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ORIGINAL ARTICLE **OPEN ACCESS**

Estimation and Analysis of Aerosol Optical Depth (AOD) over the Nainital Town, Kumaun Himalaya using AERONET data

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ABSTRACT
Global warming is primarily a consequence of excessive emission ofthe greenhouse gases i.e., carbon dioxide, methane, CFCs owing to anthropogenic and biogenic activities. The concentration of dry carbon, haze, fog and clouds are found to be increasing in the Nainital town. We present here the study of Aerosol Optical Depth (AOD) with angstrom exponent and precipitable water over the Nainital town, Kumaun Himalaya region using AERONET data from 2008 to 2011. We found that during the monsoon season the AOD took its highest values of 0.515, 0.395 and 0.390 during 2008 to 2010 respectively. We found the highest value of angstrom exponent (1.546) in the post-monsoon season of 2010, we found the maximum and it was least in 2009 (1.131). We found that the angstrom exponent and AOD are anti-correlated with a correlation coefficient of -0.59. The precipitable water was also studied and found that it shows the same trend as AOD. Both of these parameters are highly correlated with a correlation coefficient of 0.79.
Keywords: AOD, AERONET data, precipitable water

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INTRODUCTION

Earth's atmospheric system can be affected by aerosols which are one of the major components to change the radiative processes and climate partly absorbing the solar radiation and partly scattering the radiation [7, 8, 9, 14]. For the climate change the aerosols are major components and for the climate models these are major source of uncertainty [7, 5, 12]. The aerosols can change the local and global climate effectively.

The uncertainties in the aerosols are because of their extended spatial and temporal distribution, but simultaneously the lack of detailed study at regional and global scaleis also one of the reasons for these uncertainties [1-3, 7]. Number of techniques is used for the analysis of aerosol optical and microphysical properties. To discuss the dominant aerosol types and typical aerosol transport mechanisms the magnitude of aerosol optical depth (AOD) and the spectral dependence of AOD with respect to wavelength (i.e., Angstrom exponent, α_{ext}) are commonly studied [10, 1].

For the study of the optical properties of aerosol a ground based aerosol monitoring network is established namely Aerosol Robotic Network (AERONET) [9]. In this AERONET program, optical properties of different aerosols are discussed like optical properties of marine [19], desert dust, urban aerosols and biomass burning etc [4, 16-18].

From the above discussion, it is clear that the aerosol properties are still required to debate. Therefore, here we present a study of optical properties of aerosols namely AOD, Angstrom exponent and precipitable water (from 2008 to 2011). The present paper is organized as follows: section 2contains the description of datasets. The analysis and results are described in section 3. Section 4 presents the discussion and summary of the paper.

MATERIAL AND METHODS

Data –Set

The CIMEL sun and sky radiometer has two operating modes: direct measurements of the sun at wavelengths of 0.34, 0.38, 0.44, 0.5, 0.67, 0.87, 0.94, and 1.02 μm to determine the aerosol optical depth (AOD) and water vapour content (WVC), and measurements of the sky at wavelengths of 0.44, 0.67, 0.87, and 1.02 μm to determine microphysical and optical properties [7, 8].A network of ground-based solar photometers, a system of data inversion, and related records make up the "Aerosol Rbotic Network (AERONET)" global network of photometers [7]. The network routinely observes the direct sun to determine the aerosol optical depth. Additionally, it extracts and disseminates data on the global aerosol columnar characteristics from observations of sky radiance.

In this study we have used the AERONET data downloaded from https://aeronet.gsfc.nasa.gov/. We have used the data for Nainital town where we have used the data of AERONET version 3 and AOD level 2. The Nainital town is the lesser Himalaya region of North Indian Himalaya. The location of the study area lies under N 29.359 and E 79.458 with an elevation of 1939 meter from mean sea level. We have used AOD at 500 nm ($\tau_{a,\,0.5}$) for our analysis because it is taken as the representative of whole spectral range of AOD, as 500 nm is closest to the central part of the AERONET AOD data spectral range. Similarly the angstrom exponent (α_{ext}) is taken at 440-870 nm for our analysis. We have analysed the data from 30 April, 2008 to 25 February 2011. The data of July, August 2008, February, August and September 2010 was not available.

