Pollution 2022, 8(1): 211-224
DOI: 10.22059/POLL.2021.327809.1146

RESEARCH PAPER

Atmospheric Aerosol Loading and Properties over India: A review

Vikram Mor[*1] **and Rajesh Dhankhar**[2]

1. Department of Environmental Science, Shree Guru Gobind Singh Tricentenary University, Gurugram, Haryana, India-122005
2. Department of Environmental Science, Maharshi Dayanand University, Rohtak, Haryana, India-124001

Received: 26.07.2021, Revised: 27.09.2021, Accepted: 24.11.2021

ABSTRACT

Atmospheric aerosols are very crucial from air pollution and health perspective as well as for regional and global climate. This paper attempts to summarize the aerosol loading and their properties such as Aerosol Optical Depth (AOD), Single Scattering Albedo (SSA), Angstrom exponent, and Radiative forcing, over India. All the above mentioned parameters have shown significant variability with change in the site and season. From various studies it was observed that AOD is relatively higher over Northern part of India as compared to Southern and Eastern part. Generally, lower values of SSA were observed over all sites during winter and post-monsoon seasons which indicates the dominance of absorbing type aerosol during these seasons. Also the ARF within atmosphere showed comparatively higher values during November-December and lower value during August and September all over the India. The current state of knowledge about aerosol sources, interactions and their effects on environment is limited because of its complexity. Therefore, more focused research in needed to understand the aerosol's role in climatic phenomenon.

Keywords: Aerosol properties, AOD, SSA, Angstrom exponent, Radiative forcing, Indian subcontinent.

INTRODUCTION

India is one of the densely populated developing countries where industrialization and construction work is going on a large scale, which adds up high load of aerosols into the atmosphere every year. Atmospheric aerosols are minute/microscopic particles in solid or liquid phase suspended in the atmosphere including sea-salt, mineral dust, sulphates, nitrates, ash, soot, and black carbon. These can be originate from both natural processes such as volcanic eruption, windblown dust, forest fires, sea spray etc. as well as from anthropogenic activities such as agriculture, industrial, burning of fuels etc. (Ranjan et al., 2007; Pipal and Satsangi, 2015; Gawhane et al., 2019; Fadnavis et al., 2019). Aerosols are mixed and transported by atmospheric motions and removed from the atmosphere either by the surface of the Earth (dry deposition) or by clouds and precipitation processes (wet deposition) (Emerson et al., 2018; Tai et al., 2017; Mori et al., 2014; Shannigrahi et al., 2015; Dolskeand Gatz, 1985). Atmospheric aerosols are crucial entities which not only influence the radiative budget but also affect the Indian monsoon and other regional atmospheric phenomenon.

---

* Corresponding author Email: vikramseemla@gmail.com

In recent years, atmospheric aerosols are receiving more attention from scientific communities due to influence on air quality, global climate, atmospheric visibility and human health (Ancelet et al., 2013; Chung et al., 2012; Pachauri et al., 2013; Kumar et al., 2018; Mishra and Kulshrestha, 2021; Gulia et al., 2021; Gunthe et al., 2021). Atmospheric aerosols represent the nature of atmosphere and strongly influence the climate system and earth's radiative budget directly by absorbing and scattering solar radiation (Alam et al., 2012; Charlson et al., 1992; Che et al., 2005; Liu et al., 2011; Sinha et al., 2013) and indirectly, through their role as cloud condensation nuclei (Huang et al., 2010; Levy et al., 2013; Takamura et al., 2007).

Different types of aerosol scatter and absorb solar radiation at varying degrees, depending on their optical and physical properties. Generally, aerosols are believed to employ a cooling influence on climate e.g. sulphate, nitrate produces a cooling effect on globe by scattering and reflecting incoming solar radiations (Charlson et al., 1992; Kiehl and Briegleb, 1993). In contrary, aerosols such as elemental carbon or equivalent to black carbon which are effective absorber of solar radiation acts as the most important driver of aerosol induced global warming (Bollasina et al., 2011; Bond et al., 2013) (Figure 1).

