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Correlative study of Aerosol Optical Depth with Precipitable water over five AERONET stations worldwide

Santosh Sapkota[1,*], Sabin Gautam[1], Aayush Gautam[2], Bhairab Ale[1]

[1]*Prithvi Narayan Campus, Tribhuvan University*
[2]*Birendra Multiple Campus, Tribhuvan University*

[*]Corresponding author. Email: ssapkota922@gmail.com

Abstract

Ground-based measurements were taken at various locations, including Kathmandu Bode, Beijing, Gandhi College (located in the South Asian zone, highly polluted area), Canberra, and UNC Gaitan (located in the South Eastern zone, low polluted area), from January to December 2016. The study investigated the seasonal and inter-annual AOD that were obtained using the CIMEL Sun photometer, as a part of the Aerosol Robotic Network (AERONET). The data showed that Kathmandu (0.45±0.01), Gandhi College (0.45±0.02 and Beijing (0.85±0.03) had higher Aerosol optical depth (AOD) values compared to other stations, with Beijing being a high-altitude site. The analysis found that pre-monsoon AOD were higher over Kathmandu (0.45±0.01), Gandhi College (0.45±0.02), UNC Gaitan (0.28±0.001), and Canberra (0.06±0.002). On the other hand, the monsoon AOD was higher over Beijing (0.85±0.03). The study identified factors contributing to the higher AOD values in specific regions. Beijing, Gandhi College, and Kathmandu, located in Asian monsoon regions, experienced high aerosol loading due to economic activities, vehicles, urbanization, vegetation fire, land clearing for crop cultivation, as well as winter biomass burning, heating needs, and pollution from bricks kilns, factories, and vehicles. Canberra and UNC Gaitan had higher AOD values primarily due to biomass burning, household activities and dust. AOD values are higher for shorter wavelengths and vice-versa. We conducted a correlation analysis between AOD and precipitable water at different wavelengths and observed one-to-one correspondence. The columnar water vapor (CWV) exhibited a high correlation with AOD in Canberra (Coefficient of determination, R^2 = 0.61) at 1640 nm but had no relationship with AOD in Gandhi College (Coefficient of determination, R^2 = 0) at 1640nm. There is a weak negative correlation between AOD and precipitable water over Kathmandu and UNC Gaitan, but there is a positive correlation in Canberra, Beijing and Gandhi College.

Keywords
Aerosol, Aerosol Optical Depth, Precipitable water.

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1 Introduction

Aerosols are tiny solid or liquid particles that are suspended in the atmosphere due to both natural and manmade (anthropogenic) causes, with sizes ranging from nanometers (nm) to tens of micrometres (µm). Aerosols are produced in the atmosphere through various natural and anthropogenic processes, and they get dispersed horizontally and vertically through prevailing atmospheric circulation. In recent years, there has been a substantial increase in interest in studying natural and anthropogenic aerosols because of their influence on climate through direct and indirect radioactive effects [1]. Despite this, aerosols are still a major source of uncertainty in the prediction of climate change due to inadequate information on the variabilities of aerosol characteristics on regional and temporal scales [1]. Aerosol optical properties, i.e., the physical and chemical characteristics of the aerosol, are responsible for diffusing or absorbing both incoming and outgoing radiation and thus have an impact on both the climate and the earth's radiative balance [2]. In addition to their indirect effects on cloud formation, reducing visibility, and human health [3]the scientific community has become increasingly interested in suspended aerosol particles during the past few decades. The most complete variable for determining the aerosol burden in the atmosphere from ground-based equipment is aerosol optical depth (AOD). This variable is employed in regional studies to describe aerosol size distribution and evaluate air pollution [4–6]. AOD is measured using ground-based Sun photometers between the wavelengths of 340 and 1020 nm, with extended wavelength versions also having 1640 nm [7]. South Asia comprises India, China, and Nepal. It is densely populated and people face environmental threats in terms of air pollution, monsoon floods, droughts and associated climate change [8]. Australia and America lie in Eastern Asia. It was acclaimed that the AOD of shorter wavelengths is more dominant than the longer ones because of the Angstrom exponent [9]. Anthropogenic aerosols over South and East Asia can significantly change the energy balance of the Earth-atmosphere system on regional scales [10].

Precipitable water vapor, or simply, precipitable water is the total amount of water vapor in the zenith direction, between the underlying surface (or a surface of particular height) and the top of the atmosphere. It is crucial to monitor and comprehend how precipitable water vapor content changes because it affects atmospheric water movement, energy conversion, and the formation of clouds and precipitation [11, 12]. We analyzed the Correlation between aerosol optical depth (AOD) and precipitable water (PW). Conducting a correlation analysis between the aerosol optical depth (AOD) data and precipitable water can provide valuable insights into the proposed method for estimating the relationship between these two variables.

