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Monitoring the spatio-temporal variations of aerosols over Bangladesh

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Abstract:*Nowadays climate change is the burning issue and atmospheric aerosols are vital parameter of the global climate system. So, atmospheric aerosols are one of the hot topics for present scientific research. There is lack of study dealing with monitoring of aerosol patterns over Bangladesh. In this study, an assessment of the spatial and temporal variations in aerosol load over Bangladesh are examined using MODerate resolution Imaging Spectroradiometer (MODIS) Level 3 remote sensing data during the years of 2002-2011. The results show that AOD is increasing across Bangladesh and reveal a higher AOD values in western part but a much cleaner environment in eastern part of the country. The high aerosol loading area is found to be increasing from west to east since 2002. An assessment of monthly mean variations in AOD is reported the maximum AOD values in June and the minimum AOD values in October. On analyzing the regional AOD patterns in seven different divisions of Bangladesh it is found that Dhaka and Sylhet divisions are showing decreasing AODtrends where all others showing increasing trends during 2002-2011. Annual mean AOD is highest in Rajshahi division while lowest in Sylhet division. These findings about aerosol patterns over Bangladesh will prove useful for future aerosol studies in Bangladesh.*
Keywords: *Aerosol, AOD, MODIS, Bangladesh, Regional*

I. Introduction

Atmospheric aerosols play a crucial role to determine the conditions of lower atmosphere and earth's surface. Aerosols are tiny particles suspended in air. The particles may be solid or liquid or both with typical diameter range between few nanometers to few micrometers. Aerosols have various compositions, sizes, shapes and optical properties. Particles at the higher ends interact directly with sunlight known as direct effect. Lower ends particles interact with clouds called indirect effect of aerosols. The amount of aerosols in the atmosphere is measured by mass concentration or optical properties of aerosols. Aerosol optical depth (AOD) the vertical integral of incident solar radiation through the entire height of the atmosphere as scattered or absorbed by air masses is a popular way to study about aerosols. Cloud processing and wet deposition are the ways of aerosol removal from atmosphere. Aerosols also remove from atmosphere by dry deposition and coagulation processes. Aerosols have relatively shorter lifetime than many other atmospheric gases and they travel long distances regularly. As a result the properties of aerosols vary substantially with spatial and temporal distributions due to their non-uniform distribution, short lifetime in atmosphere and removal processes. Spatio-temporal variations of aerosols can modify the shape, size and radiative properties of clouds. Increase in aerosols concentrations may increase the cloud condensation nuclei as increase cloud droplets. Aerosol radidiative forcing may positive or negative depending upon the aerosol types and loading. The total radiative forcing of aerosol as the sum of direct and indirect radiative forcing by anthropogenic aerosols at the top of the atmosphere is negative. Monitoring of aerosol distributions on a global scale with the large spatial and temporal heterogeneities has only way of satellite remote sensing. During last two decades aerosols are monitoring from space and the coming decades is planned to observed with enhance capabilities [8]. On this scenario the impacts of aerosols are needed to study on a regional scale rather than global basis. Satellite bases information about aerosol optical properties are cost effective way to study aerosol distribution over a longer time period. MODerate resolution Imaging Spectroradiometer (MODIS) derived aerosol optical depth (AOD) is very useful and well suited for this kind of study as it collects data with a revisit cycle of 1-2 days. Therefore aerosol parameters with a close estimation are available over a region throughout the study period [13]. Satellite based observation of aerosols during the last decades showed increasing AOD trends over South Asia [11]. Growing populations, increasing auto mobile vehicles, rapid urbanization, changing land use, and increased industrializations are the reasons of this increasing aerosol concentration over South Asia. There are, to date, relatively very few studies on aerosols over Bangladesh. [14], [17] found that the highest AOD in summer season and minimum in post-monsoon seasons over India and Indo-Gangetic plain.

This study has examined the spatial and temporal aerosol distributions over Bangladesh using MODIS satellite data during the period of 2002-2011. In addition, regional AOD trends in seven divisions have been investigated during the last decade.

II. Methodology

2.1. Study area

Bangladesh is one of the most vulnerable countries for climate change impacts in the world. Geographically it is a part of the Indo-Gangatic plain, one of the most aerosol loading regions in the world. It has the highest population density (1,237.51 persons/km^2) in the world excluding small countries. It has 161,083,804 populations and 130,168 km^2 land areas. Various natural disasters such as floods, tornadoes, and tidal bores affect regularly in Bangladesh. The urbanization and industrialization are proceeding rapidly. The tropical climate of Bangladesh is characterized by wide seasonal variations in rainfall, high temperatures, and high humidity. April is the hottest and January is the coldest month of the country. Heavy rainfall is the characteristic of Bangladesh with exception in northwestern region of Rajshahi which has a relatively dry environment. Therefore geographically Bangladesh is a most desired country for study of spatio-temporal patterns of various atmospheric conditions. For regional study data for seven selected divisions (Fig.1) are analyzed also variations of AOD over Bangladesh are investigated.

