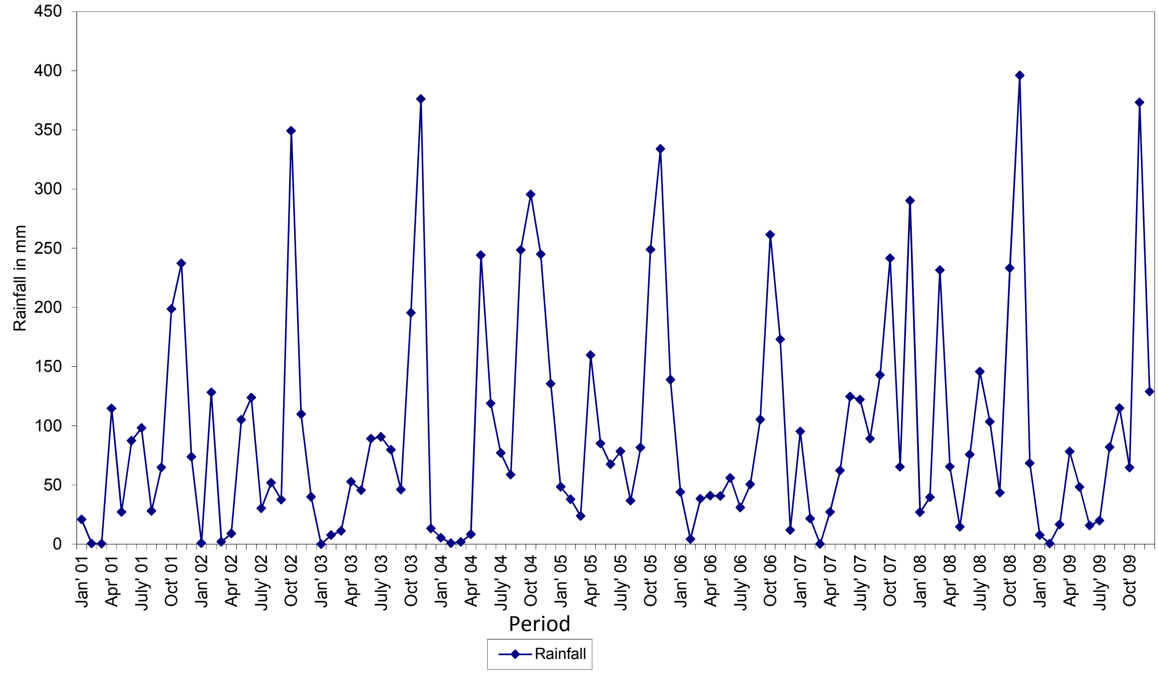

Fig. 2. Monthly rainfall variation over Madurai city 2001–2009.