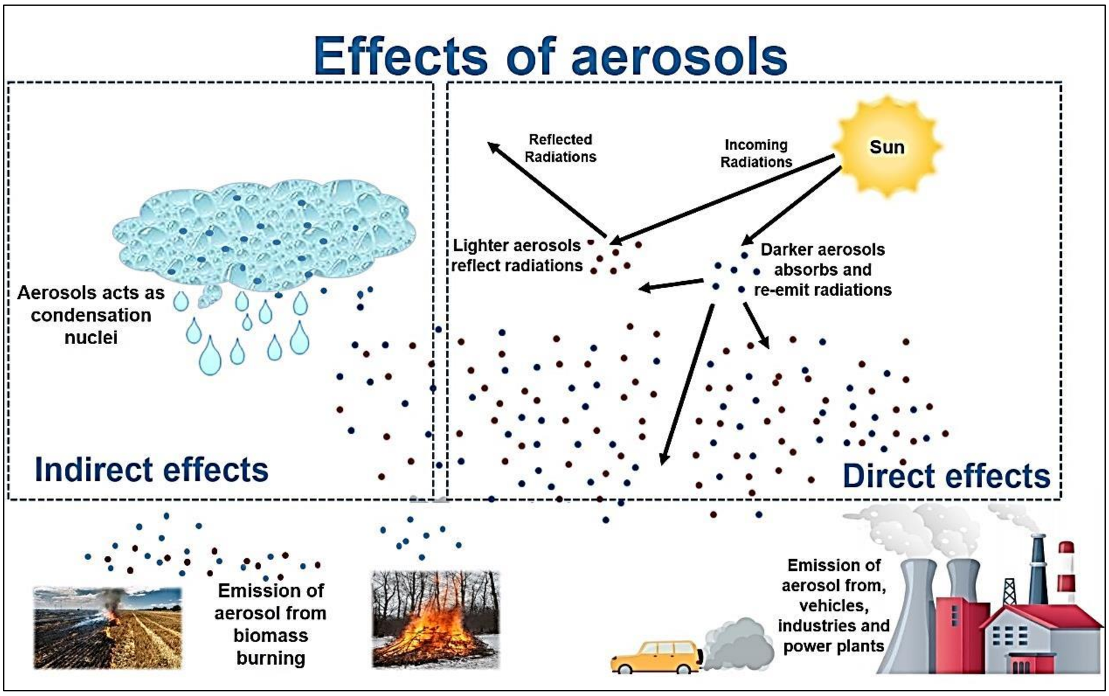

Fig 1. Direct and indirect effects of atmospheric aerosols.

The effect of aerosol on earth-atmosphere system was very complex due to their interaction with cloud cover because aerosol particles act as cloud condensation nuclei (CCN) and ice nuclei (IN), which affects the cloud albedo, cloud lifetime and the precipitation processes (Andreae et al., 1995; Gu et al., 2012; IPCC 2007; Jiang et al., 2011; Lohmann and Feichter, 2005; Simpkins, 2015; Nakata, 2018).

Therefore, accurate assessment of aerosol's optical and radiative properties is crucial to overcome the uncertainties associated with global warming and to completely understand impact of aerosols on Earth-atmosphere system. In India, various studies have been carried out regarding the assessment of aerosols optical properties, their spatial, temporal variation, and their impact on radiative budget and climate (Bisht et al., 2015; Dey and Girolamo, 2011; Patel and Kumar, 2015; Srivastava et al., 2014; Vaishya et al., 2018, Brooks et al., 2019;

Bansal et al., 2019; Govardhan et al., 2019). This paper summarizes the literature regarding aerosols optical and radiative properties over Indian subcontinent.

AEROSOL OPTICAL PROPERTIES

Aerosols optical properties are govern by their interaction with solar radiation. From the climate prospective, the most crucial aerosol optical properties are AOD, SSA and angstrom exponent. All these properties determine how the aerosol particle interacts with solar radiation. These properties are ultimately depends upon the chemical nature, composition and source of emission. Aerosol optical properties show strong diurnal, seasonal and annual variability over northern India. These variations has been attributed to variety of emission sources, coupled with meteorological conditions, boundary layer dynamics and mixing state (Lodhi et al., 2013; Ram et al., 2012b; Ram and Sarin, 2009; Tiwari et al., 2015a)**.**

Aerosol Optical Depth (AOD)

