Research Journal of Chemical Sciences E-ISSN 2231-606X
Vol. **6(2),** 40-44, February **(2016)** *Res. J. Chem. Sci.*

Diurnal and Monthly Variation of Aerosol Optical Depth and Angstrom's Parameters in Kathmandu Valley, Nepal

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Available online at: www.isca.in, www.isca.me
Received 27th January 2016, revised 13th February 2016, accepted 17th February 2016

Abstract

Aerosol optical depth (AOD) is measured at five optical channels by Microtops II Sunphotometer at Institute of Engineering, Pulchowk, Lalitpur, Nepal from November 2011 to March 2013 in clear non cloudy days. The Angstrom's turbidity parameters, α and β, have been calculated from AOD measurements and their variation have been analyzed on daily and monthly basis. The result shows that value of α and β varies throughout the day because of the change in meteorological parameters. It is observed that during the measurement period, the monthly average minimum and maximum values of α are 0.24 and 1.27 in September 2011 and December 2012 respectively. Likewise the value of β is 0.16 in December 2012 and 0.43 in April 2012. The variation between the parameters α and β is observed in anti-correlation throughout the day during all months indicating continuous distribution of the fine and coarse particles.

Keywords: Aerosol, AOD, Microtops II Sunphotometer, Angstrom's exponent, Turbidity coefficient, Relative humidity, Seasonal variation.

Introduction

Air pollution is a major environmental challenge in various regions of the world[1]. Using measurements, modeling and satellite observation, the different layers of regional scale plumes of atmospheric pollution have been identified in south Asia that extended from the Himalayan range to the north of Indian Ocean[2]. These plumes comprise high level of short lived aerosols, black carbon and ozone. These pollutants have found several significant implications on the global and regional climate changes, crop yield and human health.

Aerosols are suspended solid particulate materials and liquid droplets in the atmosphere. Having natural and anthropogenic origin, their size varies from 0.001 µm to 100 µm. They interact with incoming solar radiation and outgoing terrestrial long wave radiation by scattering and absorbing and produce radiative effect of cooling and warming the atmosphere. The climatic impact of aerosols has been confirmed by many researcher groups around the world[3]. They take major role in enhancing poor air quality and pollution in the environment as well as harmful effect in human health.

When passing through the earth's atmosphere, the solar radiation is attenuated due to scattering by aerosol particles and absorption by water vapour and gases such as carbon dioxide, carbon monoxide, ozone etc[4]. However, in clear sky days, aerosols dominate in attenuation of solar radiation at visible and near-infrared wavelength ranges[5,6]. Aerosol optical depth is a measure of attenuation of direct solar radiation by aerosols that is affected by the amount, type and size of aerosols. So, it is a measure of total integrated particulate load in vertical direction in the atmosphere. Being a dimensionless quantity, it gives a measure of opacity of a vertical column of the atmosphere. It is one of the important factors that influence the solar radiation in the earth's atmosphere[7]. It is a useful index of atmospheric pollution especially in studies of long-term changes in the composition of the atmosphere and the global climate change. The seasonal variation of Angstroms parameters with temperature along with the causes for higher values of β during pre-monsoon and lower values during other seasons have been discussed in the present study.

As the capital city of Nepal, Kathmandu Valley (27.7° E, 85.2° N) is the largest metropolitan city at foothill of Himalaya region and represents one of the highly polluted areas in the world[1]. With 30 km east-west cross-section and 20 km north-south cross-section, the valley comprises three districts; Kathmandu, Lalitpur and Bhaktapur. With a mean altitude of 1350 m a.m.s.l., the valley has unique topographic feature that is surrounded by high mountains of altitude ranging from 2,000 m to 2,800 m forming a bowl shape which traps plumes with aerosols for long time[8,9]. A thick, gray layer of pollution can be observed above the valley from every corner [10]. Within the last few years, there has undergone a rapid, but unplanned urbanization due to high population growth, abrupt land use change, and socioeconomic transformation, leading to face sever air pollution. Within the past quarter of century, the population has quadrupled to more than 3 million and total vehicle grew to more than 700,000, by 14 times in this period. An estimation of energy consumption is found to be increase at 3.2 percent by 2050[11]. A large number of vehicles running in the valley for serving public and tourist in almost all seasons contribute in increasing the air pollution. Although the massive earthquake 2015 disturbed almost brick factories, there are still small industries, construction factories, road and building reconstructions etc. which help to blow up the natural dusts into the atmosphere[12]. The wind enters the valley from north-west and some time from south west part and passes out through the east south region of Banepa.