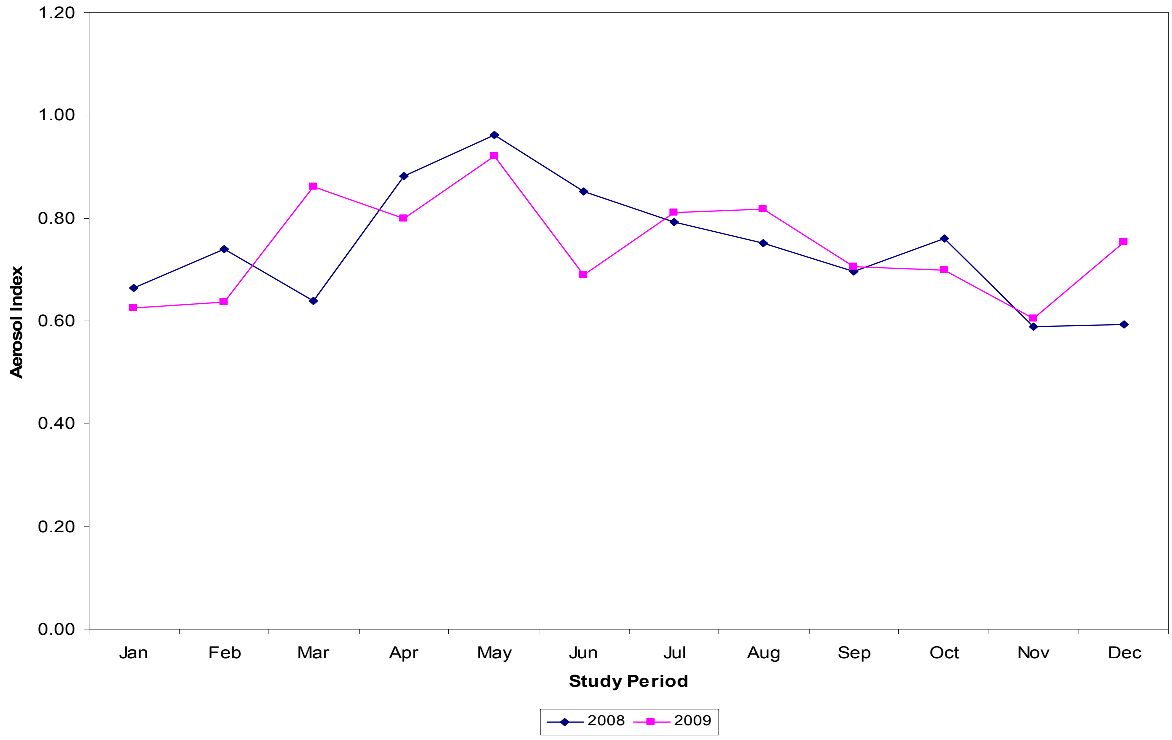

Fig. 3. Monthly Variations of Aerosol Index over Madurai 2008–2009.

present study revealed that the variations in aerosol index values are found to be more during the drought year and less in the active monsoon year. Fig. 4(a) shows the monthly variations of cloud effective radius for the years 2008 and 2009. The cloud effective radius (CER) is weighed mean values of the size distribution of cloud droplets in the atmosphere. CER values are found to be maximum in March and minimum was in July for the year 2008. For 2009 the maximum was found in November and minimum was in February respectively. The seasonal variation of CER values indicates maximum variations during post-monsoon season and minimum during the winter season in both the years 2008 and 2009. The reduction of cloud effective radius during monsoon season could be due to the effect of aerosols on microphysical properties of cloud (Bhawar and Devara, 2010). The changes in cloud properties as a result of variations in atmospheric circulation would affect the aerosol concentrations. In addition, aerosols originated from burning of biomass inhibited the cloud droplet growth thereby caused an increase in the droplet residence time, which ultimately resulted in the low probability of warm rain since the cloud droplets attained higher altitude. These results make clear the cloud microphysical impacts of continental aerosols on the ISMS through the transverse monsoon circulation (Patra *et al.*, 2005). It is clearly inferred from the study that Madurai is receiving its maximum rainfall during the post monsoon season and it may be attributed to the increased size of cloud effective radius which brought more rainfall during this season. Bhawar and Devara (2010) studied in Pune, and they observed that as the increase in CER which increases the COD and this could results in more rainfall and vice-versa. Fig. 4(b) shows the monthly variations of COD for 2008 and 2009. Maximum and minimum values of COD for 2008 were observed during April and May. Meant for 2009 maximum was in March and minimum was in May respectively. Seasonal variations of COD found much during the post monsoon season and minimum was observed during monsoon season. In the present investigation COD and CER have optimistic relationship with each other 2008 and adverse relation for 2009. Local meteorological parameters are playing a major role in the aerosol and rainfall variations. The temperature in the city has been varied continuously. Monthly mean temperature values in 2008 are varied as of 24.6°C to 32.1°C. Maximum mean temperature was observed during May and slightest was recorded around January. Variations in mean temperature during 2009 were ranged from 25.1°C to 32.3°C and towering was observed in June and minimum was in January. AOD over Madurai is changing in consonance with temperature which obviously shows a rise in temperature which caused lifting of aerosols that effects the size distribution and resulted in higher quantity of AOD. Normally, increase in surface temperature causes lifting of aerosols that effects size distribution and results in higher AOD. The surface temperature is high during 2009 compared to 2008, and AOD also shows a continuous increase in 2009 than in 2008. The monthly mean values of wind speed over the study area diverse from 2.2 m/s to 5.8 m/s and from 2.6 to 7.2 m/s during 2008 and 2009 respectively. An exponential increase in daily averaged AOD with wind speed which could cause spurious backscatter and influence the retrieved aerosol loading (Moorthy and Satheesh, 2000).