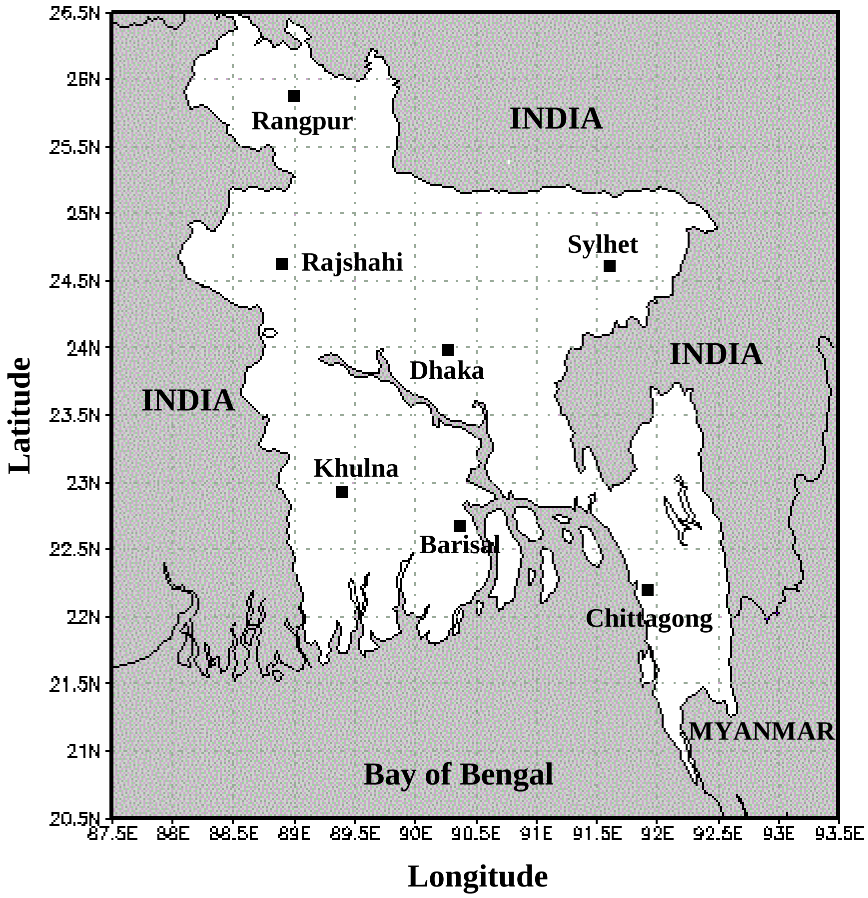


Fig. 1. Map showing the study area.

2.2. Dataset and analyses

Aerosol optical depth (AOD) can be measured by both in situ and remote sensing measurement system. Here the satellite remote sensing retrievals of MODIS are used. To study the large spatial and temporal heterogeneities of aerosol distributions satellite remote sensing is essential. Monitoring aerosols from space has been completed for over two decades and is developed for the coming decade with enhanced abilities [8], [6], [10]. MODIS has a unique collaboration of features such as, a wide spectral range of electromagnetic energy; calculations at three spatial resolutions of all day and every day; and it has a wide domain of view. Terra is the first large multi-instrument EOS satellite and it passes from north to south across the equator in the morning. A second EOS satellite with MODIS instrument is Aqua which passes south to north over the equator in the afternoon. The MODIS sensors traveled NASA's Terra and Aqua satellites have 36 spectral channels which provide a plenty of information on atmospheric, terrestrial, and oceanic circumstances. Aerosol retrieval is different over land [4] from over oceans [23]. For our investigations we have used MODIS Terra Level-3 data. MODIS retrieves aerosol optical depth at three visible channels have high accuracy of ±0.05±0.2τ over vegetated land [2], [4], [9], [19]. The NASA MODIS aerosol retrieval algorithm has recently been upgraded. Because of the greater plainness of the ocean surface, MODIS has the unique potential of retrieving not only aerosol optical depth with greater accuracy, i.e., ±0.03±0.05τ [18], [19], [20], [23] but also quantitative aerosol size parameters (e.g., effective radius, fine-mode fraction of AOD) [5], [7], [19].

III. Results And Discussion

3.1. Aerosol concentrations over Bangladesh

The monthly time series and trend of AOD over Bangladesh during 2002 to 2011 is presented in Fig. 2. It could be seen that AOD is showing an increasing trend across Bangladesh indicating an increase in aerosol loading during the last decade. In the view of all of the year's time series observed in Bangladesh the highest peak AOD is recorded in 2002. The AOD increasing rate in South Asia is about 10.17% which is considered one of the largest AOD increasing trends over globe [12] and this increase in mainly because of increase in anthropogenic aerosols. 0.24° C/decade warming rate at troposphere (<5km) is estimated over the Himalayan region from 1950s by [16].

The spatial distribution of AOD over Bangladesh for the period 2002 to 2011 is shown in Fig. 3. It could be seen that AOD distributions show high spatial variations over Bangladesh. The western parts of the country especially Rajshahi and Khulna divisions show high AOD values indicating high aerosol concentrations in western areas while the eastern Sylhet and Chittagong divisions are showing lower AOD values indicating a cleaner environment with lower aerosol loading.Similar results are also found by [26] and [27].

The high aerosol distributions and increasing trend of AOD in Bangladesh are because of increasing populations, growing economics, urbanization and industrialization which are accepted for the reasons of increasing aerosol concentration over South Asia as have been reported in India [1], [3], [21].

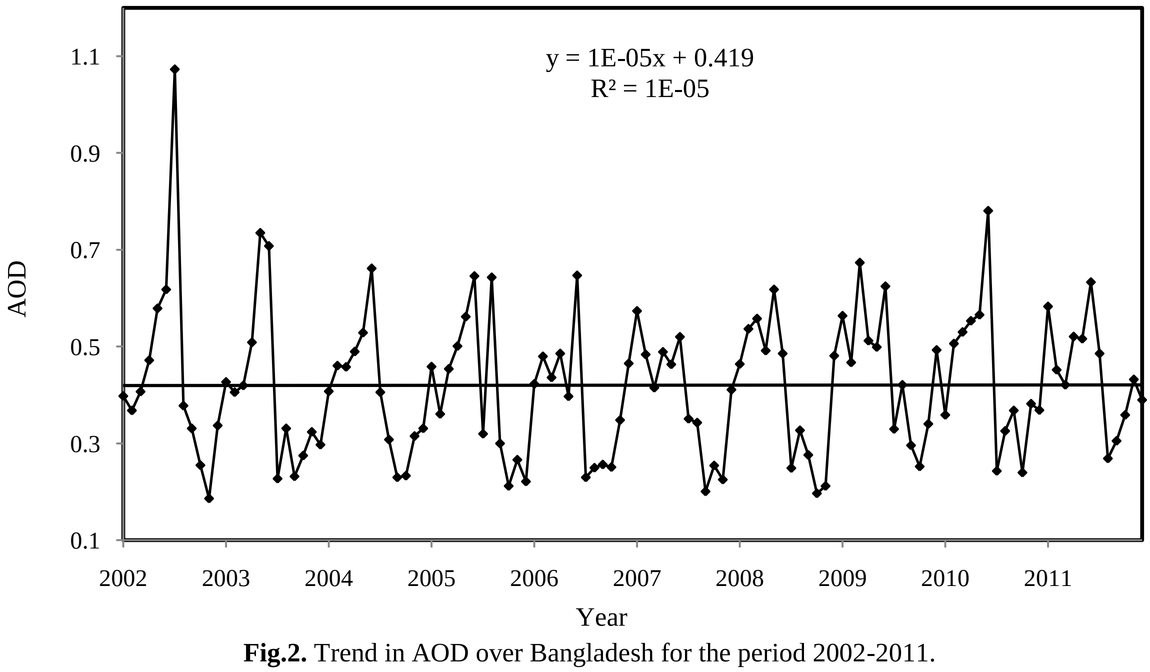


Fig.2. Trend in AOD over Bangladesh for the period 2002-2011.