RESULTS

We have analysed the properties of AOD with angstrom exponent and precipitable water. The seasonal, monthly and yearly variations of these parameters are also analysed. Linear regression analysis is done between these parameters. The results are presented in the following subsections.

Seasonal Variation of Angstrom Exponent and AOD

We have taken winter season as average value of three months from December of previous year to February of current year. Pre-monsoon season is considered from March to May of a year. Similarly monsoon and post-monsoon seasons are taken from June to August and September to November respectively. The angstrom exponent (α_{ext}) is plotted with Seasonal average for four years (2008-2011) in the left panel of Figure 1. We found an increasing trend of angstrom exponent (taken from 440 to 870 nm) from 2009 to 2011 for the winter season, while for pre-monsoon and monsoon season we found a decreasing trend in angstrom exponent from 2008 to 2010. But we didn't get year wise decreasing or increasing trend in post-monsoon season. In the post-monsoon season of 2010, we found the maximum angstrom exponent (1.546) and it was least in 2009 (1.131). In 2008, the angstrom exponent increases from pre-monsoon to post-monsoon, while it decreases from winter to pre-monsoon season and then increases from pre-monsoon to post monsoon season in 2009. The angstrom exponent decreases from winter to monsoon season but becomes highest in post-monsoon season in 2010. The average value of α_{ext}in winter season of 2010 was found as 1.282 and it was 0.855, 0.894 and 1.308 in pre-monsoon, monsoon and post-monsoon season respectively.

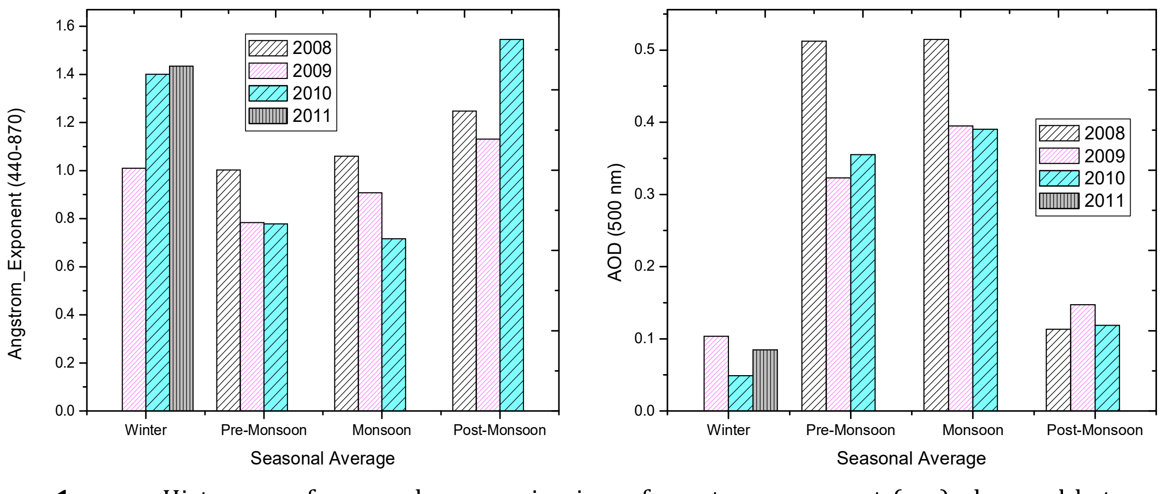

Figure 1: Histogram of seasonal average in view of angstrom exponent (α_{ext}) observed between 440-870 nm (Left panel) and AOD at 500 nm ($\tau_{a,\,0.5}$)(right panel).