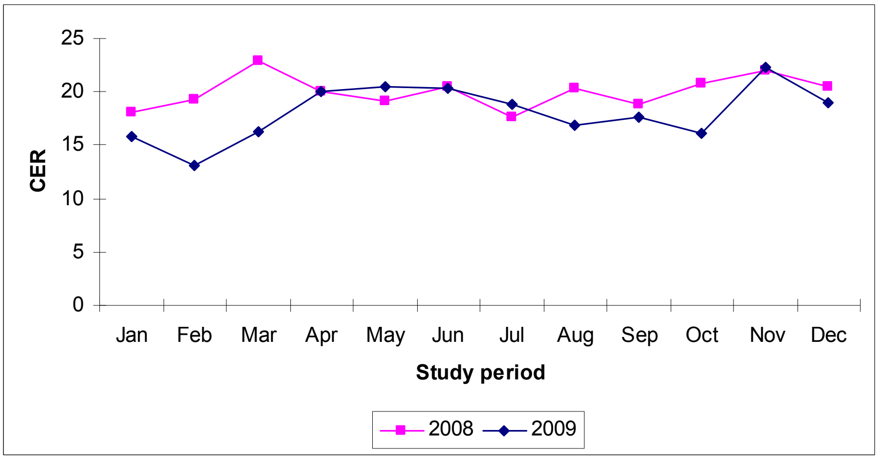

Fig. 4(a). Monthly cloud effective radius variations over Madurai 2008–2009.

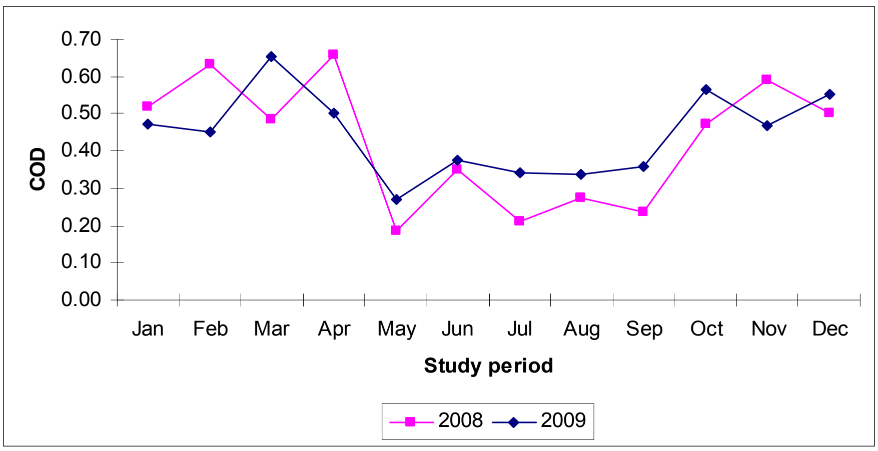

Fig. 4(b). Monthly variations of cloud optical depth over Madurai 2008–2009.