AOD is strongly dependent on wavelength and it is a common parameter to identify both sources of aerosol generation and their evolution as it represents the aerosol loading in the atmospheric column (Kumar et al., 2013; Mukherjee and Vinoj, 2020). The spectral dependence of AOD varies with various aerosol types due to their different chemical and physical properties on the basis of the source of generation and evolution of aerosol. Large spectral dependence was observed in many studies and higher values were found at shorter wavelengths than longer wavelengths (Balarabe et al., 2016; Kumar et al., 2013; Mishra et al., 2013; Srivastava et al., 2012). Mishra et al. (2013) also reported strong wavelength dependence at shorter wavelengths than longer wavelengths, thereby suggesting the dominance of fine mode particles in comparison to coarse mode particles in the atmosphere (Srivastava et al., 2012). This clearly shows systematic wavelength dependence according to classical Mie scattering theory.

In another study, (Ranjan et al., 2007) similar trends of decreasing AOD with increasing wavelength was observed over Rajkot from March-2005 to March-2006. They have found that the higher wavelength AODs are more influenced by naturally produced coarser dust aerosols, while the fine mode aerosol particles are mostly generated from various anthropogenic activities which show more contribution to AOD at shorter wavelengths than longer wavelengths. From this it is evident that lower wavelength AOD are more sensitive to fine mode particles while higher wavelength AOD are more sensitive to coarse mode particles.

AOD also showed seasonal variations in spectral dependence because it is a function of particle size distribution (Suman et al., 2013). Srivastava et al. (2012) observed large spectral dependence of AOD during winter season due to dominance of fine mode aerosol and less spectral dependence during summer season, due to the more contribution of coarse-mode aerosols like dust particles. Dominance of coarse mode particles enhances AOD at both shorter and longer wavelengths equally whereas on the other hand fine mode aerosol enhances more AOD at shorter wavelength than longer wavelength; therefore leads to less spectral dependency during pre-monsoon and monsoon seasons (Schuster et al., 2006).

Several studies have shown significant monthly and seasonal variations in AOD over different sites of Indian subcontinent such as Manora peak (Srivastava et al., 2015), Pune (More et al., 2013), Kanpur (Ram et al., 2016); Delhi (Soni et al., 2010; Tiwari et al., 2016);

Greater Noida (Sharma et al., 2014); Jaipur (Verma et al., 2015). This clearly indicates the variability in emission sources, meteorological and atmospheric conditions with seasons.

Table 1. Seasonal variation in AOD at different locations of India.

Study area	Period	AOD at 500nm				Reference
		Winter	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	
Kanpur	2005-2010	0.63	0.59	0.60	0.76	Kaskaoutis et al., 2012
Jaipur	2011		0.50-0.80			Tiwari et al., 2013
Dibrugarh	2001-2007	0.31	0.45	0.25	0.19	Gogoi et al., 2009
Ahmedabad	2002-2005	0.32	0.42	0.43	0.43	Ganguly et al., 2006
Kullu valley	2006-2009	0.20	0.34	0.26	0.21	Guleria et al., 2012
Delhi	2011-2013	0.95	0.82	0.86	1.0	Tiwari et al., 2016
Varanasi	2011	0.90	0.67	0.68	0.78	Tiwari and Singh, 2013a
Goa	2000-2002	0.41	0.48			Suresh and Desa, 2005
Hyderabad	2009-2010	0.39	0.53	0.37	0.37	Sinha et al., 2012
Kharagpur	2009-2010	0.82	0.71			Pani and Verma, 2013
Nainital	2005-2008	0.11	0.30	015	0.09	Ram et al., 2010
Trivandrum	2000-2003	0.43	0.40	0.29	0.38	Moorthy et al., 2007
Port Blair	2002-2008	0.31	0.26			Beegum et al., 2012
Patiala	2009	-	-	-	0.64	Sharma et al., 2012
Anantapur	2005-2006	0.46	0.50	0.37	0.40	Kumar et al., 2009
Delhi	2001-2012	0.77	0.78	0.74	0.91	Lodhi et al., 2013

Higher values of AOD during post-monsoon and winter seasons were attributed to the paddy crop residue burning in northern part of India (Prasad et al., 2006; Ram et al., 2010; Singh, 2010). Fire crackers burning on Diwali festival also contributes to the higher AOD during post-monsoon season. In another study, Chatterjee et al. (2012) found 25% and 40% increases in AOD values during winter and pre-monsoon season over Darjeeling for the time period of 2008. They have also observed 0.55% increase in AOD for every 1% increase in anthropogenic aerosols during winter and 0.46% increase in AOD with 1% increase in wind generated dust aerosols during pre-monsoon season. From this it is evident that during pre-monsoon season, wind generated natural dust aerosol while during winter anthropogenic aerosols play major role in increment of AOD.