Year wise seasonal variation of AOD at 500nm is shown in the right panel of Figure 1. We didn't get any proper trend except for the monsoon season which decreases from 2008 to 2010. Winter season shows its maximum AOD content in 2009 and minimum in 2010. Same pattern is exhibited in pre-monsoon season also, but in post-monsoon season highest AOD content is shown in 2009 and lowest in 2008.From 2008 to 2010, highest value of AOD was found in monsoon season and the values are 0.515, 0.395 and 0.390 respectively. Since for 2011 only the data of winter season was available and the value came to be 0.085. We got the lowest values of AOD in winter season with an average value of 0.079 and highest values in monsoon season with an average value of 0.433. In pre-monsoon season the average value of AOD was found to be 0.397, while that in post-monsoon season was 0.126.

Year-wise variation of AOD, angstrom exponent and precipitable water

Year wise variation of AOD at 500 nm ($\tau_{a,\,0.5}$) is shown in Figure 2 (top left panel). We found that AOD takes its highest value in 2010 and the value is 0.2444. In, 2011 the value is least (0.0911) but this is because of the availability of data only up to February 2011. Similarly the data we have taken is available from April 2008, so we get comparably less amount of AOD (0.2399) in year 2008. The content of AOD in 2009 was 0.2405.

In the right panel of Figure 2, we have plotted year wise variation of angstrom exponent (440-870 nm). We found the highest value of angstrom exponent in 2011, although only the data of January and February, 2011 was available. The value of α_{ext}in this year was 1.367. Angstrom exponent was found 1.173 in the year 2008 and it is second highest value among the available data, although the data in 2008 was available from May 2008. We found the lowest value of angstrom exponent (0.967) in 2009 and in 2010, it was found to be 1.107.

Year wise variation of precipitable water is shown in the lower panel of Figure 2. We got a decreasing trend in precipitable water with the progression of time (in year). The maximum value was obtained in 2008 and it was 1.066 cm, while it was 0.948, 0.944 and 0.364 cm in 2009, 2010 and 2011 respectively.