In 2008 during monsoon (JJAS) the link between AOD and other factors such as COD, CER, temperature, aerosol index, rainfall and wind speed were studied by using correlation analysis which shows a positive relation except OLR. Hence values are positively associated with each other the rise in these parametric values will induce aerosol optical depth. The outgoing long wave radiation shows negative link. Hence significant collision-coalescence process takes place in clouds to form rain which result in positive rainfall anomaly and consequently negative OLR anomaly (Rahul *et al.*, 2008). In the post monsoon (OND) temperature and aerosol index shows a negative correlation but the COD, CER, rainfall, OLR and wind speed shows a significant positive relation. The aerosol index values are in positive which indicates the presence of absorbing aerosols such as mineral dust and smoke in the atmosphere (Bhawar and Devara, 2010). The absorbing aerosols caused the vertical and horizontal temperature variations in the summer, which in turn alter the seasonal rainfall (Bhawar and Devara, 2010). The reduction in the solar radiation at the surface will reduce the surface temperature, which will in turn further reduce the OLR. The outgoing long wave radiation (OLR) is a strong function of the atmospheric temperature and humidity (Haywood *et al.*, 2005). The mean parametric values of post monsoon are greater than the monsoon for the study area which implies that the study area receives major rainfall in the post monsoon (OND). CER for the both seasons are positively associated, larger the CER, more the size of cloud droplet and more chances for rain occurrence. As suggested by Storelvmo *et al.*, in 2006 the COD is directly correlated with rainfall, hence in monsoon and in the post monsoon COD and rainfall are directly correlated with positive relation and so in this period maximum rainfall occurred. In the present study for both the seasons, it is found that whenever the surface wind speed is high the AOD value is high and vice-versa. The influence of wind speed on aerosol optical depth in the whole atmospheric column is complex (Platt and Patterson, 1986; Villevalde *et al.*, 1994; Smirnov *et al.*, 1995; Moorthy *et al.*, 1997; Kusmierczyk-Michulec *et al.*, 1999). The correlation between wind speed and aerosols also depends on the size of aerosols. Different wind speed affects different size of particles (Smirnov *et al.*, 2003). The association between AOD and surface wind speed is complicated, because it may either remove aerosols from or may bring in fresh aerosols to the experimental site.

In the drought year of 2009, during monsoon (JJAS) the association between AOD and other parameters such as COD, CER, OLR, temperature and wind speed were negatively correlated except rainfall and aerosol index. The variation in AI is significantly large in the year 2009 (drought) as compared to that in 2008 (active monsoon). Fig. 5(a) shows the monthly AOD and aerosol index variations over Madurai for 2008 and 2009. It was observed that during post monsoon of 2008, AOD reached maximum peak and aerosol index found to be minimum. Considering post monsoon of 2009, AOD was in minimum and aerosol index was in maximum. The higher value of surface temperature in the pre-monsoon supports the presence of absorbing dust aerosols from the AI values. Large number of absorbing dust aerosols, heat the lower troposphere but cool surface and they compete for small amount of water vapour resulting in less amount of rain (Ramanathan *et al.