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CHAPTER 16

Study of the aerosol parameters and radiative forcing during COVID-19 pandemic over Srinagar Garhwal, Uttarakhand

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16.1 Introduction

Atmospheric aerosols are the tiny particles in solid/liquid/mixed phases within the ranges of $10^{-3}$ to 100 $\mu$m \cite{Despres2012}. Aerosol has a significant influence on the radiation budget and atmospheric hydrological cycle \cite{Ramanathan2001}. The best mechanism of radiative balance is by scattering the incoming solar radiation, as a result of increasing the Earth’s albedo, absorbing solar radiation and terrestrial radiation \cite{Jacob1986}. Aerosols also act as cloud condensation nuclei, which is helpful to the formation and growth of cloud droplets. The decrease in cloud droplet size may inhibit precipitation formation, extending the cloud lifetime \cite{France2013}.

Various studies have been already carried out to understand the impact of aerosols under a variety of meteorological conditions at a large number of places. The studies were also conducted over different cities of India such as Delhi, Jaipur, Kullu Valley, Nainital, Kanpur, etc. The emphasis in most of these studies is to study the variation trend in aerosol loading and heterogeneity, optical, and microphysical properties in different time periods \cite{Alam2012, Tiwari2013, Kaskaoutis2007}.

On January 30, 2020, the patient zero of deadly COVID-19 virus was reported in the Kerala state of India and in terms of precautions, the social distancing, and lockdown is the prominent way to handle this pandemic, thus the Prime Minister of India announced a nationwide lockdown from March 25, 2020 to April 14, 2020 \cite{Gautam2020}. Based on Moderate Resolution Imaging Spectroradiometer, aerosol products (aerosol optical depth [AOD], single scattering albedo [SSA], and Angstrom exponent [AE]), Ranjan et al. (2020) observed a significant reduction (~45%) in the AOD due to the lockdown over the Indian region. Whereas, Pathakoti et al. (2020) observed only 24%–25% reduction in the AOD during the first phase of lockdown in India.

In the present study, we have reported the aerosol loading and its consequence changes in weather in the year 2019–2020. The findings were also compared nationwide before lockdown (January 1, 2020 to March 24, 2020) and lockdown period (March 24, 2020 to July 31, 2020) conditions to understand the relatively changed AOD due to COVID-19 pandemic.
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16.2 Site description and meteorology

Keeping this objective in mind, we have started observations at the Chauras Campus of Hemvati Nandan Bahuguna, Garhwal University, Srinagar Garhwal (78°46′56″E, 30°13′7″N) during the January 1, 2019 to July 31, 2020 and using an automatic weather station. Further, the data of AOD, SSA, and AE were extracted from satellite-based level 3 Moderate Resolution Imaging Spectroradiometer dataset (https://giovanni.gsfc.nasa.gov/giovanni) and the extracted data were used to calculate and plot the temporal and seasonal variations of aerosol optical parameters (AOD, SSA, and AE) over the Srinagar (Garhwal) Uttarakhand. The Srinagar is situated at the altitude of 560 m asl at the bank of Alaknanda river. The region experience temperate climate; and the temperatures vary from subzero to 43°C with the annual rainfall of 1550 mm. The forest area of the Uttarakhand is 34,691 km², which contributes 64.79% of its geographical area (Forest Survey of India, 2009).

Fig. 16.1 shows the variations of the environmental parameters recoded from January 01, 2019 to July 31, 2020. Due to valley topography, the weather remained sunny and very hot and atmospheric temperature varied from 9.10 to 34.87°C with an average temperature of 21.68 ± 6.86°C during the year 2019. But in the year 2020, the temperature is relatively lower that varies from 8.71 to 33.16°C along with the average values of 21.61 ± 6.85°C. Wind speed remained sometimes high and low and varied from 0.81 to 6.57 m/s with an average level 2.87 ± 1.12 m/s. However, the wind speed is slightly changed in the range 1–6.33 m/s along with an average of 2.56 ± 1.31 m/s during 2020. The wind direction remained westerly and sometimes changed from westerly to easterly. Relative humidity (RH) varied from 27% to 97.07% with an average RH of 69.91% ± 11.41% during 2019. But in the year 2020, the RH changed in the typical range of 33.80%–96.33% with an average 71.03% ± 12.66%. The background meteorological parameters of Srinagar Garhwal Valley (SGV) is also described by the Panicker et al. (2019) and Gautam et al. (2018).