In the present study, for the first time, we analyse aerosol characteristics from five locations spread over a large region in South Asia and the southeastern zone during different seasons to examine the space-time variation in aerosol characteristics, the correlation between AOD and Precipitable water and the effect of long-range transport. Daily measurements of aerosol optical depths in the 870nm–1640nm wavelength region made during 2016 over Kathmandu Bode, Gandhi College, Beijing, Canberra, and UNC Gaitan are used in the study. An analysis and documentation on the monthly and seasonal variabilities in aerosol optical characteristics, attain significance in the context of air quality, air pollution and regional and global climate.

2 Data and Methodology

This research is focused on the various aerosol properties over five stations. We have used AERONET (level 2 version 3) data for our analysis which are quality-assured data of these sites over the period of a year from January 2016 to December 2016. We have plotted a correlation analysis between AOD and Precipitable water.

The term "correlation analysis" refers to the process of establishing a link between two (or more) quantitative variables using a scatter plot and straight-line assumptions [13]. The connection between the quantitative variables assesses both the direction and "strength" or "extent" of an association between the variables. When two variables have a correlation value of 1, it means that they are perfectly associated positively, a correlation coefficient of -1 means that they are perfectly related negatively, and a correlation coefficient of 0 means that there is no linear relationship between the two variables [14]. The coefficient of determination (R^2) is calculated as the proportion of the variability in the dependent variable that is explained by the regression mode.

$$R^2 = 1 - \frac{\text{sum of square regression (SSR)}}{\text{total sum of squares(TSS)}} \quad (1)$$

The closer R^2 is to 1, the better the regression model explains the variability in the dependent variable. If R^2 is closer to 0, it means that the regression model does not explain much of the variability. We performed the graphical analysis using the Levenberg-Marquardt least orthogonal distance method. The data were then analyzed by using Non-linear regression analysis and the least square technique, and a coefficient of determination (R^2) was obtained, where m is the slope, and c is the intercept, which represents AOD or PWV measurements from Aeronet. A personal correlation coefficient (R) was calculated to determine the significance of the correlation.

To explore the seasonal fluctuations in aerosol optical characteristics, the study establishes four distinct seasons: pre-monsoon (March–May), summer (June–September), post-monsoon (October–November), and winter (December–February).

Table 1: Station with the geographic location of different countries of the world.

SN	tation Name	Country	Longitude	Geographic Latitude	AMSL (m)
1	Kathmandu Bode	Nepal	27.680°N	85.103°E	1297
2	Gandhi College	India	25.871°N	84.261°W	60
3	Beijing Radi	China	40.005°N	116.379°E	59
4	Canberra	Australia	35.271°S	149.111°E	600
5	UNC Gaitan	South America	4.311°N	72.3518°W	192