*, 2001). During post monsoon rainfall, CER and wind speed were negatively related with aerosol optical depth. COD, temperature, OLR and aerosol index were correlated positively. Hence due to the negative relation of rainfall in the post monsoon of drought year produce less rainfall. Fig. 5(b) represents the monthly AOD and rainfall variations over Madurai for 2008 and 2009. During 2008, in post monsoon the AOD was increases with the increase of rainfall but for other seasons in 2008 show an opposite result i.e., increase in AOD with decrease in rainfall and vice-versa. But for 2009, post monsoon shows an increase in rainfall with decrease in AOD. For other season AOD increase with rainfall. CER in 2009 during the monsoon and post monsoon is less as compared to 2008 which suggests that the cloud formation was less in 2009 oppose with 2008. Negative correlation was found for the both seasons, less CER leads to cloud dissipation and hence less rain. Clouds formed but dissipated in shorter period. For both the seasons, it is found that the surface wind speed and AOD shows up and down variations. Thus higher surface wind speed values are associated with removal of aerosols and lower surface wind speed with addition of aerosols in both the years (Rahul *et al.*, 2008). OLR indirectly associated with rain i.e., when the OLR shows a positive relation then the rainfall shows a negative relation and vice versa for the drought year. The negative AOD anomalies during the drought year clearly indicate the scarcity of larger particles (like sea salt etc.) which are basically hydrophilic, and lack of such bigger particles for significant collision-coalescence process to take place in clouds to form rain (and also to help cause convection over the Ocean) results in the observed negative rainfall anomaly and consequently positive OLR anomaly. The COD and rainfall are indirectly correlated with AOD, during monsoon COD shows negative correlation with AOD and the rainfall shows a positive relation with AOD meanwhile in the post monsoon COD shows positive correlation but the rainfall shows negative correlation. Fig. 5(c) shows the monthly AOD and COD variations over Madurai for 2008 and 2009. AOD increases with increase of COD for winter, summer and post monsoon of 2008 whereas for monsoon AOD decreasing with rise and fall of COD. During 2009 at the monsoon starting stage AOD rises and at the end of monsoon it falls down. Fig. 5(d) shows monthly AOD and CER variations over Madurai for 2008 and 2009. Post monsoon of 2008 displays an increase of AOD with an increase of CER meanwhile for other seasons AOD increases with decrease of CER. Monsoon of 2009 shows a decrease of AOD with decrease of CER and an increase of AOD with increase of CER for other seasons. Hence less amount of rainfall was received in 2009 when compared with the year 2008.The relationship between aerosol optical depth and surface wind speed is often found to be complicated since; it may either remove aerosols from or may bring in fresh aerosols to the experimental site. The correlation between aerosol concentration and surface wind speed is relatively high in lower altitudes, which implies that the effect of surface wind speed on aerosol concentration is more significant at lower altitudes (Parameshwaran *et al.*, 1995). The post-monsoon season revealed an increasing trend of aerosol loading associated with modest wind speed shows that active in flow of aerosols from the neighbouring areas.