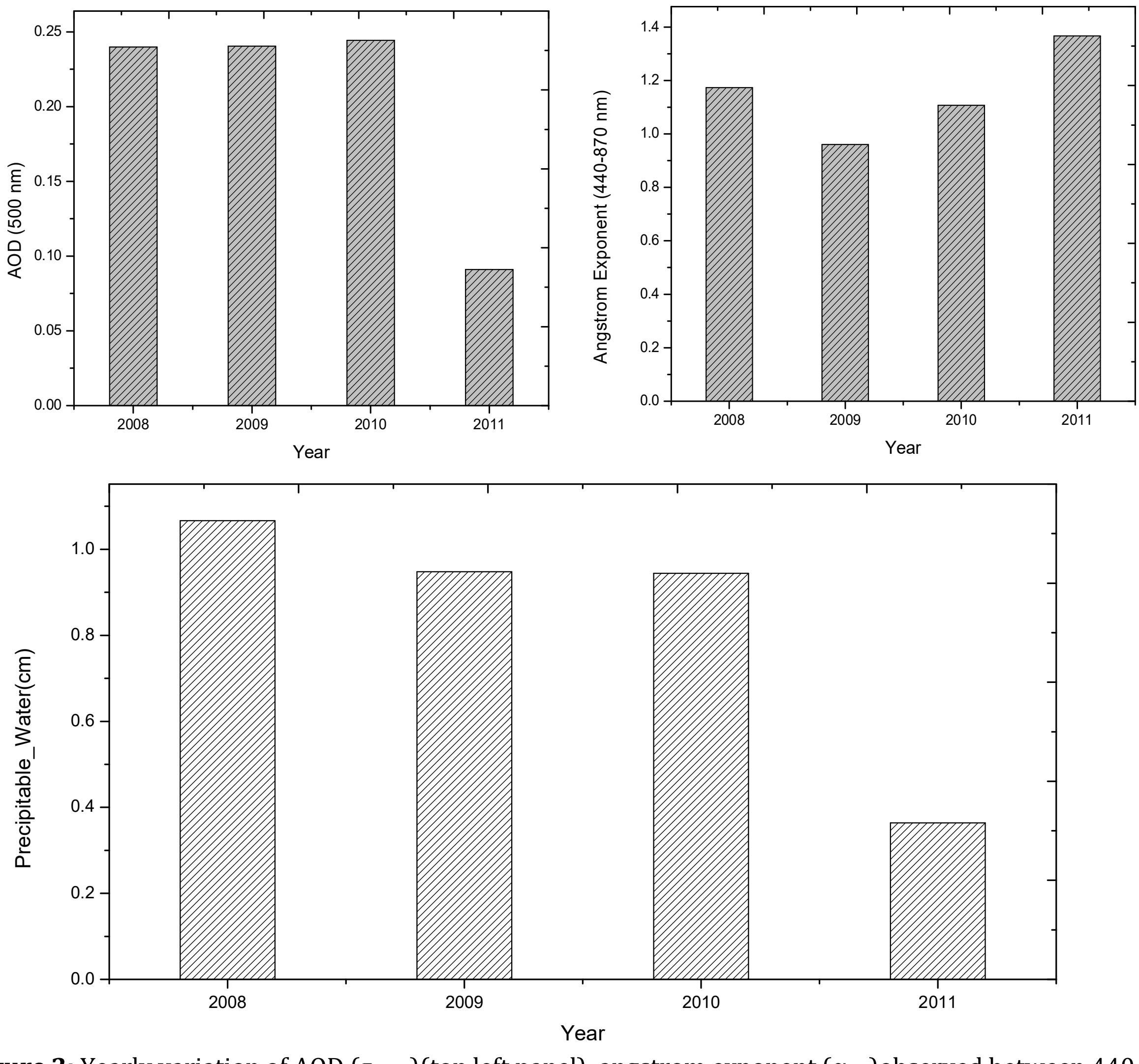

Figure 2: Yearly variation of AOD ($\tau_{a,\,0.5}$)(top left panel), angstrom exponent (α_{ext})observed between 440-870 nm (top right panel) and precipitable water (lower panel).

Monthly variation of precipitable water

The monthly variation of precipitable water for different years is shown in Figure 3. In the left top panel of Figure 3 monthly variation of precipitable water is shown for 2008. The maximum precipitation of water was 2.145 cm in the month of the June and minimum value was obtained in the month of November and December (0.409 and 0.447 cm respectively). Similar trend was found in 2009 also (top right panel of Figure 3). From January to July, the value of precipitable water rises; from July to December, it falls. The lowest value was obtained in the month of December and it was 0.384 cm and in January it was 0.396. The highest value of precipitable water was 2.132 cm (in July). In 2010 (bottom left panel of Figure 3), it was found that the precipitable water had a proper trend of growing (from January to July) and falling (from July to December). The highest value found was 2.163 cm and lowest value was found to be 0.290 cm in January. In 2011 (bottom right panel of Figure 3), only two month data (January and February) was available. It increases from January to February and the values were 0.273 and 0.455 cm.