Various studies have reported higher AOD over northern part of India as compared to southern part (Dey et al., 2012; Gautam et al., 2007; Prasad et al., 2007; Sarkar et al., 2006; Singh et al., 2004). The similar pattern has been reported by Tiwari and Singh (2013).

Angstrom Exponent (α)

Angstrom exponent (α) is a function of aerosol size distribution and depends on the relative dominance of fine to coarse mode aerosols (Gadhavi and Jayaraman 2010; Deep et al., 2021). Higher values of angstrom exponent mean the contribution of the fine mode particles dominating, whereas lower values of angstrom exponent indicate the dominance of coarse size particles (Alam et al., 2011).

Kumar et al. (2011) observed significant seasonal variation in α value over Pune with annual range of 0.3-1.7. The average values of alpha during post-monsoon, winter and pre-monsoon season are 1.19, 1.27 and 0.99, respectively. Kaskaoutis et al. (2012) and Lodhi et al. (2013) have reported the higher values of angstrom exponent during post-monsoon and winter seasons over Delhi, Kanpur, respectively. Which are associated with the dominance of anthropogenic aerosols whereas the lower values during pre-monsoon and monsoon seasons are associated with higher loading of dust over Indo-Gangetic Basin.

In another study, Sharma et al. (2014) also observed the similar annual mean pattern over Greater Noida with large values (>1.0) during post-monsoon and winter while the lower values (<0.7) during pre-monsoon and early monsoon seasons. Large variability in angstrom exponent values has been observed during monsoon, this indicates heterogeneous atmosphere with large variability in source, type and optical properties of aerosols, while lower range of angstrom exponent was observed during late post-monsoon and winter. Similarly large range of angstrom exponent (0.06-1.19) and (0.15-1.37) has been observed over Kanpur and Gandhi College (Indo-Gangetic plain) during pre-monsoon (Srivastava et al., 2011).

In another studies over Delhi, Srivastava et al. (2012) and Singh et al. (2010) also observed lower values of angstrom exponent during summer which are associated with the dust dominated coarse mode aerosol and higher values during post-monsoon period, indicates the dominance of fine mode particles associated with anthropogenic activities, biomass burning and firecrackers burning during the festival month.

Over Dibrugarh, Gogoi et al. (2009) and Pathak et al. (2010) reported the highest value of angstrom exponent during monsoon season with peak value in July while lowest values during pre-monsoon with minimum value in April.

Table 2. Values of angstrom exponent at different sites.

Study area	**Period**	**Angstrom exponent**				**Reference**
		Winter	**Pre-monsoon**	**Monsoon**	**Post-monsoon**	
Kanpur	2005-2010	1.24	0.66	0.77	1.27	Kaskaoutis et al., 2012
Jaipur	2011		0.38-0.60			Tiwari et al., 2013
Dibrugarh	2001-2007	1.14	085	0.87	1.12	Gogoi et al., 2009
Ahmedabad	2002-2005	1.0	0.3	0.4	1.0	Ganguly et al., 2006
Kullu valley	2006-2009	1.13	0.9	1.0	1.42	Guleria et al., 2012
Delhi	2011-2013	1.02	0.51	0.89	1.03	Tiwari et al., 2016
Varanasi	2011	1.11	0.70	0.72	1.2	Tiwari and Singh, 2013a
Goa	2000-2002	1.48	1.14			Suresh and Desa, 2005
Hyderabad	2009-2010	1.41	1.11	0.67	1.26	Sinha et al., 2012
Kharagpur	2009-2010	1.33	0.71			Pani and Verma, 2013
Nainital	2005-2008	-	-	-	-	Ram et al., 2010
Trivandrum	2000-2003	1.0	0.85	0.32	1.20	Moorthy et al., 2007
Patiala	2009	-	-	-	-	Sharma et al., 2012
Anantapur	2005-2006	-	-	-	-	Kumar et al., 2009
Delhi	2001-2012	0.97	0.49	0.66	0.93	Lodhi et al., 2013
Kanpur	2001-2003	1.26	0.60	0.66	1.12	Singh et al., 2004

Over Pune (Pandithurai et al., 2007) observed monomodal distribution of angstrom exponent during winter with a modal value around 1.4, whereas a bimodal distribution was observed during pre-monsoon with modal values of ~0.5 and ~1.2. Bimodal distribution during pre-monsoon indicates the presence of combination of anthropogenic and dust aerosols due to strong winds.