CONCLUSION

Understanding the relationship between aerosol parameters and rainfall through cloud parameters is the major focus of this study. Aerosols inevitably play an imperative role in the cloud formations as well as rainfall over a particular place and particular season. The present study has been concentrated on the trends of aerosol optical depth and rainfall over the years 2001 to 2009 and assessed the impacts of aerosol optical depth on rainfall on two successive monsoon and post monsoon seasons for the years 2008 and2009. This study explicitly revealed that aerosol optical depth shows an increase in very small scale and this may be due to the increase in the anthropogenic sources of aerosol

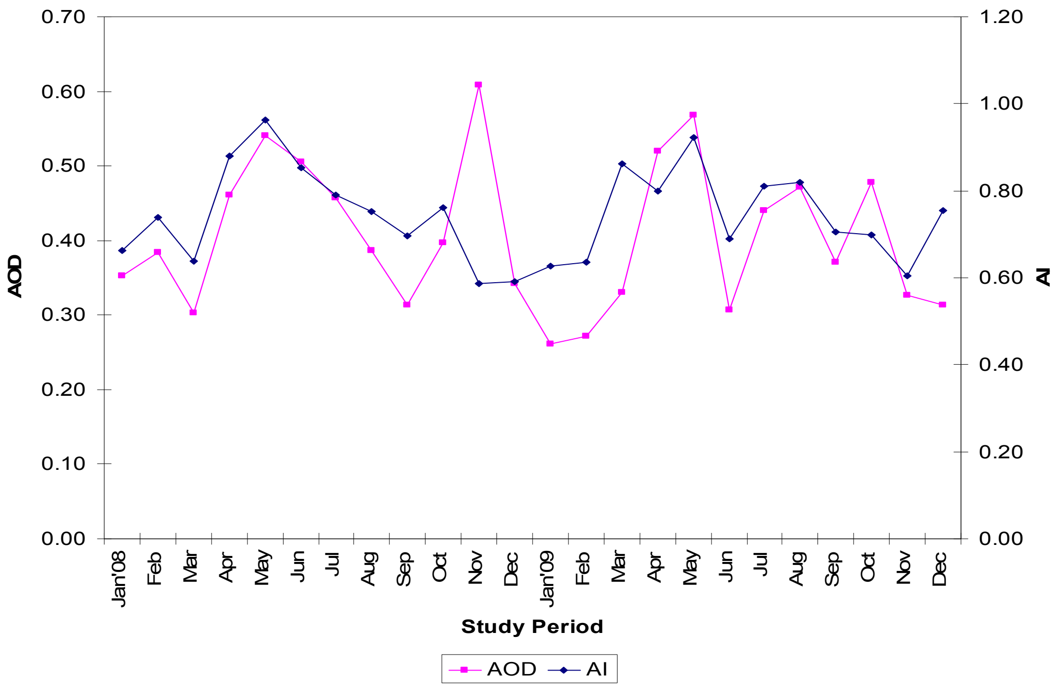

Fig. 5(a). Monthly AOD and AI variations over Madurai 2008–2009.

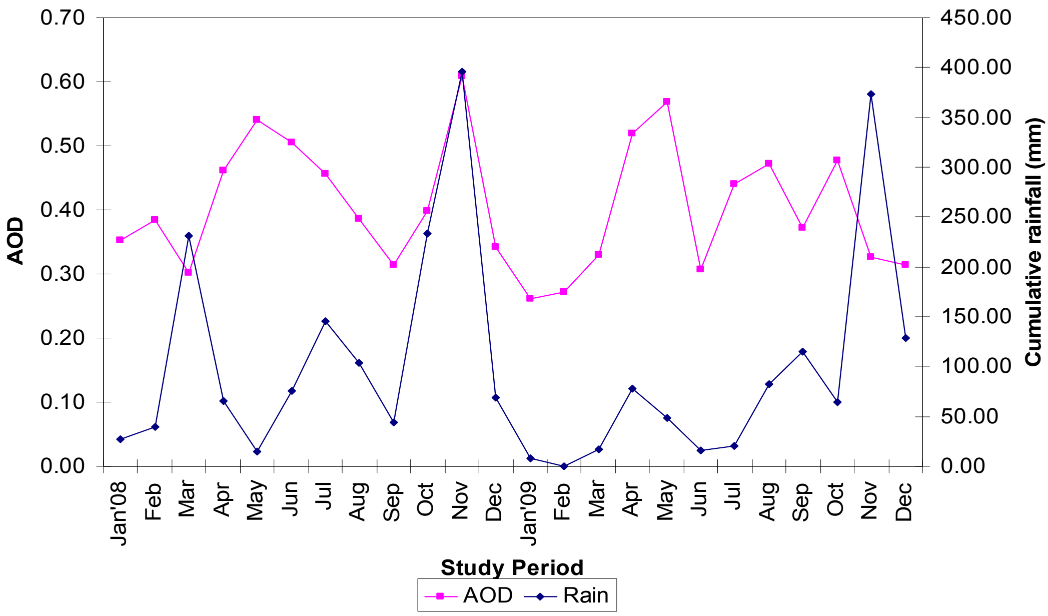

Fig. 5(b). Monthly AOD and rainfall variations over Madurai 2008–2009.