![Time series variation of environmental parameters](image)

**FIG. 16.1** Time series variation of (A) temperature, (B) relative humidity, (C) wind speed, and (D) wind direction at measurement site during January 01, 2019 to July 31, 2020.
16.3 Result and discussions

16.3.1 Variability of aerosol parameters

The AOD has higher levels in the days of June and July of both the year 2019 and 2020. Furthermore, a drastic decline in AOD levels during the months of August and September (Fig. 16.2) was reported in the year 2019. The lower AOD levels in monsoon are may be due to rain and washout (Vinoj et al., 2004). The lockdown has potentially impacted the AOD levels, it is decreased by the approximately 32% in the first week of lockdown and it is reduced by 30.1% in the first phase of lockdown. Furthermore, in the daily variation of AOD levels are reduced in the range of 20%–58.3% during lockdown period (March 24, 2020 to July 31, 2020) as compared to same period of 2019.

In the year 2019, the monsoon was normal and intensified rainfall was observed during the months of August and September over the region. But in the year 2020, lower AOD values were also reported after the July 15, 2020. The reason behind the high AOD values could be the higher aerosol loading activity in early June, July 2019 of monsoon (June, July, and August) months. The AOD levels also showed a significant increase especially in the days of October and November 2019 during postmonsoon (PoM) seasons (October, November, and December) due to burning of biomass. The lower AOD values 0.10 and 0.06 were observed during the winter (January and February) season of 2019 and 2020, respectively (Ramachandran and Cherian, 2008). High AOD values of 0.93 and 0.72 in

![Daily variations of AOD 550 nm and Angstrom exponent (412–470) nm at Srinagar Garhwal Valley during (A) January 01, 2019 to December 31, 2019 and (B) January 01, 2020 to July 31, 2020 and further classified into before lockdown (January 1, 2020 to March 24, 2020) and after lockdown (March 24, 2020 to July 31, 2020) period.](image-url)
premonsoon (PrM) season (March, April, and May) are due to high convective and lifting of aerosols from dry surfaces. Transportation of air mass from Thar desert regions due to dominant northwesterly winds also contributed toward higher AOD values (Sandeep et al., 2020; Li et al., 2017).

Fig. 16.2 represents the daily variation of AE over Srinagar valley from January 1, 2019 to July 31, 2020. The lower values of AE (α) indicate the significant contribution of the larger size aerosols particles and vice versa. In the present study, AE varies in the range of 0.74–1.8 for the year 2019 and 0.95–1.8 for the year 2020, which reveals the presence of various types of atmospheric aerosols over the monitoring site. The different types of aerosols have a different sources & origin, which is also governed by the meteorological parameters over the location.

The monthly variation of the AOD and SSA showed a similar trend during the year 2019 and 2020 (Fig. 16.3). The lowest value of AOD was reported in March (0.27) and the highest value AOD was reported in July (1.37 and 0.80) for both the years 2019 and 2020. But in August of 2019, a drastic change (~38.56%) was observed due to intensified rainfall events in the next months of monsoon season. In the corresponding SSA values, the lowest levels were observed in February (0.92) and April (0.91) for the year 2020 and whereas high values were found in August (0.955) and June (0.952) in the year 2019 and 2020, respectively (contradictory statement for year 2020).

The AOD levels in April, May, June, and July of the year 2020 are remarkably deduced by 15.30%, 15.77%, 8.39%, and 41.74% as compared to the year 2019 along with SSA level that changed in the range of 1%–10% as compared to 2019. The SSA values vary from 0.91 to 9.5 in our study, which lies in the previously reported range (0.88–0.94) by researchers in India Moorthy et al. (2007); Patel and Kumar (2015).

Fig. 16.4 depicts that in the premonsoon season, α is comparatively smaller with α < 1.0 ($r \geq 0.5 \mu m$), which reveals to the presence of larger size of aerosols emitted due to the burning of agricultural wastes (biomass burning [BB]) as well transportation of aerosols from Thar and Sahara desert (Singh et al., 2004). Whereas in the winters α > 1.0 ($r \geq 0.5 \mu m$), which purely indicates the dominance of smaller aerosol. Tiwari and Singh (2013) also observed the temporal variation of the AE over Varanasi (Indian Gangetic plains) in the range of 0.25–1.8 during 2011.