3 Results and Discussion

3.1 Variation of AOD with wavelength

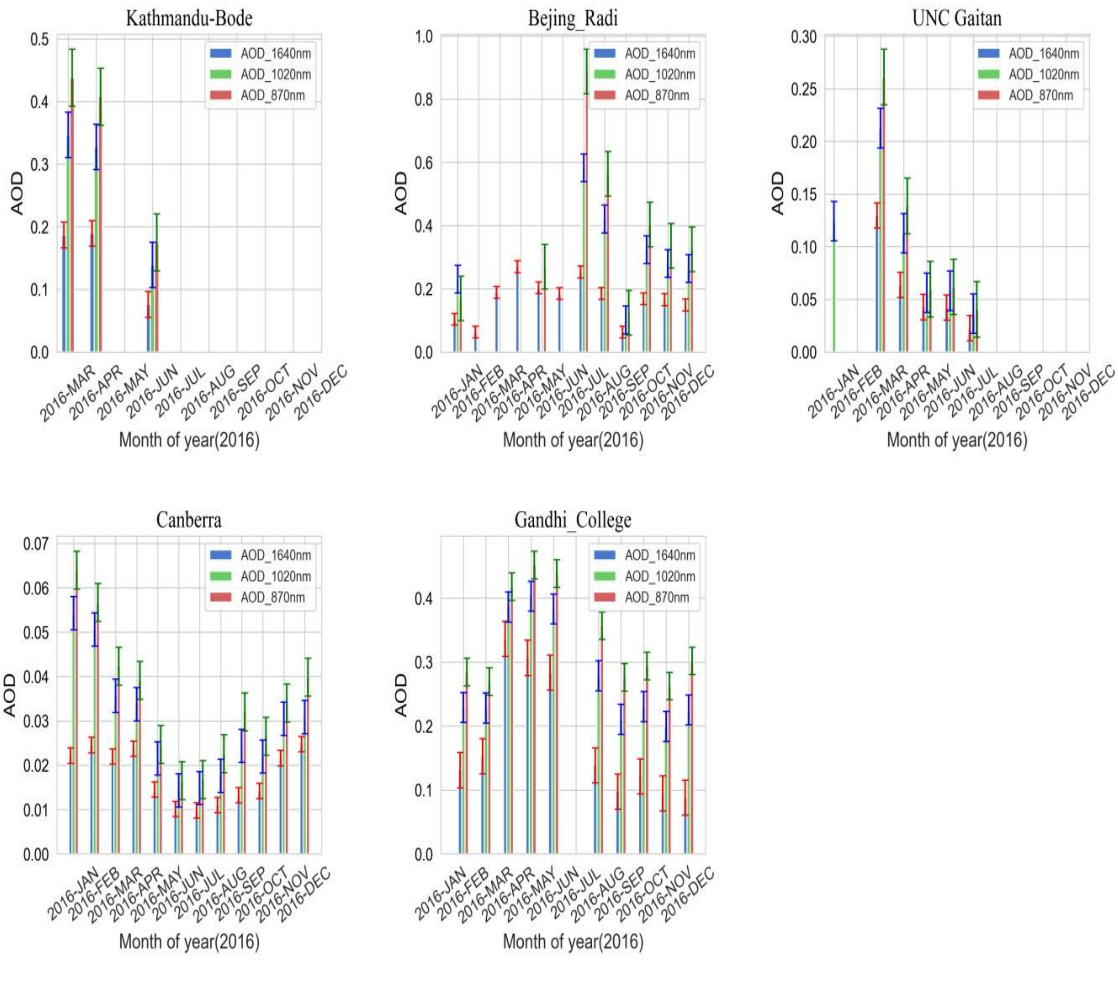

Figure 1: Variation of AOD with wavelengths at different stations over the world.

In contrast to UNC Gaitan, the difference in AOD at shorter and longer wavelengths is not significant, suggesting a lower concentration of fine-mode aerosols. AOD could not be measured over UNC Gaitan and Kathmandu due to fog, cloudy and overcast conditions during the post-monsoon and winter seasons. AOD over UNC Gaitan was found to be highest (0.28±0.001) and lowest (0.04± 0.001) during pre-monsoon and monsoon season. The highest value of AOD is due to affected by the long-range transport of dust particles.

Over Beijing, monthly average spectral AOD, which was typically at its highest during the summer, with a high of (0.9± 0.08) in June, indicating the most intense desert dust advection. The lowest monthly mean spectral AOD (0.1±0.002) occurs during the winter season, with the lowest value occurring in January. The highest and lowest monthly mean AOD occurred in July and December, respectively, according to AOD (750nm) data from pyrheliometer measurements [15, 16], which acquiesce with our values.

Moreover, the monthly average maximum AOD at Gandhi College value of (0.45±0.03) during premonsoon. The monthly average AOD varied from 0.1±0.02 to 0.45±0.03, which is significantly less than the range seen in Beijing and Kathmandu. Previous Studies of AOD (500 nm) [17] explored that the highest AOD in Gandhi College occurs in June indicating the majority of the year due to hygroscopic growth and Biomass burning. During the pre-monsoon season, the majority of dust came from arid regions of western China and Mongolia, which moved eastward, showing the dominance of coarse particles [18].

Based on the values of AOD, Canberra is the most pristine site than other stations. The highest AOD was in December (0.07±0.001), and the lowest was in June (0.02±0.008). AOD values at Canberra peaked in pre-monsoon (0.06± 0.002), while AOD values were down in monsoon (0.01±0.002). This can be explained by the extensive and frequent wildfires over the tropical north of Australia. This is likely a consequence of the relatively high rainfall during the wet season and large smoke emissions during the subsequent burning season. The rainfall likely suppressed the smoke emissions due to the high level of moisture in the air, but it also promoted the growth of vegetation, leading to an increase in smoke emissions during the subsequent dry seasons which lead to higher AOD.

3.2 Correlative Analysis between Precipitable Water (PW) and AOD

We have calculated the Coefficient of determination of AOD having three different wavelengths with Precipitable Water. The Coefficient of determination (R^2) between AOD and Precipitable Water for respective stations is mentioned in the table below.

At Kathmandu station, the coefficient of determination (R^2) between AOD and precipitable water are 0.04, 0.027, and 0.027, respectively, which indicates a weak positive correlation (Fig 2). that when there is more precipitable water, there is a decrease in aerosols or particulate matter in the atmosphere.