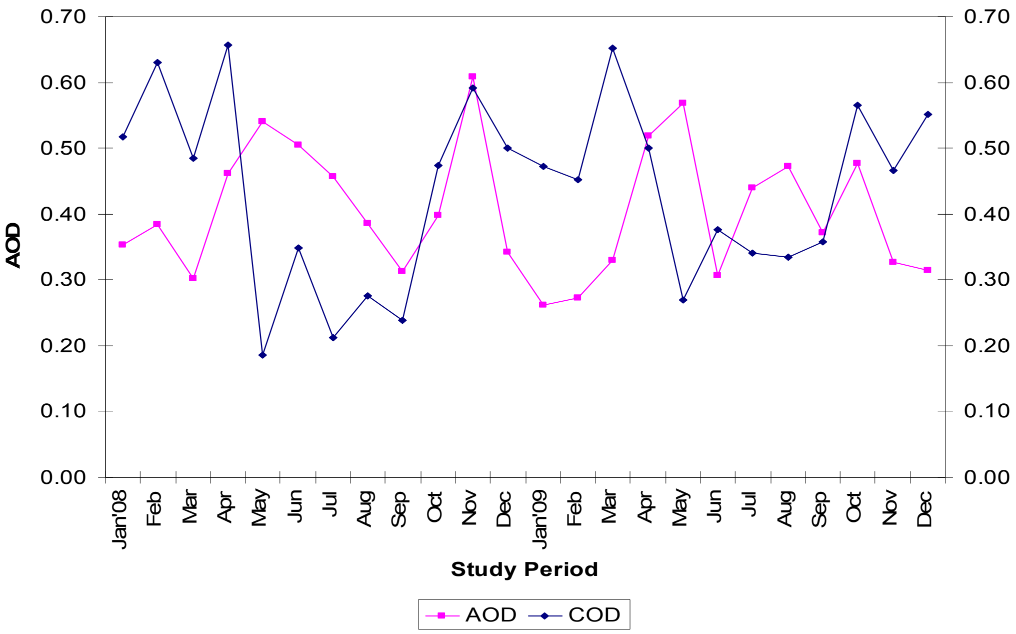

Fig. 5(c). Monthly AOD and COD variations over Madurai 2008–2009.

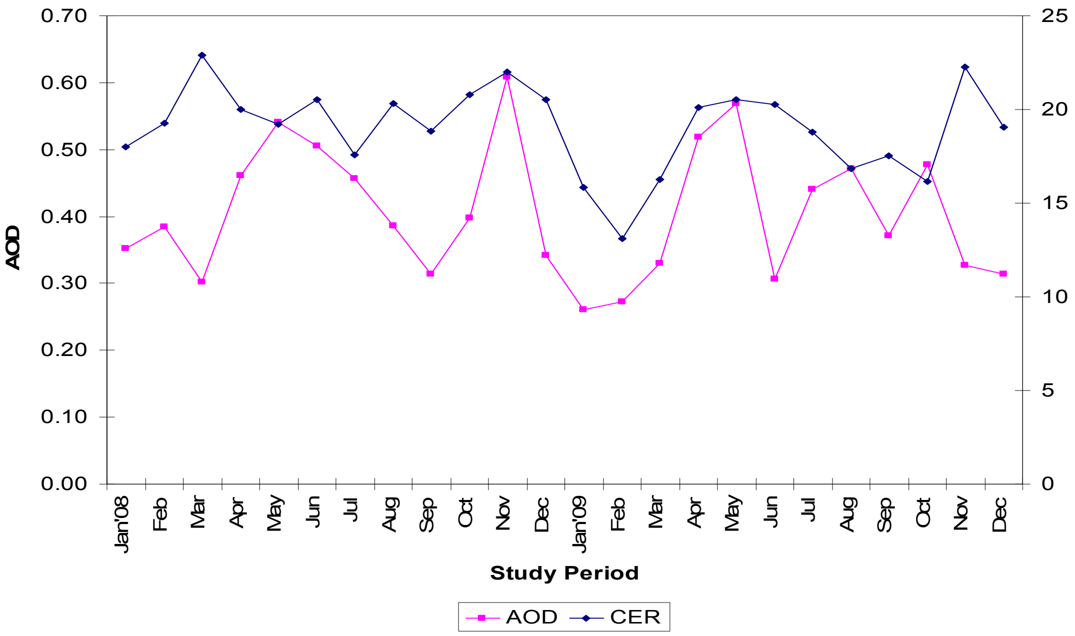

Fig. 5(d). Monthly AOD and CER variations over Madurai 2008–2009.

in and around the study area. Monsoon and post monsoon seasons of 2008 have more rainfall than the year 2009 because of aerosol optical depth has positive relationship with cloud optical depth, cloud effective radius, aerosol index, temperature and wind speed. As far as variations concerned, the aerosol index were more during the drought year and less in the active monsoon year. In case of cloud effective radius, it is directly related with rainfall and the study observed that during the post monsoon seasons, only cloud effective radius was found as upper limit. In addition, cloud optical depth also has direct association with cloud effective radius and rainfall in the study periods.

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