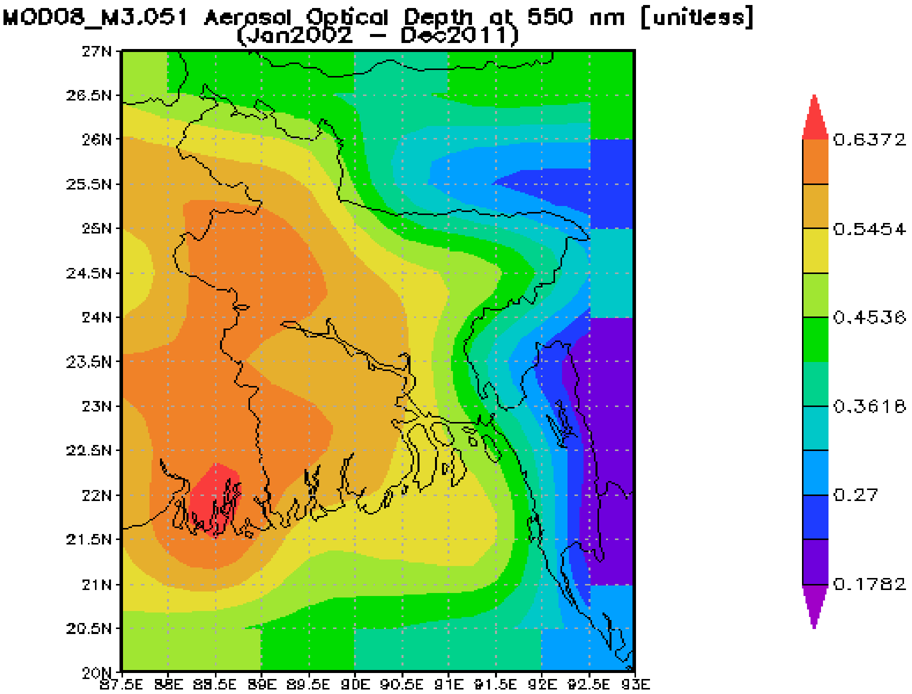
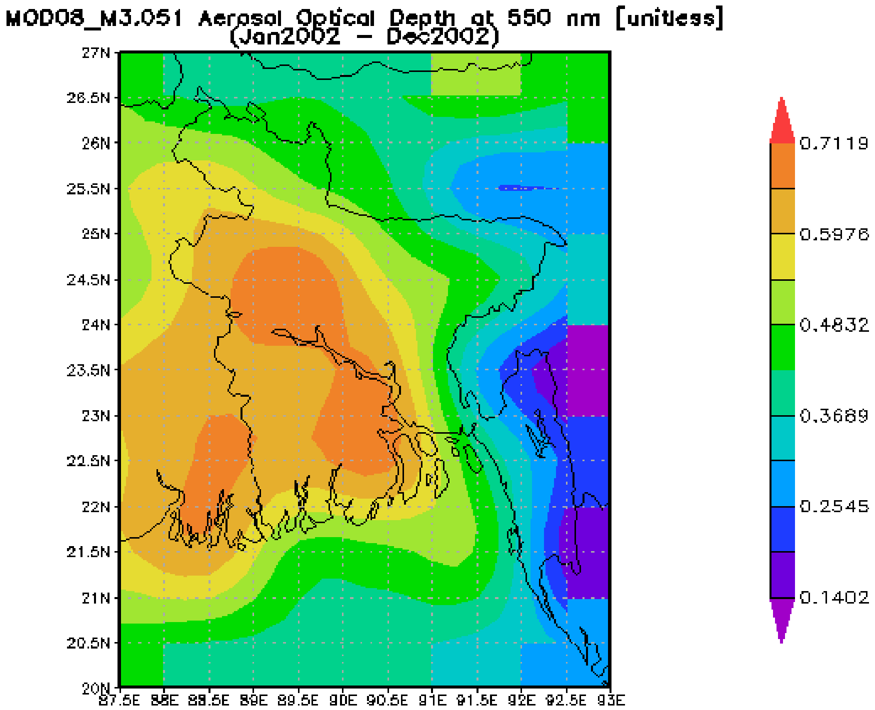


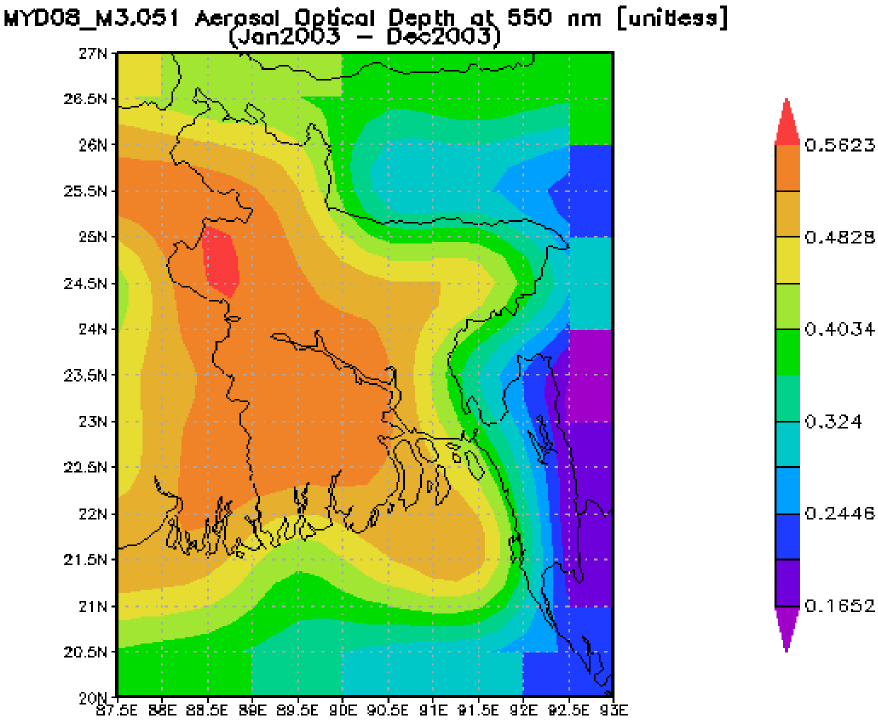
Fig.3. Annual-mean spatial distribution of the Terra-MODIS AOD over Bangladesh during the period 2002-2011.