Single Scattering Albedo (SSA)

Single scattering albedo (SSA) is another crucial parameter for measurement of aerosols radiative forcing which characterizes the effect of scattering and absorption properties of atmospheric aerosols (Manoj et al., 2020). Srivastava et al. (2011) studied aerosols properties over Kanpur and Gandhi College from April-June 2009 and reported average SSA values >0.85 over both stations. They have found relatively lower values (0.89) over Gandhi College than Kanpur (0.92) which indicates the more concentration of absorbing type aerosols over Gandhi College than Kanpur.

Tiwari et al. (2015) reported the SSA value of 0.93±0.03 over Delhi during winter season. Higher values of SSA attribute to the presence of higher concentration of scattering type secondary aerosols, i.e. SO_4^{2-} and NO_3^{-} which are mainly released by coal combustion and vehicular emission. In another study, at the similar site Soni et al. (2010) observed average SSA values of 0.79±0.05 at 500nm for the study period (January 2006 to January 2007) and found strong variation with minimum monthly average value of 0.74±0.03 during January and maximum value of 0.89±0.04 for August. Higher SSA during August month may be associated with the dominance of water soluble aerosol particles.

Table 3. Single scattering albedo at different sites.

Study area	Sampling period	SSA	References
Chennai		0.77	Ramachandran, 2005
Kanpur	2001-2003	0.92	Singh et al., 2004
Hisar	2004	-	Ram and Sarin., 2009
Allahabad	2004	-	Ram and Sarin., 2009
Pune	2004-2009	0.83	Kumar et al., 2011
Delhi	2008-2009	0.70	Soni et al., 2010
Manora peak	2006-2008	0.81	Srivastava et al., 2015
Bangalore	2001	0.78	Babu et al., 2002

Single scattering albedo (SSA) also showed strong spectral dependence during different seasons. Soni et al. (2010) observed decrease in SSA with increase in wavelength during winter season (December and January) when the local anthropogenic pollutants dominating over Delhi while increase in SSA with increasing wavelength during dust dominated pre-monsoon season (represented by May and June). For the dust dominated and local pollution dominant months, huge difference in SSA values of the order of 0.15 was observed at higher wavelengths (1.0 and 1.5 μm).

SSA showed steepest decreasing trend of 0.13 as wavelength changes from 0.35 to 1.50 μm during August month of monsoon season, which is the cleanest month in terms of black carbon aerosols. But during the winter season the variation is very less with minimum slope due to the presence of higher loading of black carbon aerosols. During other months, SSA showed decrease with increase in wavelength but lies in between the extreme values of January and August, due to the presence of mixed type aerosols.

Similar spectral dependence of SSA for different seasons have been reported by Patel and Kumar (2015) over Dehradun, Srivastava et al. (2012) over Delhi, Sharma et al. (2012) over Patiala and Pandithurai et al. (2008) over Delhi.

Aerosol Radiative Forcing (Arf)

Direct aerosol radiative forcing can be defined as the difference in net solar flux (down minus up) at the surface or at the top of atmosphere (TOA), with and without aerosols. Various studies have been carried out to understand the effect of aerosols radiative forcing on global and regional climate but still there is uncertainty due to variations in source of emission and aerosol's interaction with clouds (Pathak et al., 2019; Sivan and Manoj, 2019; Budhavant et al., 2020; Vinod, et al., 2020).