Materials and Methods

Aerosol optical depth is measured by using Microtops II Sunphotometer manufactured by Solar Light Company Inc., USA. It is a multi-band sun photometer designed to study the spatial variation of aerosol characteristics at five narrow wavelength bands 340, 440, 500, 675 and 870 nm. The instrument has five accurately aligned optical collimators with 2.5° as a full field of view. The internal baffles in the device are integrated into it to eliminate internal reflections. Each channel is fitted with a narrow band interference filter and a photodiode suitable for the particular wavelength range[13]. AOD is determined by Langley method assuming the validity of the Bouguer-Lambert-Beer law. The optical depth due to Rayleigh scattering has been subtracted from the total optical depth to obtain AOD. The Micrtops II sunphotometer has many settings in it such as GPS receiver, universal date and time, geographic coordinates, altitude and atmospheric pressure of the measurement site[13]. Since the sun is taken as the source, the instrument is operated only in clear, non cloudy days. The measurements have made on the clear sky days from 3:15:00 to 12:15:00 hrs UT at 15 minute time interval.

On passing through the atmosphere, the solar radiation, I reaching the earth's surface, from Bouguer-Lambert-Beer law, is

$$I = I_0 e^{-\tau(\lambda)m} \tag{1}$$

Where I_0 is the direct solar radiation at the top of the atmosphere, τ(λ) is the aerosol optical depth (AOD) and m is relative air mass[14]. From AOD measurements, turbidity parameters can be calculated[15] as

$$\tau(\lambda) = \beta\lambda^{-\alpha} \tag{2}$$

where α is the wavelength exponent and β is the turbidity coefficient. The wavelength exponent, α is an accounts of the columnar aerosol size distribution in the atmosphere and the turbidity coefficient, β is a measure of aerosol concentration there in vertical direction. The value of β generally varies from 0.0 to 0.5. It is called turbidity because the solar radiation is scattered by matter than air molecules in the atmosphere. Therefore, the measurement of AOD is a quantitative measure of the extinction of solar radiation by aerosol scattering and absorption.

At 1 µm, we have

$$\tau(\lambda) = \beta \tag{3}$$

As the wavelength exponent, α indicates the aerosol size distribution, it is not a constant of nature but simply a parameter defined by the arbitrary procedure chosen for its determination. Generally, α is taken as 1.3 since it was originally suggested by Angstrom[5]. It varies from zero to 4 with large values indicating a relatively high ratio of small particles to large particles and small value indicating smaller particles of the order of air molecules.

The linear equation in logarithmic format from Equation-2 is given by

$$\ln\tau(\lambda) = \ln\beta - \alpha\ln\lambda \tag{4}$$

Equation-3 gives the values of Angstrom's parameters α and β by least squares analysis of spectral optical depth at any two wavelengths.

Results and Discussion

AOD in Kathmandu Valley have observed variation throughout the days of observation period. This variation is impacted by the changes in the meteorological parameters. The Angstorm's parameters, α and β also show strong diurnal variation. The diurnal change in AOD and Angstrom's parameters α and β on March 25, 2013 are shown in Figure-1 and Figure-2 respectively. AOD before noon is higher and gradually decreases to afternoon with relatively uniform values due to stable meteorological conditions. One of the affecting parameters to AOD is relative humidity which is higher (75.2%) at the morning relative to the afternoon (60.3%)[16]. The higher temperature during the day time causes evaporation or condensation of moister in the atmosphere that lowers down AOD and changes on the parameters α and β.

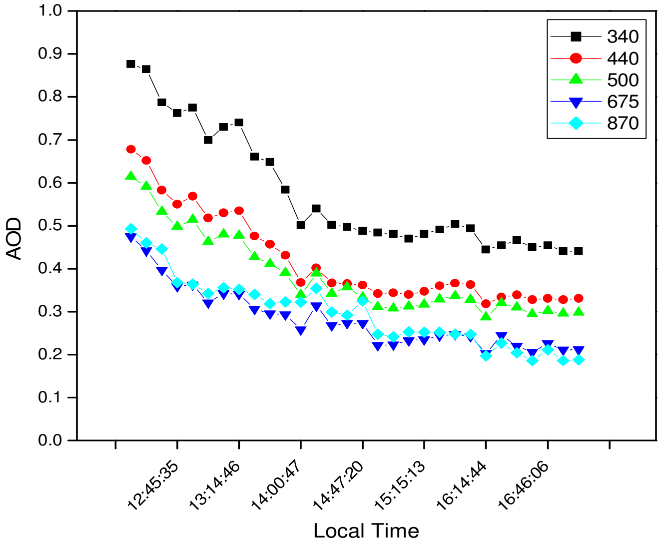

Figure-1
The diurnal variation of AOD on March 25, 2013

Figure-3 shows the diurnal variation of α and β on May 24, 2012 which is in similar pattern as in March 25, 2013. An anti correlation is observed in α and β throughout the days in these figures; when β increases, then α decreases and vice versa[17]. However, in stable meteorological condition, α and β remains uniform.