The annual spatial distributions of AOD over Bangladesh for each year from 2002 to 2011 are shown in Fig. 4. It could be seen that the highest AOD concentration areas over Bangladesh are came to light rapidly. Our analysis showed that the highest AOD areas in western part with a half sphere shape is extending over the whole Bangladesh except the Chittagong &Sylhet divisions. The eastern parts always reveal much cleaner environment with a lower AOD values. Sometimes a high AOD levels are also observed in the harbor areas of Bay-of-Bangle close to the largest Chittagong Sea port of Bangladesh. The western part of Bangladesh is warmer, more vegetated and with more humidity than eastern part also the local activities are also more in the western part. Droughts are occurred in north-western parts frequently as Rajshahi is the hottest division in Bangladesh with minimum rainfall. So, dust activities are higher in these areas than others. Farraka barrage may be another reason for high AOD in this area. Due to this barrage during the last few years the land condition and draughtness are becoming critical in these areas. Therefore the land cover change is a vital reason to high AOD values Rajshahi division. These high AOD values also reflect the occurrences of local activities, vegetated areas over the western region. Approximately 90% air routes are situated across this western part may also be another reason of high AOD values. Southern parts are affected by high sea salt and marine aerosol loading and high humidity. All of these reasons cause of higher AOD in western parts.

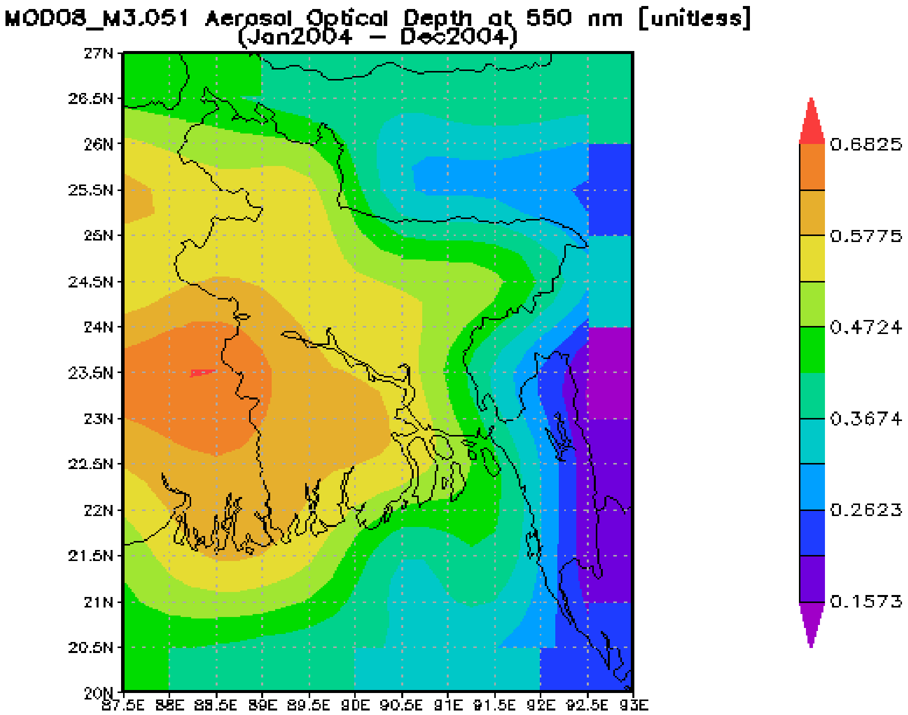
So, it may be accepted that increases in aerosol concentrations over Bangladesh are a result of large & increasing population, changing land cover, growing urbanization & economics, industrialization, increasing vehicles, biomass burning, dense fog, higher temperature, higher humidity, increasing marine aerosols, anthropogenic aerosols loading and huge air masses loading by sea salts and dust particles [26], [27].


MOD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jan2002 – Dec2002)
27N
26.5N
26N
25.5N
25N
24.5N
24N
23.5N
23N
22.5N
22N
21.5N
21N
20.5N
20N
87.5E 88E 88.5E 89E 89.5E 90E 90.5E 91E 91.5E 92E 92.5E 93E
0.7119
0.5976
0.4832
0.3689
0.2545
0.1402

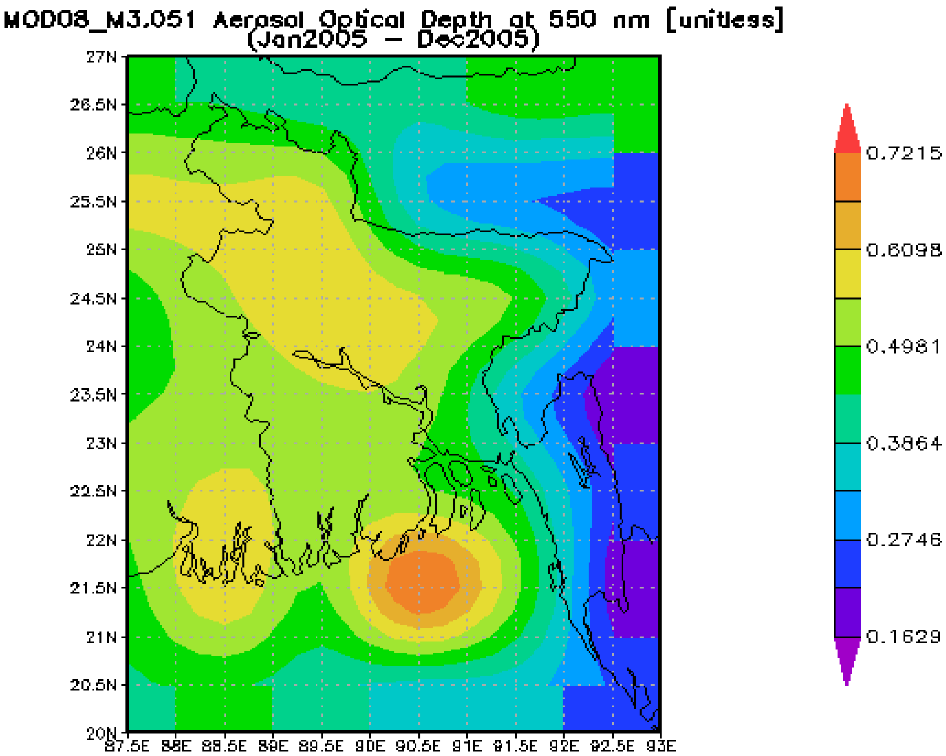
2002


MYD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jan2003 – Dec2003)
27N
26.5N
26N
25.5N
25N
24.5N
24N
23.5N
23N
22.5N
22N
21.5N
21N
20.5N
20N
87.5E 88E 88.5E 89E 89.5E 90E 90.5E 91E 91.5E 92E 92.5E 93E
0.5623
0.4828
0.4034
0.324
0.2446
0.1652