Srivastava et al. (2015) studied ARF over Manora Peak in the Himalayan foothills for a period of more than two years (from February 2006 to May 2008) and found that monthly mean variability in the radiative forcing ranged from -2 to +14 Wm^{-2}, -3 to +50 Wm^{-2} and +3 to +65 Wm^{-2} for TOA, at the surface and within the atmosphere, respectively. Author also observed comparatively more pronounced atmospheric forcing (+28.4±4.9) along with large heating rate (0.80±0.14) during March to May 2008. This suggests the relatively higher concentration of absorbing aerosols (mineral dust and BC) over the station. The large difference between TOA and surface forcing demonstrates much higher absorption of solar radiation within the atmosphere, which causes heating of the atmosphere, reduction of eddy heat convergence and reduction in surface temperature (Ge et al., 2010).

Singh et al. (2010) observed average forcing of the order of −67 Wm^{-2} and 4 Wm^{-2} at surface and TOA, which leading to atmospheric forcing of +71 Wm^{-2} for the period of (1 January 2006- 31 January 2007) over Delhi. The maximum surface forcing of −110±20 Wm^{-2} was found during May, whereas the minimum during August (−46±8 Wm^{-2}). The maximum TOA forcing at 21±2 Wm^{-2} was found during June, while the minimum forcing -1.4±0.4 Wm^{-2} was during November. Radiative forcing within atmosphere was maximum (115±19 Wm^{-2}) during June, while the minimum (46±9 Wm^{-2}) was during August. Generally higher values of ARF were found during summer as compared to the winters due to the contribution of higher concentration of dust aerosols in summer. Afterwards, as the monsoon started during July–August the values were decreased and remained more or less constant during winters (after September), except for the month of October, which also had high AOD due to the increase in smoke and particulate matter owing to fire cracker burning during this festival months.

Singh et al. (2014), estimated radiative impacts of fireworks during Diwali festival from October 29 to November 2005 (Diwali on November 01) over Varanasi, to investigate change in radiative forcing between fireworks affected and non-affected periods. They reported +10±1 Wm^{-2} and +12±1 Wm^{-2} TOA forcing, whereas the surface forcing was -31±7 Wm^{-2} and -17±5 Wm^{-2} for affected and non-affected periods respectively. An additional cooling of about 20% at the TOA and about 45% at surface was estimated, which was caused by the higher loading of aerosols due to extensive burning of crackers and fireworks during that period. The estimated atmospheric forcing for affected and no-affected period was +41±6 and +29±4 $Wm^{-2,}$ respectively, which exertes an additional atmospheric heating of ~0.23 $Kday^{-1}$, during affected period.

Table 4. Aerosol radiative forcing at top of atmosphere (TOA) and bottom of atmosphere (BOA) over different sites.

Study Area	Study period	BOA	TOA	Reference
Delhi	2007	-69 to -78	-	Srivastava et al., 2012
Kanpur	2001-2010	-42 to -57	-12 to -18	Kaskaoutis et al., 2013
Dibrugarh	2010-2014	-27	-6	Pathak et al., 2015
Ahmedabad	2006-2008	-31 to -41	-4 to -12	Ramachandran and Kedia, 2012
Bangalore	2004-2005	-20 to -42	+2 to +5	Satheesh et al., 2010
Hyderabad	2008-2009	-65 to -80	-17 to -23	Sinha et al., 2013

Kant et al. (2015) analysed ARF over two sites (Patiala and Dehradun) of Northwestern India, for pre-monsoon season of 2013. For TOA forcing, they observed the magnitude of -7.8 Wm^{-2} over Dehradun and -1.08 Wm^{-2} over Patiala. Negative magnitude of TOA forcing suggesting that more solar radiation are back scattered to the space than received in the atmosphere. The magnitude of atmospheric ARF estimated over Patiala and Dehradun was +54.81 Wm^{-2} and +37.34 Wm^{-2}, which gives rise to a heating rate of 1.0 K day $^{-1}$ and 1.5 K day $^{-1}$, respectively.

CONCLUSION

Scientific investigations of atmospheric aerosol in India have a long history but it has progressed considerably in the recent time. From various studies it was observed that most of the Indian cities have higher aerosol load throughout the year but the properties of aerosols vary significantly from site to site.

- The major contribution to the aerosol loading during winter and post-monsoon season was from anthropogenic sources while during summer season natural coarse mode particles were dominated.
- Generally, lower values of SSA during post-monsoon and winter seasons clearly indicating the dominance of absorbing type aerosol such as black and brown carbon originated from the anthropogenic activities.
- Higher values of SSA over Delhi and Northern India are associated with high dust storms and high humidity during pre-monsoon and monsoon seasons, respectively.
- From ARF studies it was clear that aerosol contributed to the warming of atmosphere during winter and post-monsoon seasons.