The daily average values of α and β are obtained by averaging all set of data of a day of a month. Figure-4 shows the daily average variation of α and β on February 2012. The daily average of α is changing between 0.80 and 1.03, and finally falls to 0.52 while β is increasing from 0.13 to 0.67 at 14th of February. The meteorological parameters significantly influence on variation within a day as well as day to day[18].

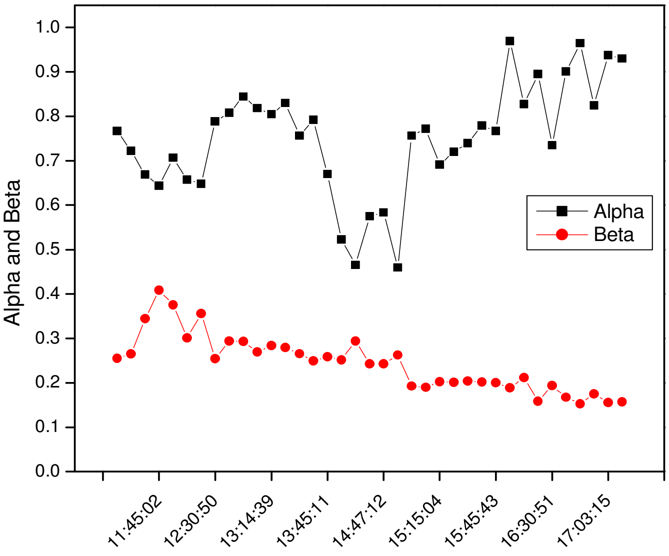

Figure-2
The diurnal variation of turbidity coefficient α and wavelength exponent β on March 25, 2013