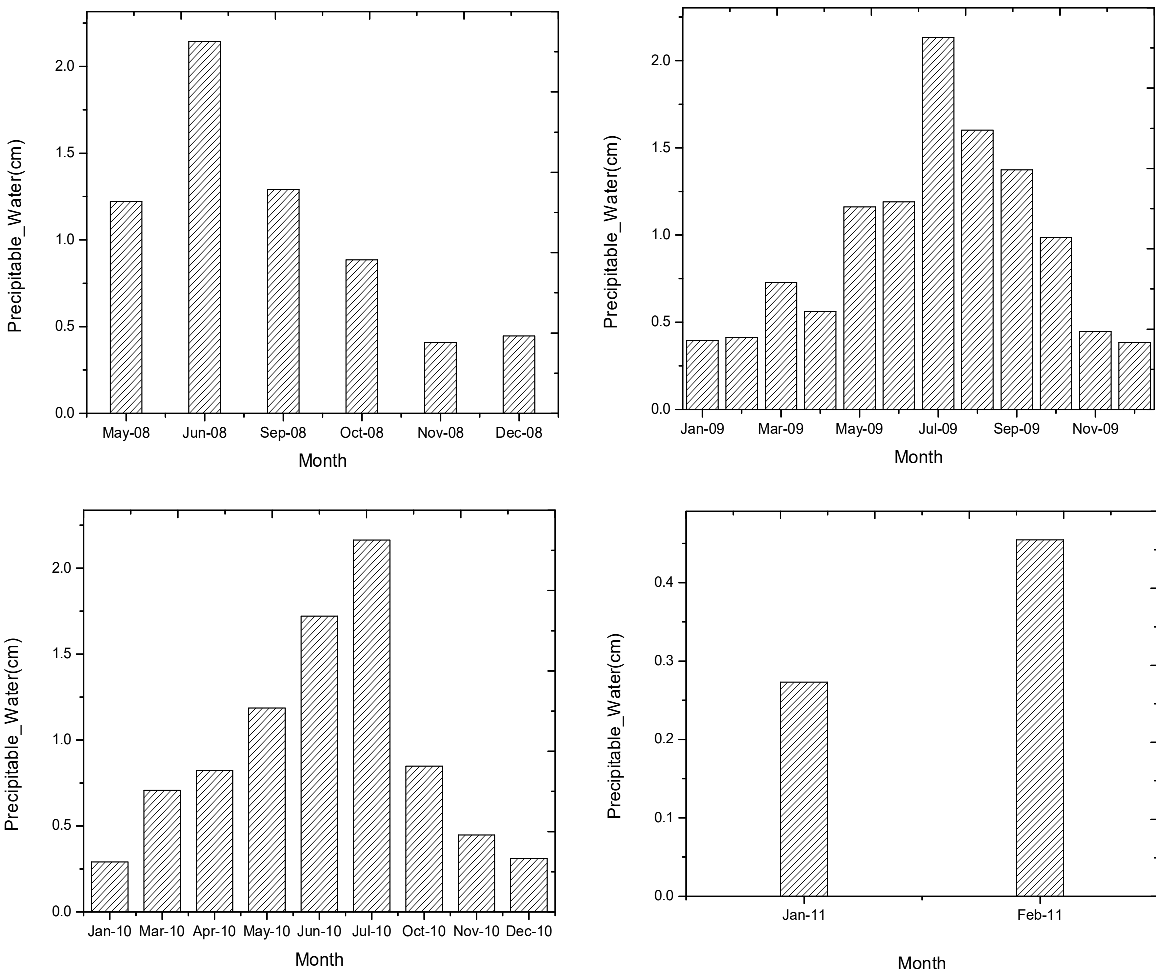

Figure 3: Monthly variation of precipitable water in 2008 (top left panel), 2009 (top right panel), 2010 (bottom left panel) and 2011 (bottom right panel).

AOD variation with angstrom exponent and precipitable water

The variation of angstrom exponent is studied with AOD at 500nm with the help of a scatter plot shown in Figure 4 (left panel).With help of a regression line analysis we found that the angstrom exponent and AOD are anti-correlated and the correlation coefficient was -0.59. The standard deviation was found to be 0.26. On the other hand the precipitable water was very well correlated (right panel of Figure 4) with AOD and this correlation coefficient was 0.79. The standard deviation was found as 0.37.