But still large uncertainties in understanding the role of aerosol in climatic phenomenon, therefore, further studies are required.

ACKNOWLEDGEMENT

Authors are thankful to Vice-chancellor of SGT University for encouragement to carry this work.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

REFERENCES

Alam, K., Trautmann, T. and Blaschke, T. (2011). Aerosol optical properties and radiative forcing over mega city Karachi. Atmos Res., 101(3), 773–782.

Alam, K., Trautmann, T., Blaschke, T. and Hussain M. (2012). Aerosol optical and radiative properties during summer and winter season over Lahore and Karachi. Atmos Environ., 50, 234–245.

Ancelet, T., Davy, P. K., Trompetter, W. J., Markwitz, A. and Weatherburn, D. C. (2013). Carbonaceous aerosols in a wood burning community in rural New Zealand. Atmos. Pollut. Res., 4, 245–249. doi:10.5094/APR.2013.026.

Andreae, M. O. (1995). Climatic effects of changing atmospheric aerosol levels. (In: Henderson Sellers, H. (Ed.), World Survey of Climatology; Future Climates of the World (341-392). Elsevier, Amsterdam.)

Babu, S. S., Satheesh, S. K. and Moorthy, K. K. (2002). Aerosol radiative forcing due to enhanced black carbon at an urban site in India. Geophys. Res. Lett., 29, 1880. doi: 10.1029/2002GL015826.

Bansal, O., Singh, A., and Singh, D. (2019). Characteristics of Black Carbon aerosols over Patiala Northwestern part of the IGP: Source apportionment using cluster and CWT analysis. Atmos. Pollut. Res., 10, 244–256. https://doi.org/10.1016/j.apr.2018.08.001.

Beegum, S. N., Moorthy, K. K., Gogoi, M. M., Babu, S. S. and Pandey, S. K. (2012). Multi-year investigations of aerosols from an island station, Port Blair, in the Bay of Bengal: Climatology and source impacts. Ann. Geophys., 30, 1113–1127.

Bisht, D. S. , Dumka, U. C., Kaskaoutis, D. G., Pipal, A. S., Srivastava, A. K., Soni, V. K., Attri, S. D., Sateesh, M. and Tiwari, S. (2015). Carbonaceous aerosols and pollutants over Delhi urban environment: Temporal evolution, source apportionment and radiative forcing. Sci. Total. Environ., 522, 431–445.

Bollasina, M. A., Ming, Y. and Ramaswamy, V. (2011). Anthropogenic aerosols and the weakening of the South Asian summer monsoon. Sci., 334, 502–505.

Bond, T., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., Flanner, M. G., Ghan, S., Karcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, Y., Sarofim, M. C., Schultz, M. G., Schultz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, S., Guttikunda, S. K., Hopke, P. K., Jacobson, M. Z., Kaiser, J. W., Klimont, Z., Lohmann, U., Schwart, J. P., Shindell, D., Storelvmo, T., Warren, S. G. and Zender, C. S. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. J. Geophys. Res. Atmos., 118, 5380–5552. doi:10.1002/jgrd.50171.

Brooks, J., Liu, D., Allan, J. D., Williams, P. I., Haywood, J., Highwood, E. J., Kompalli, S. K., Babu, S. S., Satheesh, S. K., Turner, A. G., and Coe, H. (2019). Black carbon physical and optical properties across northern India during pre-monsoon and monsoon seasons. Atmos. Chem. Phys., 19, 13079–13096. https://doi.org/10.5194/acp-19-13079-2019.

Budhavant, K. B., Gawhane, R. D., Rao, P. S. P., Chandrika, H. R., Nair, R. and Safai, P. D. (2020). Physico-chemical characterization and sink mechanism of atmospheric aerosols over South-west India. J. Atmos. Chem., 77, 17–33. https://doi.org/10.1007/s10874-020-09400-x

Charlson, R. J., Schwartz, S. E., Hales, J. M., Cess, R. D., Coakley J. R., J. A., Hansen, J. E. and Hofmann, D. J. (1992). Climate forcing by anthropogenic aerosols. Sci., 255, 423–430.