At the station, Gandhi College, R^2 between AOD and precipitable water are 0.011 and 0.025, respectively, which suggests that AOD and precipitable water are weakly correlated (Fig 3). However, the Coefficient of determination is found to be zero between precipitable water and AOD, which has a wavelength of 1640nm implying that there is no correlation, the presence or absence of aerosol particles at 1640 nm does not have a significant impact on the amount of water vapor present. Local atmospheric conditions, different altitude profiles, and statistical Noise might cause zero correlation. The weak positive correlation implies that when there is precipitable water, there is an increment of aerosols or particulate matter.

At station Canberra, the coefficients of determination, AOD and precipitable water are 0.61, 0.382, and 0.402 (Fig 4). A positive correlation between AOD and precipitable water was seen due to Aerosol cloud interaction, Bushfires and aerosol emission [19]. Similarly, at station Beijing, the coefficient of determination was found to be 0.108, 0.089, and 0.365 (Fig 5), which indicates that the AOD and precipitable water have a weak positive correlation.

Lastly, in the case of UNC Gaitan station, the coefficients of determination between AOD and precipitable water are 0.084, 0.035, and 0.198 (Fig 6). The negative correlation between AOD and precipitable water might be due to aerosol-induced atmospheric change, microphysical effects and local pollution effects [20].

Table 2: Coefficient of determination between AODs having wavelength 1640, 1020, 870 nm and Precipitable Water.

S.N.	Station Name	Coefficient of determination(R^2)		
		AOD (1640 nm)	AOD (1020 nm)	AOD (870 nm)
1.	Kathmandu Bode	0.04	0.027	0.027
2.	Gandhi College	0.00	0.011	0.025
3.	Canberra	0.61	0.382	0.402
4.	Beijing	0.108	0.089	0.365
5.	UNC Gaitan	0.084	0.035	0.198