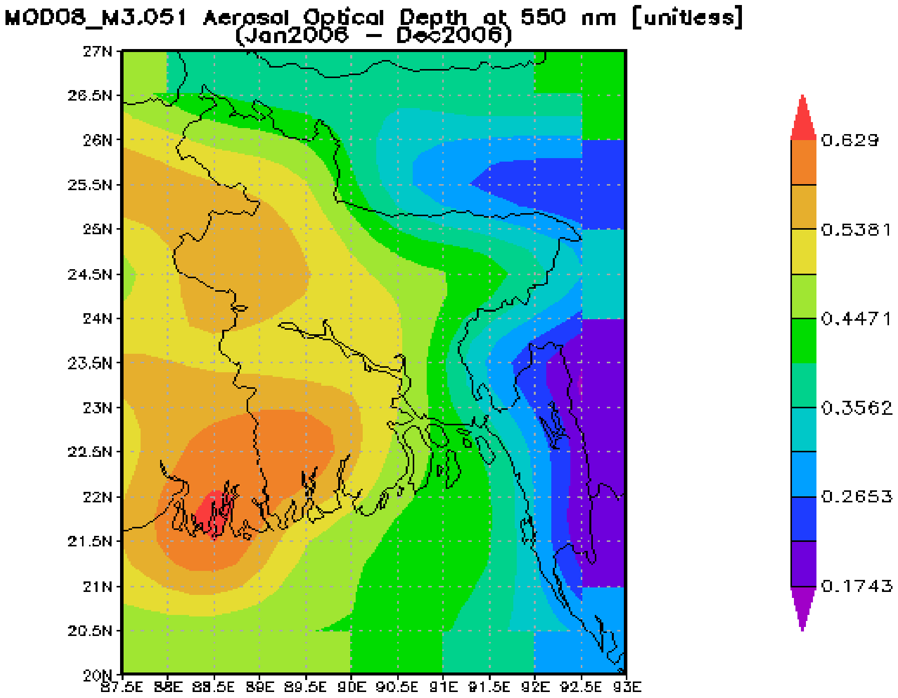
2003


MOD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jan2004 – Dec2004)
0.6825
0.5775
0.4724
0.3674
0.2623
0.1573

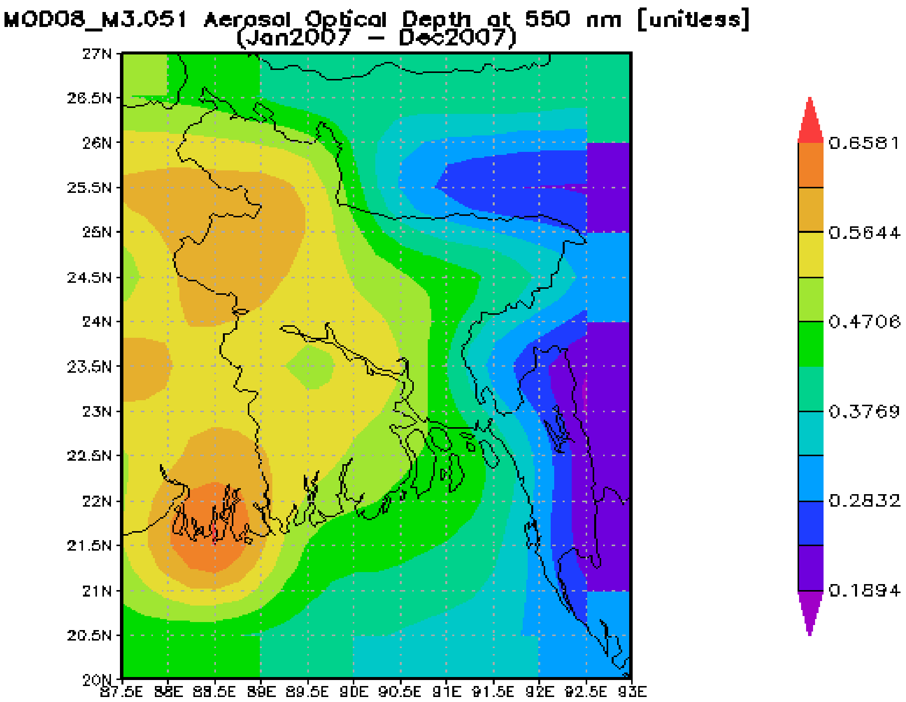
2004


MOD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jan2005 – Dec2005)
0.7215
0.6098
0.4981
0.3864
0.2746
0.1629

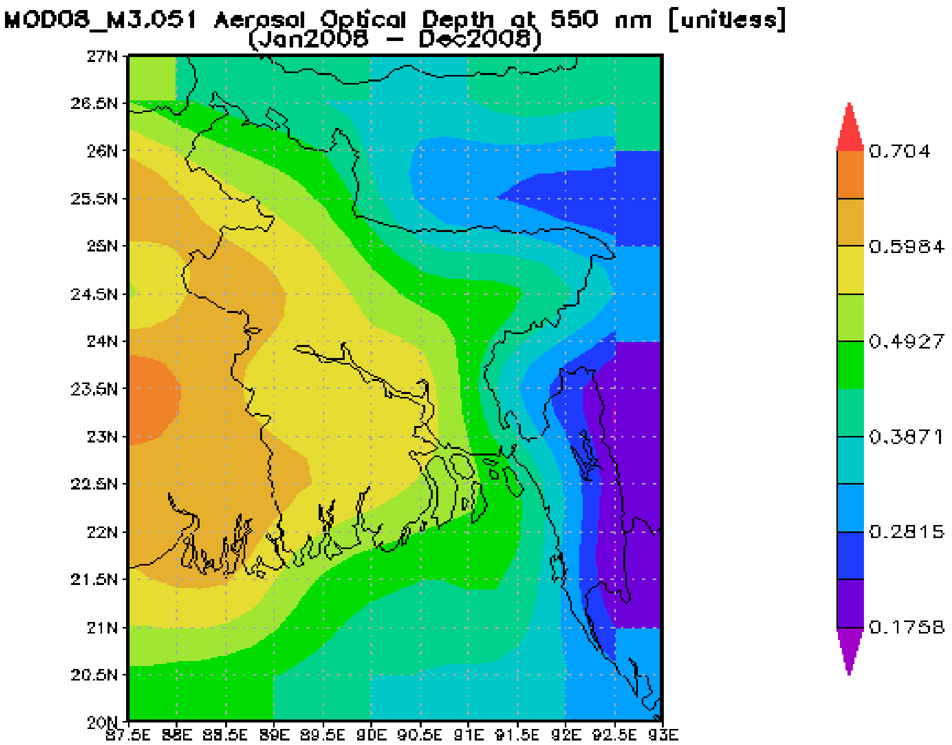
2005


MOD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jan2006 – Dec2006)
0.629
0.5381
0.4471
0.3562
0.2653
0.1743