In the atmosphere, the chemical composition of aerosols particles changed with their residence time and thus aerosols can be present in the different mixing phases, which govern the optical and physical properties of atmosphere. The variation in the RH and temperature affects the aerosol radiative forcing (Holben et al., 2001). The scatter plot between AOD550 nm and α 550 nm is a vital tool for the classification of aerosols (Kaskaoutis et al., 2007). Based on threshold values, the characterization is performed for the aerosol types and aerosol range (Kaskaoutis
et al., 2009; Patel and Kumar, 2015). In this chapter, same characterization methodology is adopted as computed by Kaskaoutis et al. (2009) over Hyderabad and Patel and Kumar (2015) over Dehradun. The desert dust (DD) consider if AOD values >0.6 and $\alpha$ < 1.0, whereas AOD values <0.2 and $\alpha$ > 0.5 is for the clean conditions (CC). BB is characterized if AOD values is >0.8 and corresponding $\alpha$ is >1.0. The anthropogenic aerosols (AA) associated in the AOD range of 0.3–0.8 with $\alpha$ > 1.0, while AOD and $\alpha$ in the range of 0.2–0.6 and 0.4–1.0 consider for mixed aerosols (MA). The seasonal scatter plot of AOD (550 nm) versus $\alpha$ 550 nm for Srinagar (Garhwal) gives fine details of four type of aerosol (Fig. 16.4). The DD is absent during 2020, but dominantly present in the PrM and monsoon of year 2019. The contribution of BB is reported very (not clear to me) only in the PrM, monsoon, and PoM. The AA has a significant contribution over the monitoring site throughout the observation. Whereas the MA was predominantly present in the atmosphere due to different atmospheric activities (BB vehicle moments, etc.). Also, the CC condition was observed in all seasons.

16.3.2 Aerosol radiative forcing

We have calculated the aerosol radiative forcing by using differential method (Conant, 2000). In which, a day with lowest AOD in every month is considered as the reference day as termed as the reference AOD, and corresponding fluxes are treated as reference fluxes. The change between the average net fluxes on rest other days

![Fig. 16.4 Scatter plot of the AOD500 nm versus Angstrom exponent (AE) for the discrimination of different aerosol types during (A) January 01, 2019 to December 31, 2019 and (b) January 01, 2020 to July 31, 2020 at Srinagar Garhwal Valley.](image-url)
and referenced day is further correlated to obtain aerosol radiative forcing. The difference between the average net fluxes on other days concerning the reference day is correlated with the change in AOD, to estimate ARF (Conant, 2000; Srivastava et al., 2011). We have also computed the seasonal radiative forcing for winter, PrM, monsoon, and PoM seasons (Fig. 16.5). During the year 2019, the PrM season shows the highest ARF ($-43.93 \pm 39.62 \text{ w/m}^2$) followed by the monsoon ($-37.50 \pm 22.3 \text{ w/m}^2$), PrM ($-30.62 \pm 24.65 \text{ w/m}^2$), and PoM ($21.06 \pm 11.8 \text{ w/m}^2$). But in the year 2020, the highest ARF was observed in the PrM ($-61.39 \pm 25.08 \text{ w/m}^2$) followed by the monsoon season ($-34.61 \pm 21.36 \text{ w/m}^2$) and winter ($-19.42 \pm 7.48 \text{ w/m}^2$). Panicker et al. (2019) also estimated atmospheric radiative forcing based on elemental carbon (EC) and organic carbon (OC) extracted from particulates matter sample over Srinagar.

16.3.3 Source appointment and transportation of aerosols

To identify the source of atmospheric aerosols over Srinagar (Garhwal), 5-day air mass back trajectories (AMBT) were computed using meteoinfo software (version 1.9) with a TrajStat Plugin (version 1.4.8b1) at 500, 1000, and 1500 m asl level are analyzed seasonally. The required input trajectory data were extracted from NOAA’s Global Data Assimilation System (GDAS, $1^\circ \times 1^\circ$) and further trajectories were calculated by using the Integrated Trajectory (HYPLIT) model of Stein et al. (2015). The AMBT were calculated for 120 hours to identify possible ways of transportation of Aerosols.

Fig. 16.6A represents that in winter season the air mass is coming from European, African countries, whereas in the PrM the trajectories are originating from the Middle East and Sahara desert via Pakistan to Srinagar as well as from Thar desert (Fig. 16.6B). In the case of monsoon, dominantly air mass is coming from the Arabian Sea and Bay of Bengal branch at a lower altitude (500 and 1000 m) but at higher altitude partially trajectories are coming from Middle East region along with local emission (Fig. 16.6C). Also Fig. 16.6D indicates the origin of air mass from Afghanistan, Middle East, and Middle West during PoM season. In the year 2020, the variation of air mass is similar to the year 2019 (Fig. 16.7) during winter, PrM, and monsoon. The long-range transports of atmospheric aerosols are dominantly during winter followed by the PrM and PoM seasons.