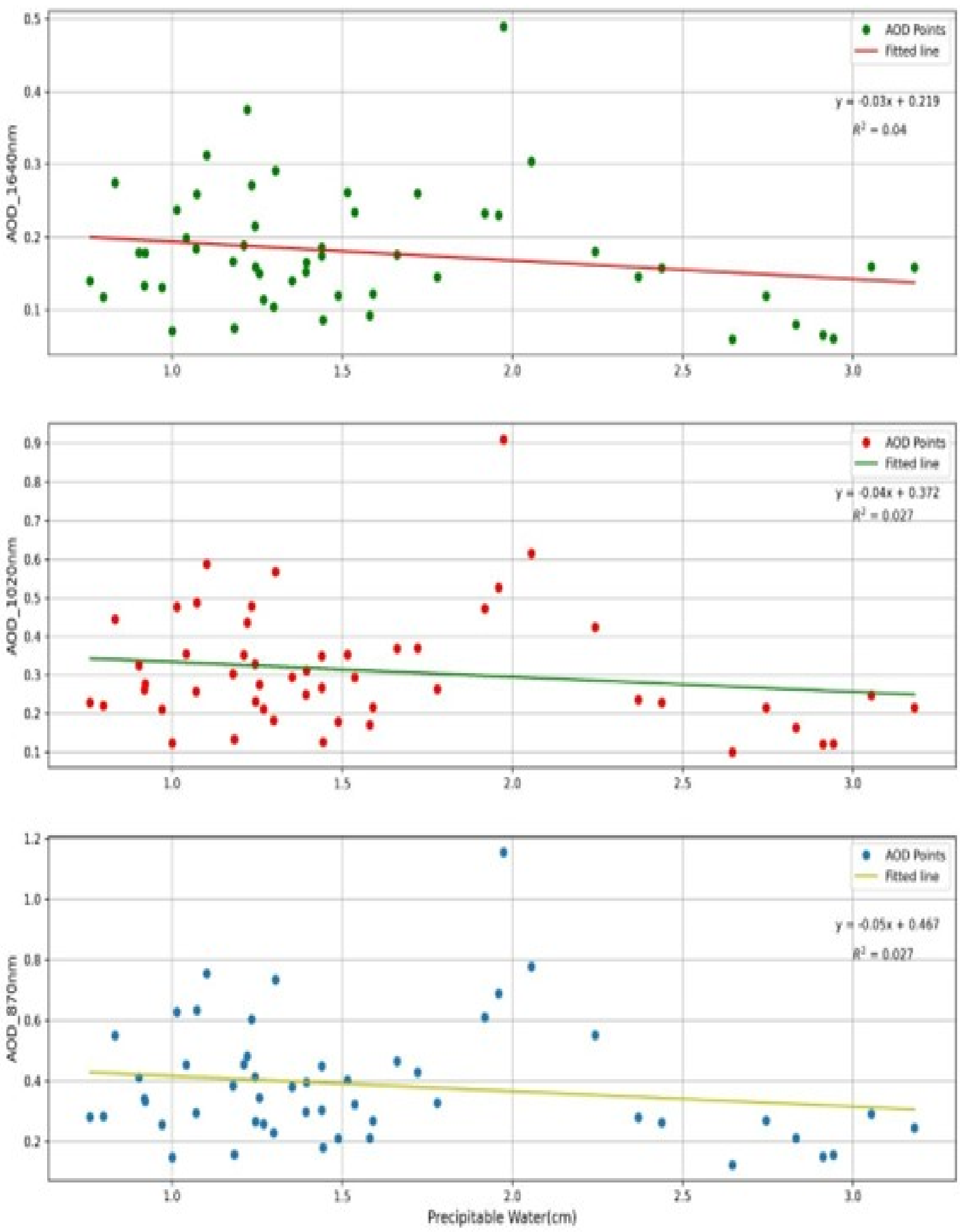

Figure 2: Correlation between Precipitable Water and AOD of Kathmandu Bode locations of Nepal at different wavelengths.

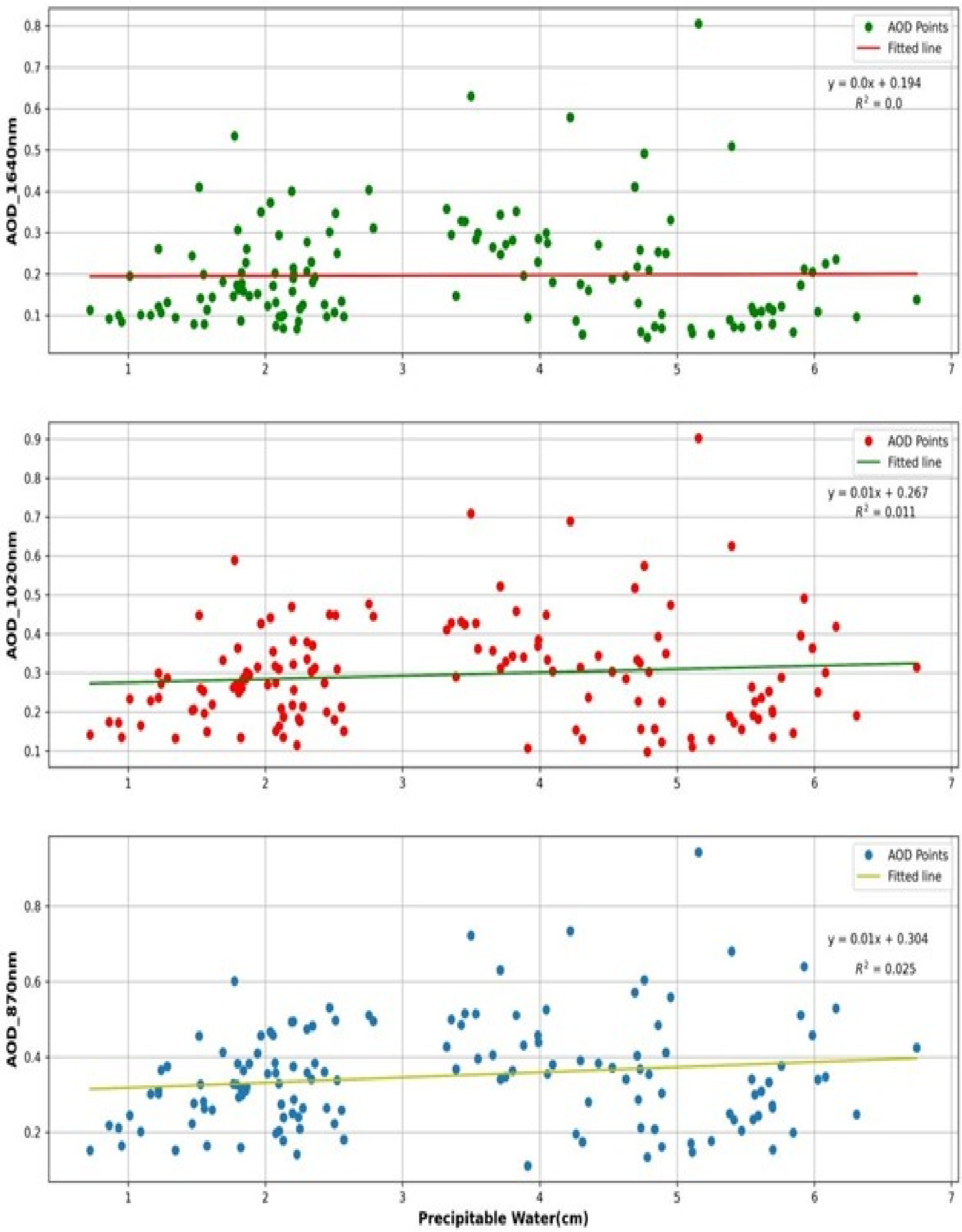

Figure 3: Correlation between Precipitable Water and AOD of UNC Gaitan, locations of India at different wavelengths.