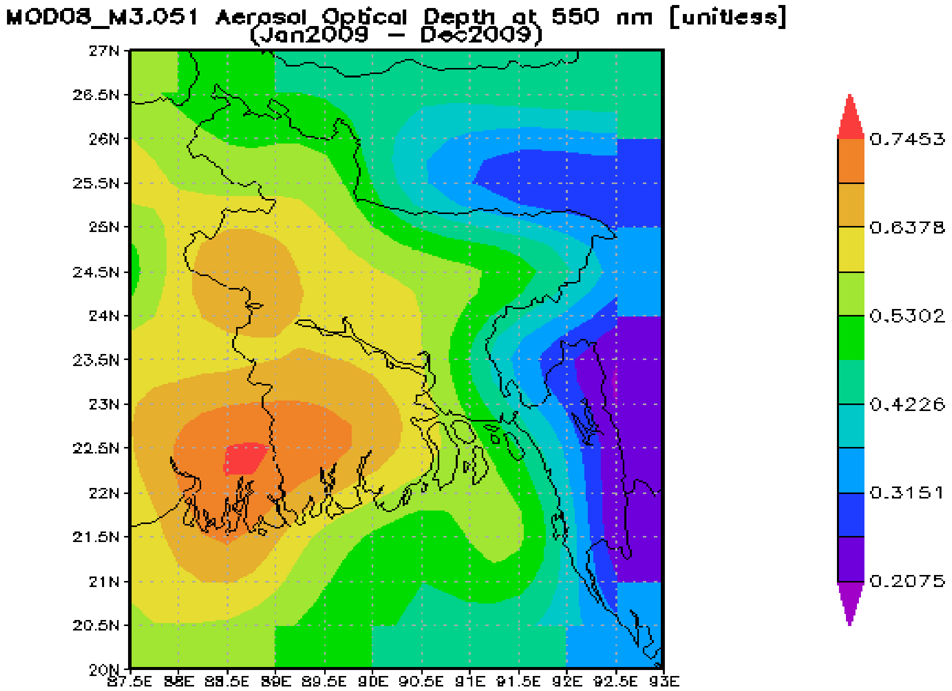
2006


MOD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jan2007 – Dec2007)
0.6581
0.5644
0.4706
0.3769
0.2832
0.1894

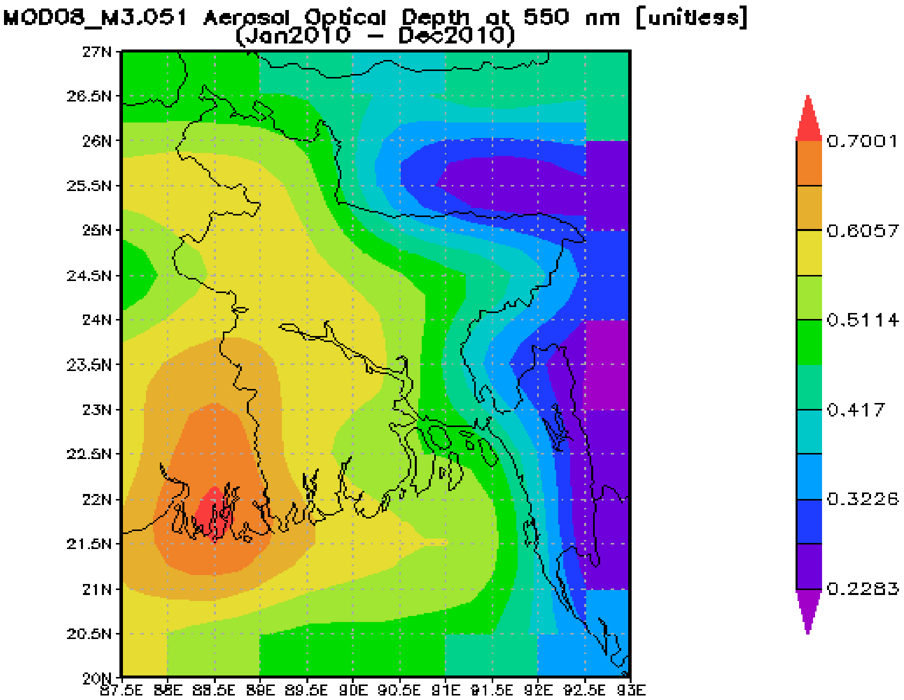
2007


MOD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jan2008 – Dec2008)
27N
26.5N
26N
25.5N
25N
24.5N
24N
23.5N
23N
22.5N
22N
21.5N
21N
20.5N
20N
87.5E 88E 88.5E 89E 89.5E 90E 90.5E 91E 91.5E 92E 92.5E 93E
0.704
0.5984
0.4927
0.3871
0.2815
0.1758