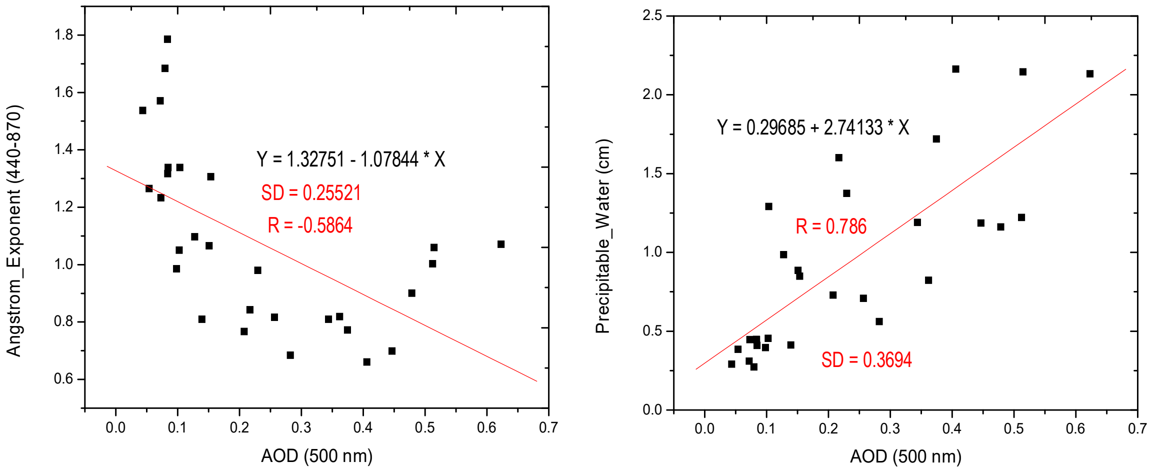

Figure 4 Scatter plots showing the variation of angstrom exponent (α_{ext}) observed between 440-870 nm with AOD ($\tau_{a,\,0.5}$) (left panel) and variation of precipitable water with AOD ($\tau_{a,\,0.5}$)(right panel).

DISCUSSION AND CONCLUSION

From Figure 1 we found that the AOD had the higher values during pre-monsoon and monsoon season over all the years under consideration. We encountered a decreasing trend in AOD during monsoon season from 2008 to 2010, means in 2008 during monsoon season the atmosphere was most hazy and rainiest season as compared to that in other years. Moreover the yearly average is also highest in 2008 which infers the increment in the natural aerosols over this year. We got the second highest AOD values for pre- monsoon season and lowest for winter season which indicates the increment in the anthropogenic aerosols during the pre-monsoon season. Seasonal variation was explained by Sing et. al, 2004. Later on it was also discussed by Dey *et. al,* [3], but they performed their study over Kanpur region. In Nainital town, because of its fame as a cold and tourism place, the population and traffic becomes so high that the mist, dust and air pollution generated in this season becomes very high. As a result the anthropogenic aerosols increase in this season, which become comparable to monsoon season. In winter and pre-monsoon season because of the cold weather of Nainital town the anthropogenic aerosols decrease.

We found an opposite relation in AOD and angstrom exponent, which can be confirmed from Figure 1 and left panel of Figure 4. In Figure 1 the seasonal variation in AOD and angstrom exponent shows the reverse relation between them, because AOD values are increased during pre-monsoon and monsoon season but angstrom exponent was increased during winter and post-monsoon season, which confirms the earlier results[2, 3, 16]. From Figure 4 also we found anti-correlation between these two parameters. During the winter and post monsoon season the coarse mode aerosols become less but the fine mode aerosols increase in number. Since the α_{ext} is measure of the particle size distribution of aerosols. Dominancy of fine mode particles increases the value of α_{ext}. During the winter and post-monsoon season the anthropogenic fine mode aerosols become higher as compared to the monsoon season (because of the snow fall during this season tourism increases), and natural coarse mode aerosols are not available during these seasons, all these effects increase the α_{ext} during these seasons.

We studied the variation of precipitable water with AOD and seasonal variation over the study period. We found that the precipitable water content was highest during the monsoon season as expected and becomes least in the winter and post monsoon seasons. The correlation between precipitable water and AOD was found very strong (0.79), which indicates the hygroscopic growth of aerosols and the results are in well agreement with various previous results studied over different areas of India [15, 6, 17, 10].

This study done over the Nainital town reveals that formation of aerosol particles and precipitable water is highest during the monsoon season. Since Nainital is a cold and tourist place so during the pre-monsoon season the dust, mist and air pollution becomes so high that AOD value becomes higher as close as that in the monsoon season.

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