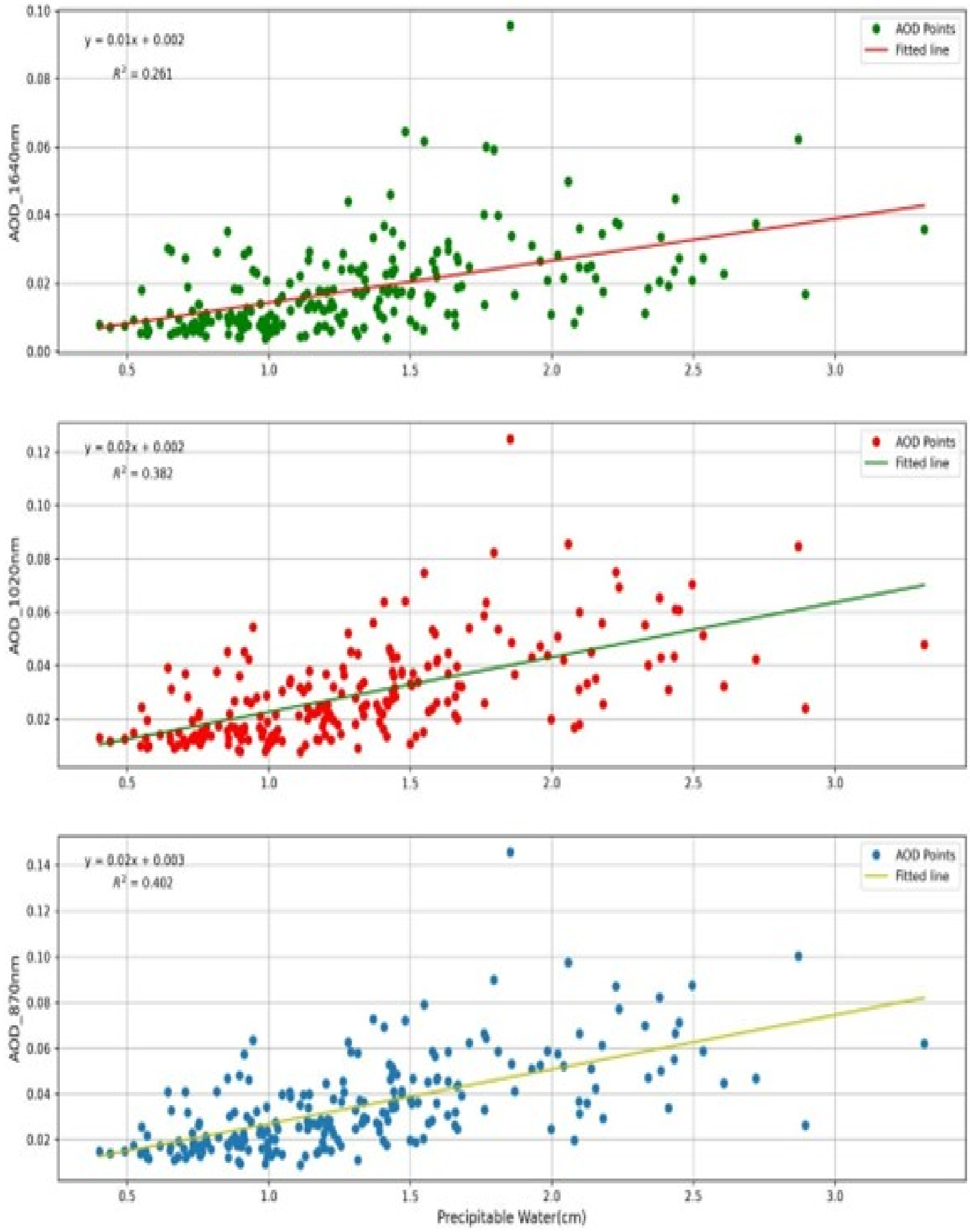

Figure 4: Correlation between Precipitable Water and AOD of Canberra locations of Australia at different wavelengths.