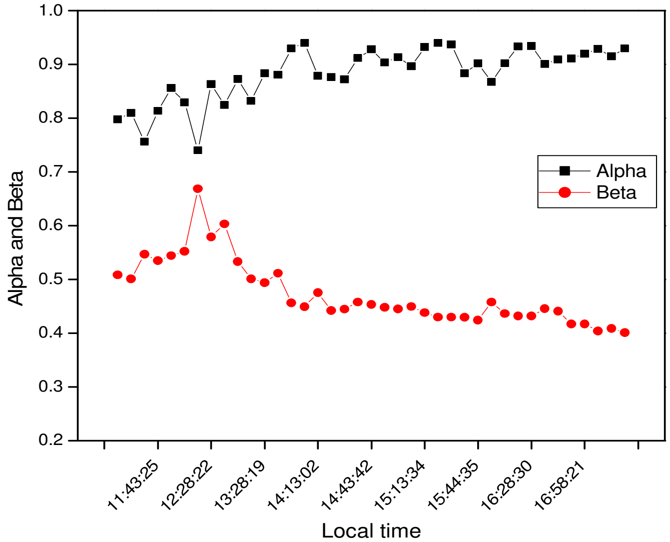

Figure-3
The diurnal variation of α and β for May 24, 2012

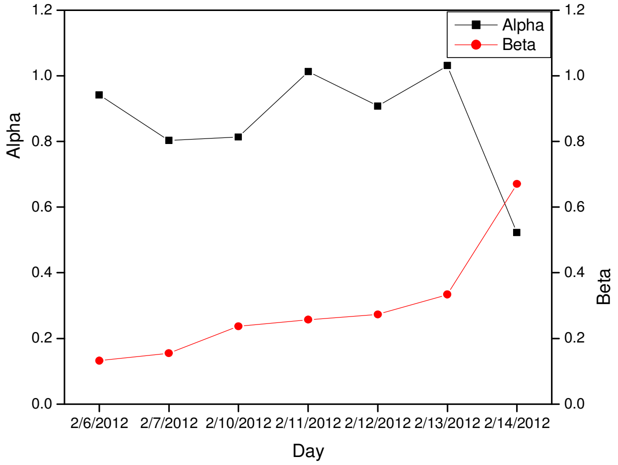

Figure-4
Daily variation of α and β on February 2012

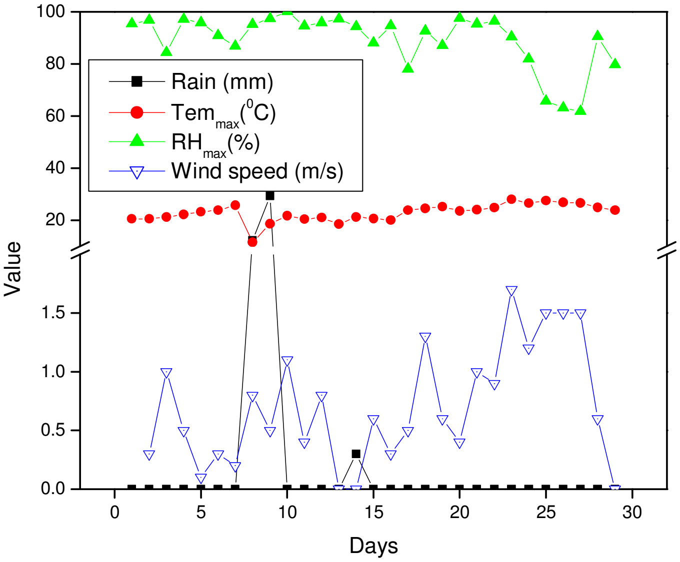

Figure-5
Meteorological parameters on February 2012 (Source: DHM, GoN, Kathmandu)

Figure-5 shows a plot of temperature, humidity, rain and wind speed in Kathmandu Valley on February in 2012 collected from Department of Hydrology and Meteorology, Government of Nepal. The change of the meteorological parameters is the characteristic of the months as well as seasons of the year. This change is subjected to the variation in the size and number of the aerosol particles and this change in aerosols affect directly to the attenuation of solar radiation[19]. Therefore, the Angstrom's parameters, α and β are expected to change throughout the months and seasons also.

Figure-6a and b show the monthly variation of α and β. The diagram 6a shows that the exponent α decreases from December 2011 to September 2012 and then increases to December 2012 that falls down again. The value of α in most of the months is smaller than 1 and this shows that the number of coarse particles is more than the fine particles in the atmosphere. Figure-6b shows that β has highest value during April 2012 which is in pre- Monsoon season. April, May and Jun of 2012 are the months with high aerosol particles in the atmosphere and small α values in these months shows that coarse particles are higher[20].