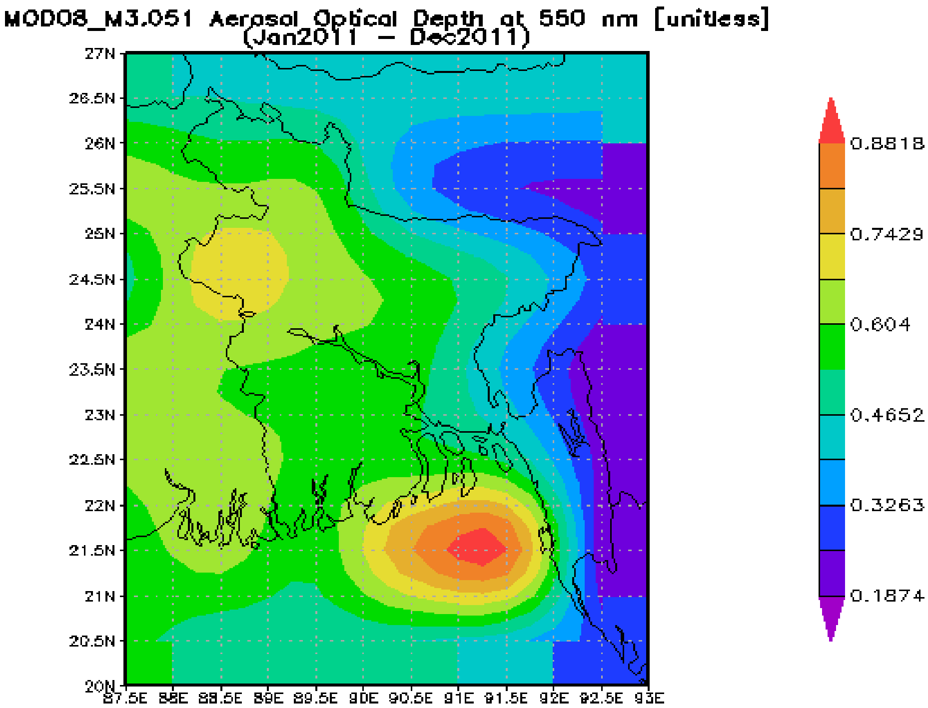
2008


MOD08_M3.051 Aerosol Optical Depth at 550 nm [unitless]
(Jan2009 – Dec2009)
27N
26.5N
26N
25.5N
25N
24.5N
24N
23.5N
23N
22.5N
22N
21.5N
21N
20.5N
20N
87.5E 88E 88.5E 89E 89.5E 90E 90.5E 91E 91.5E 92E 92.5E 93E
0.7453
0.6378
0.5302
0.4226
0.3151
0.2075

2009



2010



2011

Fig.4. Spatial distributions of AOD of Terra-MODIS over Bangladesh for each year from 2002 to 2011.

3.2. Monthly mean variation and trend of AOD over Bangladesh

Fig.5 presents the monthly mean variations of AOD over Bangladesh of 10 years during the period 2002-2011. Bangladesh presents a pronounced annual variation in AOD with increased values during March-June. During October-January there is also a shift in the maximum monthly AOD is observed. At the beginning of the summer month of March the AOD is rapidly increasing and the highest average AOD is observed in June, which is rapidly falling to a lower value in July and then by a gradual decrease reaching to a minimum value in October. This monthly variations are quite similar with [27].The minimum humidity in Bangladesh is occurred during winter. Again from March the humidity is gradually increased and at the beginning of monsoon due to the periodical wind of the Indian Ocean humidity is rapidly increased and the rainfall is started from June. Approximately 80% of total rainfall is occurred during this monsoon season. Therefore aerosols are washing out with rainfall in monsoon season; results a minimum AOD value is observed in post-monsoon month of October. Also the dust activity is disappeared in October, another reason of lower AOD at this time. AOD is again rapidly increasing from November to January. January is the coldest month in Bangladesh. During peak winter season in the month of January a narrow belt of very large AOD is observed along this area. AOD is increasing because during this time the fog activity is maximum, cause's aerosol loading increasing. Also from October the local activities as crop residue burning is increasing [22], which is the large source of aerosol emission. During February to march the high value of AOD is remain constant approximately (~0.5). A slight decreasing trend of AOD in February-March than January is observed due to decrease of fog activity.

Overall study is found that the AOD is increased rapidly from March, reaching its maximum value (0.63) in June. Where AOD is started to decrease rapidly from July and reached its minimum value (0.25) in October. The increasing AOD in summer is due to Sea salt particles loading by the strong south-westerly winds, higher temperature and higher humidity. [17] examined that water vapors and AOD are directly associated to each other as a result higher concentration of water vapor in summer leads to a higher AOD. Conversely, dry weather and lower humidity in winter result in lower AOD values.

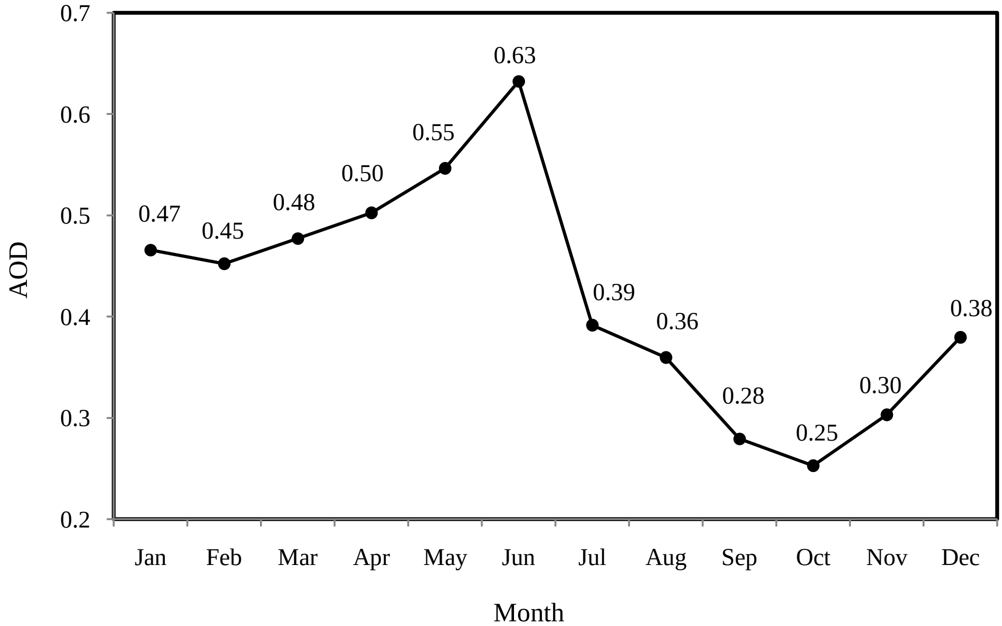


Fig.5. Monthly AOD variations of 10 years and monthly-mean trend for MODIS AOD in Bangladesh during the period 2002-2011.