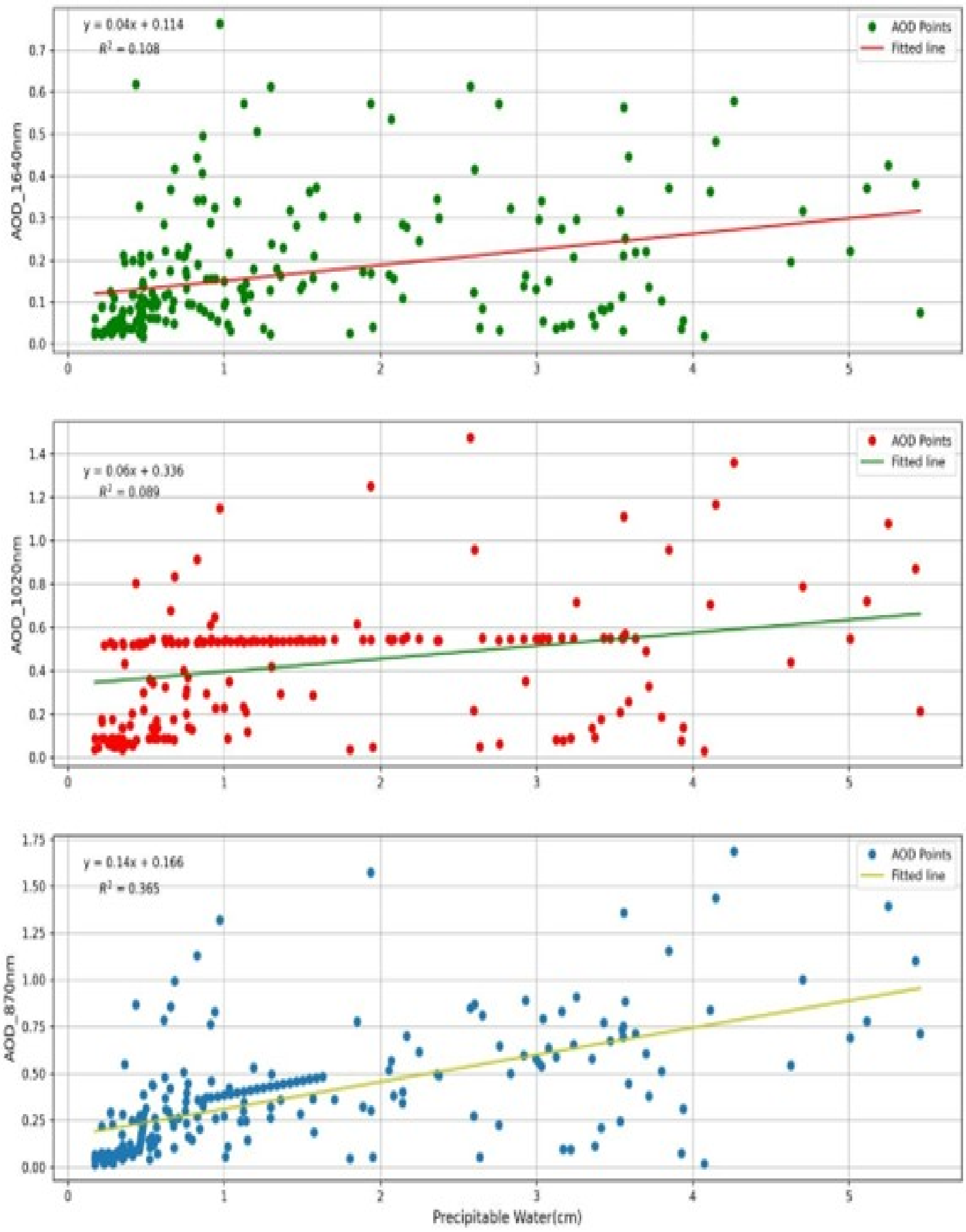

Figure 5: Correlation between Precipitable Water and AOD of Beijing locations of China at different wavelengths.