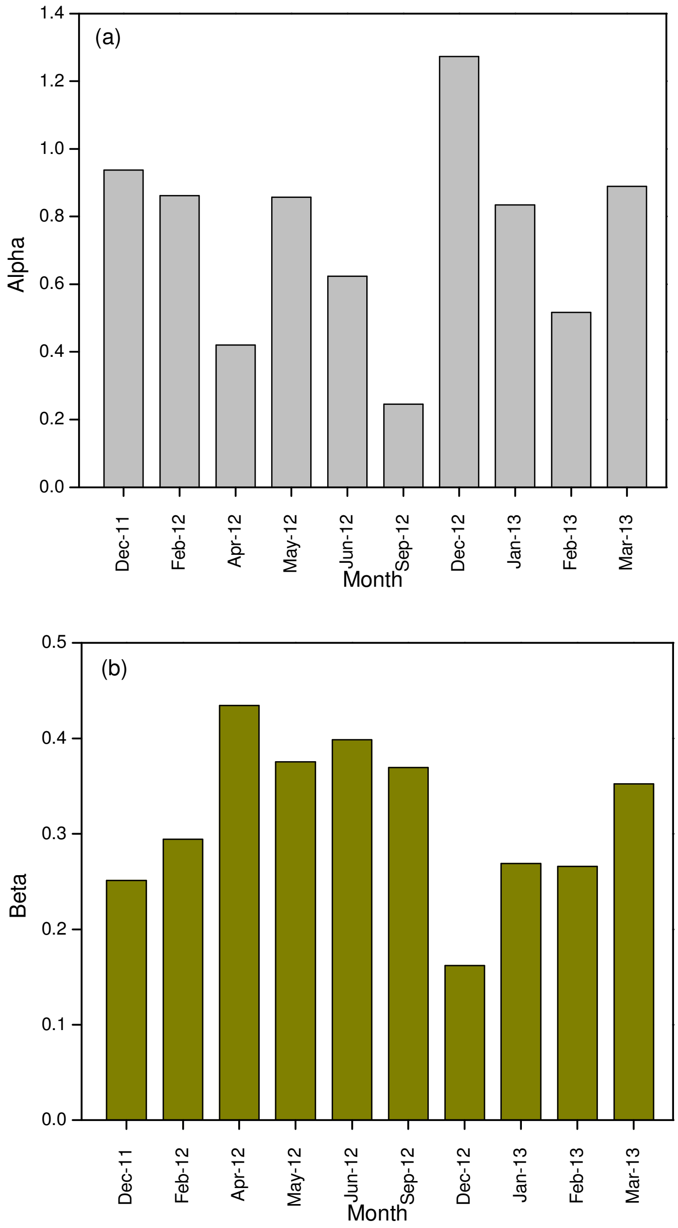

Figure-6
(a) Monthly average of α and (b) monthly average β from December 2011 to March 2013

The monthly average variation of α and β form December 2011 to March 2013 is shown in Figure-7. The variation of the parameters in the monthly average shows also an anti-correlation and it reveals that the variation of number of fine particles and coarse particle in the atmosphere is opposite to each other. With the increase of air temperature in a day, the evaporation of water raises with increase in water vapour in air. The increased water vapour stimulate for growth in size of aerosols converting fine particles (< 0.1 µm) into large particles (0.1-1.0 µm) and large to coarse particles (> 1.0 µm). The coarse particles so formed are settling down to the ground due to the gravity. Kathmandu valley is more polluted compared to Dehradun valley, India ($\alpha = 1.212$, $\beta = 0.189$)[18].

The small value of β and higher value α (= 1.27) in December, 2012 shows that aerosols in the atmosphere is low that caused by rain in previous months.

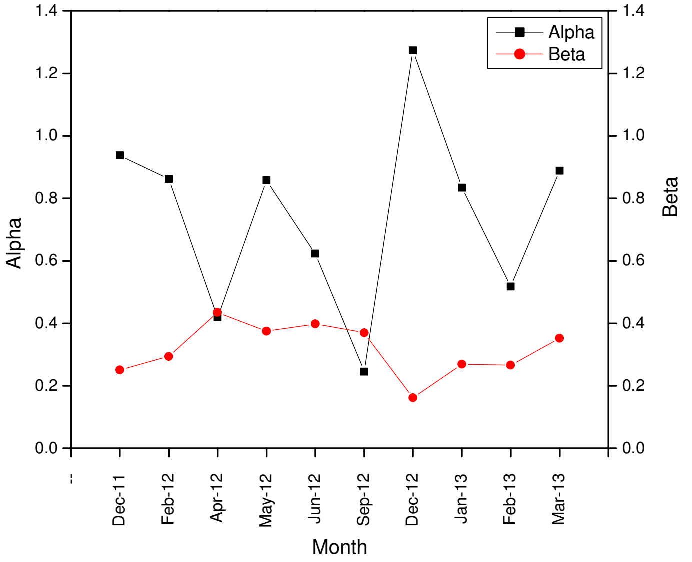

Figure 7
Monthly average variation of α and β form December 2011 to March 2013

Conclusion

The analysis of optical properties of aerosols for the observation period from December 2011 to March 2013 shows the dependency of AOD and angstrom's parameters on the meteorological parameters in the valley. The relative humidity plays important role on increasing AOD during before the noon of a day. The highest value of β is 0.435 in April 2012 with lowest value of 0.162 in December, 2012. As $\beta > 0.1$ for most of the days and months, the valley is more turbid and polluted by aerosols. The smaller value of α (< 1) in most of the months shows high number of coarse particles compared to fine particles in the atmosphere. The anti-correlation between α and β is obtained for all the observation days. Washout of aerosols by rain is the cause for low concentration of particulates in post-monsoon. With the monthly variation, Angstorm's coefficient β increases from December to May and then decreases again to a small value.

Acknowledgement

The authors are grateful to SAHR Project, IOE for providing Microtops-II Sunphotometer for measuring the data and acknowledge to Department of Engineering Science and Humanities, IOE, TU, Pulchowk for providing the opportunity of technical support. Sincere thanks also go to Department of Hydrology and Meteorology, Government of Nepal, Kathmandu for providing the meteorological data. Authors are also give sincere thanks to Prof. Dr. Ram Kumar Sharma, Dr. Rishiram Sharma, Dr. Naba Raj Karki and Dr. Rudra P Aryal for their valuable suggestions and comments.

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