The location site Srinagar is very close to Dehradun, Rishikesh, and Haridwar and these cities are comparable polluted cities in the compassion of other cities of Uttarakhand. From Rishikesh, the mountain height gradually increases with altitude. Although, there is no land for farming in surrounding regions and forest fires frequently occur in the PrM season over surrounding regions. Harvesting of the wheat crop in the PrM period, resulting in a large amount of the straw in the land farm (Badarinath et al., 2009).

![Fig. 16.5](image-url)  
**Fig. 16.5** Seasonal aerosol radiative forcing at Alaknanda Valley, Garhwal Himalaya, Uttarakhand for January 01, 2019 to December 31, 2019 and January 01, 2020 to July 31, 2020 at Srinagar Garhwal Valley.
16.3 Result and discussions

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FIG. 16.6 Five days air mass back trajectory (AMBT) analysis air mass back trajectories for the observed aerosol types over Srinagar (Garhwal), Uttarakhand for (A) winter, (B) premonsoon, (C) monsoon, (D) postmonsoon season in the year 2019 (January 01, 2019 to July 31, 2019).

FIG. 16.7 Five days AMBT analysis for (A) winter, (b) premonsoon, and (c) monsoon over Srinagar Garhwal Valley during the year 2020 (January 01, 2020 to July 31, 2020).
16.4 Conclusions

We have examined the different kind of aerosols and generation mechanism over this station. The study of the satellite-based aerosol products over the central Himalayan region provides the fine details of the characteristics of aerosol types and based on our analysis we are able to conclude our major finding as

1. Srinagar was also influenced by high AOD (550 nm), especially during PrM and it was decreased by 32% in the first week of lockdown as well as reduced by 30.1% in the first phase of lockdown.
2. In the April, May, June, and July 2020, the AOD was drastically reduced by 15.30%, 15.77%, 8.39%, and 41.74% as compared to the year 2019. The SSA level was also changed in the range of 1%-10% as compared to 2019.
3. The higher AOD levels were reported in the days of June 2019 (1.12), June 2020 (1.23), July 2019 (0.99), and July 2020 (0.83) may be due to late intensified rainfall and transportation of aerosols from Thar and Sahara deserts and local emissions. But further a drastic decline was also reported in August and September 2019 due to precipitation/ washout of aerosols from atmosphere.
4. The high values of AOD (0.93; 2019 and 0.72; 2020) in days of PrM season were attributed due to forest fire activities and lifting of aerosols particle from dry lands.
5. In this study, the AE ($\alpha$) varies in the range of 0.74–1.8 and 0.95–1.8 between the year 2019 and 2020, respectively, which indicates the presence of a different type of atmospheric aerosols from a different source and origin. The SSA value varies from 0.91 to 9.5 over SGV.
6. In the PrM days, the smaller values of $\alpha$ indicates the presence of larger size of aerosols emitted due to the burning of agricultural wastes as well as transportation of aerosols from Thar and the Sahara deserts.
7. In the winters, large value of $\alpha$ indicates the dominance of smaller size aerosol. AA significantly contributes in the entire seasons and both the years, i.e., 2019 and 2020.
8. The DD and BB type aerosols were very less, but it is present in the PrM as well as in monsoon season. We observed CC condition throughout observation and significant presence of MA type at monitoring site.
9. The 5 days AMBT analysis indicates the origin of air mass from Afghanistan, the Middle East, and Africa via the Thar desert to contribute mineral dust over the SGV.

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Abbreviation List

AOD: Aerosol Optical Depth
SSA: Single Scattering Albedo
AE: Angstrom Exponent
MODIS: Moderate-Resolution Imaging Spectroradiometer
PrM: Pre-Monsoon
PoM: Post-Monsoon
NOAA: National Oceanic and Atmospheric Administration
HYSPLIT: Hybrid Single Particle Lagrangian Integrated Trajectory
COVID-19: 2019 Novel Coronavirus
H.N.B.: Hemvati Nandan Bahuguna
FSI: Forest Survey of India
MSL: Mean Sea Level
SGV: Srinagar Garhwal Valley
RH: Relative Humidity
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