3.3. Regional aerosol patterns over 7 divisions in Bangladesh

The regional variation study of AOD is done over seven divisions of Bangladesh during the period of 2002-2011 as shown in Fig.6. It can be seen that Khulna, Rajshahi, Barishal, Rangpur and Chittagong divisions are showing increasing trends of AOD whereas Dhaka and Sylhet divisions show decreasing trends. The highest AOD levels are observed in Rajshahi and Khulna divisions. However, Rajshahi, as an arid city, has a highest temperature, minimum rainfall. Natural dust aerosols are therefore more dominant type at Rajshahi. Khulna is home of extensive forest; also a coastal and harbor region. So the higher humidity, high sea salt and marine aerosols also high temperatures are aided the high AOD values in Khulna. Also the high AOD value in Khulna is affected by the big polluted city Calcutta of India. Barisal, the coastal area is shown the highest increasing rate and fluctuations of AOD. Which is due to high loading of sea salt, marine aerosols and higher humidity.Rangpur another arid division at the northern part in Bangladesh as like as Rajshahi division is also shown an increasing trend of AOD. The natural aerosols and manmade aerosols are aided this high AOD in this division. Chittagong is showing a lower level of AOD which is also increasing. The largest sea port of Bangladesh is situated in this division. So the marine aerosols are a major source of aerosol loading in Chittagong. Also large industries and huge automobiles are produced enough anthropogenic aerosols in Chittagong. Dhaka and Sylhet are showing decreasing trends of AOD during the last decade also the minimum AOD level is observed in Sylhet. These decreasing trends in AOD may be due to decrease in natural aerosol loading [15], decreasing in biomass burning and increasing in coarse particles. Maximum rainfall and minimum temperature in Sylhet may be the causes for minimum level in AOD values. So meteorology can play a significant role in the variability of AOD. Dhaka is one of the highest over populated and polluted city in the world. Most of the industries and vehicles of Bangladesh are conducted in Dhaka. But it is very strange that the AOD is decreasing over Dhaka during the last decade. This may be due to decrease emissions of fine particles into atmosphere [25]. During the last decade elemental carbon particles mass concentration may be decreased, as two stroke engines were banded in Dhaka. Also sulfurous emission is decreased due to increased use of alternative energy sources and less sulfurous fuels. In the densely polluted location the decrease can entirely be attributed to the decrease in amount of aerosols of atmospheric sources [15]. So the overall study also confirms that, the AOD depend not only the particular aerosol loads originated from the investigated areas but also depends on adjacent regions strongly.

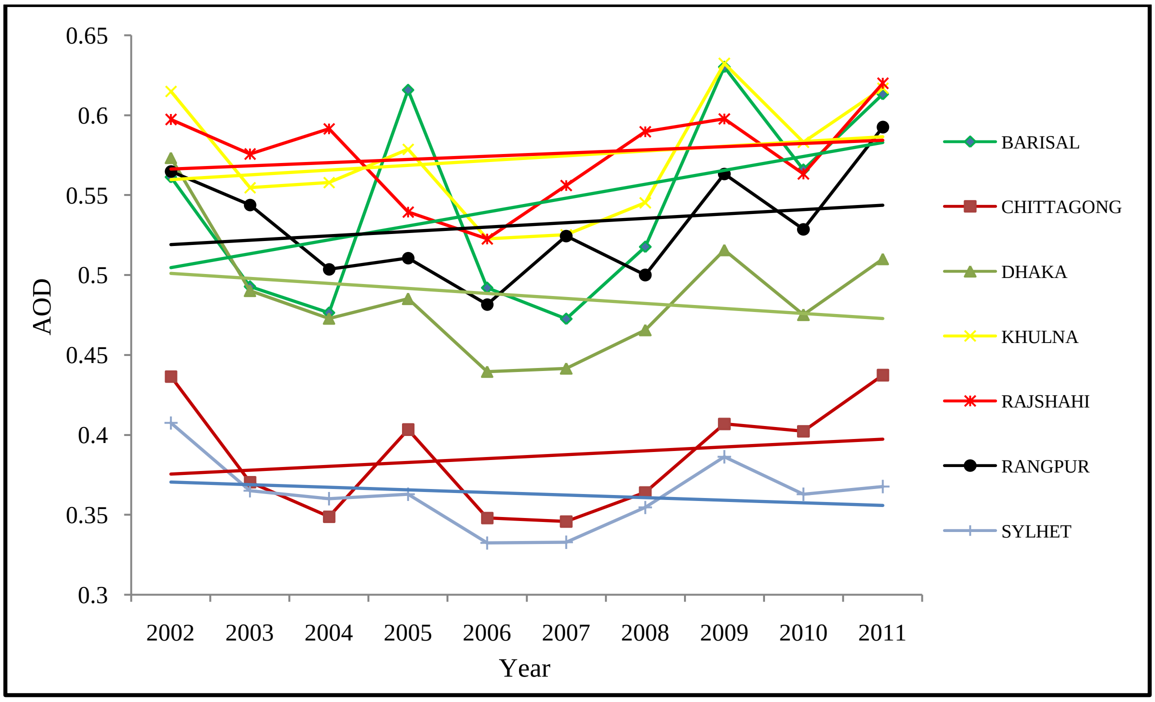


Fig.6. Trends in AOD over seven divisions in Bangladesh.

IV. Conclusion

The aim of this study is to analysis the AOD variations and trends over Bangladesh based on Terra-MODIS remote sensing data during the last decade (2002-2011) and to develop an understanding of the impact of aerosols on atmosphere. The annual mean and monthly mean AOD variations and trends along with the regional AOD trends of seven divisions are investigated during the years of 2002-2011 across Bangladesh. AODs are increasing across Bangladesh during the last decade. The highest AOD levels are found in the western part of Bangladesh because of pollutions of India combining with comparatively tempered and arid environment. Monthly mean variations of AOD report that the highest AOD value is found in June whereas the lowest in October. The highest AOD value in June is interpreted as being a result of high temperature, higher humidity and a higher wind velocity, where the lowest AOD value in October due to a result of cleans and cool environment after rainy season by rain washout process. Regional AOD trends are indicating that aerosols vary regionally with different geographical circumstances. AOD trends are increasing in all of the divisions except Dhaka and Sylhet divisions. Decreasing trend in Dhaka may be a reason of decreasing emission of fine carbon particles combining with decreasing anthropogenic aerosols. Sylhet and Chittagong divisions have lower levels of AOD values where all other divisions have higher values of AOD. The lower levels of AOD in Sylhet and Chittagong may be due to the lower temperature, higher rainfall and overall a cool & clean environment in these areas. There are some limitations of this study as it had no scope to compare the satellite AOD values with ground station AOD values in Bangladesh, also aerosol study is so latest work in Bangladesh, as a result the findings and comments are needed to verify in a greater details in future. It is therefore recommended that further more research works are needed in aerosols to achieve a better understanding of spatio-temporal variations in aerosols and their climate impacts.

Acknowledgements

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