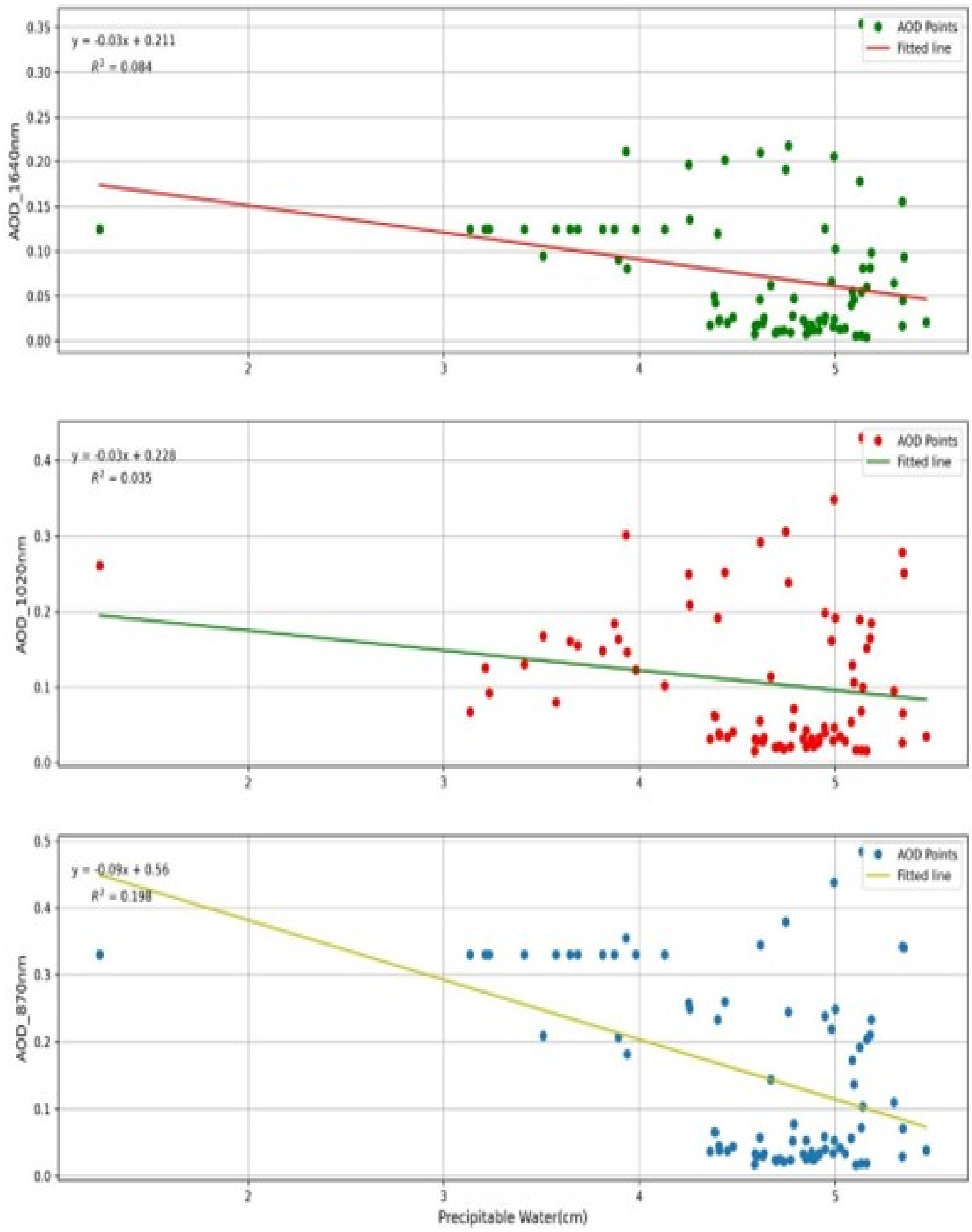

Figure 6: Correlation between Precipitable Water and AOD of UNC Gaitan locations of South America at different wavelengths.

4 Conclusion

The aerosol optical properties as a variation of AOD and its correlation with precipitable water are investigated over five stations. The values of AOD with wavelengths of 870nm have a higher value than AOD with wavelengths of 1020 and 1640nm. Thus, AOD with short wavelengths can have a higher precision in measuring the size of aerosols. The monthly variability of the aerosol optical depth is significant over all stations due to the prevailing meteorology, airmass transport, and atmospheric conditions. Monthly and seasonal variations of the AOD are different for each month. The lowest AOD was seen in Canberra (0.03 ± 0.001) but the highest was in Beijing (0.85 ± 0.02). The higher AOD was seen during pre-monsoon due to agricultural activities, biomass burning and local products. The amount of aerosol plays an important role in precipitation. If there are a large number of aerosols, then water molecules will have more options for condensation because of which small clouds are formed with no or very few precipitations as water droplets in the cloud need to reach critical size for a downpour. Because precipitation is strongly associated with AOD, when there are fewer aerosols in our atmosphere, more water molecules bond to those few particles, generating huge as well as gray clouds that lead to rainfall. As a result, the maximum number of aerosols flush out because it rains. The positive correlation between aerosol (AOD) and precipitable water was seen in Beijing, Gandhi College, and Canberra. However, negative correlation between AOD and Perceptible water in Kathmandu and UNC Gaitan. The correlation between AOD and precipitable water (PW) was significantly good in Canberra, but other stations have a poor correlation. There is no correlation between the AOD wavelength of 1640 nm and the water precipitable at Gandhi College. This study provides a positive correlation between aerosol and precipitable water, due to large dust particles associated with dry air. These can be further studied by using a combination of numerical simulations and satellite observation data.

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