Chatterjee, A., Ghosh, S. K., Adak, A., Singh, A. K., Devara, P. C. S., and Raha, S. (2012). Effect of dust and anthropogenic aerosols on columnar aerosol optical properties 30 over Darjeeling (2200 m asl.), Eastern Himalayas, India. PLoS ONE, 7(7), e40286. doi:10.1371/journal.pone.0011122.

Che, H. Z., Shi, G. Y., Zhang, X. Y., Arimoto, R., Zhao, J. Q., Xu, L., Wang, B. and Chen, Z. H. (2005). Analysis of 40 years of solar radiation data from China, 1961–2000. Geophys. Res. Lett., 32, L06803. doi:10.1029/2004GL022322.

Chung, C. E., Ramanathan, V. and Decremer, D. (2012). Observationally constrained estimates of carbonaceous aerosol radiative forcing. PNAS 109(29), 11624–11629.

Deep, A., Pandey, C. P., Nandan, H., Singh, N., Yadav, G., Joshi, P. C., Purohit, K. D. and Bhatt, S. S. C. (2021). Aerosols optical depth and Ångström exponent over different regions in Garhwal Himalaya, India. Environ. Monit. Assess. 193, 324. https://doi.org/10.1007/s10661-021-09048-4.

Dey, S. and Girolamo, L. Di. (2011). A decade of change in aerosol properties over the Indian subcontinent. Geophys. Res. Lett., 38, L14811, doi:10.1029/2011GL048153.

Dey, S., Girolamo, L. Di., Van, D. A., Tripathi, S. N., Gupta, T. and Mohan, M. (2012). Variability of outdoor fine particulate (PM2.5) concen- tration in the Indian subcontinent: a remote sensing approach. Remote Sens. Environ., 127, 153–161.

Dolske, D. A. and Gatz, D.F. (1985). A field comparison of methods for the measurement of particle and gas deposition. J. Geophys. Res., 90,, 2076–2084.

Emerson, E. W., Katich, J. M., Schwarz, J. P., McMeeking, G. R. and Farmer, D. K. (2018). Direct measurements of dry and wet deposition of black carbon over a grassland. J. Geophys. Res. Atmos., 123(12), 277–290.

Fadnavis, S., Müller, R., Kalita, G., Rowlinson, M., Rap, A., Frank, J., Gasparini, B. and Laakso, A. (2019). The impact of recent changes in Asian anthropogenic emissions of SO2 on sulfate loading in the upper troposphere and lower stratosphere and the associated radiative changes. Atmos. Chem. Phys., 19, 9989–10008. https://doi.org/10.5194/acp-19-9989-2019.

Gadhavi, H. and Jayaraman, A. (2010). Absorbing aerosols: contribution of biomass burning and implications for radiative forcing. Ann. Geophys., 28(123), 103–111.

Ganguly, D., Jayaraman, A., Rajesh, T. A. and Gadhavi, H. (2006). Wintertime aerosol properties during foggy and nonfoggy days over urban center Delhi and their implications for shortwave radiative forcing. J. Geophys. Res., 111; D15217. doi:10.1029/2005JD007029.

Gautam, R., Hsu, N. C., Kafatos, M. and Tsay, S. C. (2007). Influences of winter haze on fog/low cloud over the Indo-Gangetic plains. J. Geophys. Res., 112, 05207. doi:10.1029/2005JD007036.

Gawhane, R. D., Rao, P. S. P., Budhavant, K., Meshram, D. C. and Safai, P. D. (2019). Anthropogenic fine aerosols dominate over the Pune region, Southwest India. Meteorol. Atmos. Phys., 131, 1497–1508. https://doi.org/10.1007/s00703-018-0653-y.

Ge, J. M., Su, J., Ackerman, T. P., Fu, Q., Huang, J. P.and Shi, J. S. (2010). Dust aerosol optical properties retrieval and radiative forcing over northwestern China during the 2008 China–US joint field experiment. J. Geophys. Res., 115, (D00k12). doi:10.1029/2009JD013263.

Gogoi, M. M., Moorthy, K. K., Babu, S. S. and Bhuyan, P. K. (2009). Climatology of columnar aerosol properties and the influence of synoptic conditions: First-time results from the northeastern region of India. J. Geophys., Res., 114, D08202, doi: 10.1029/2008JD010765.

Govardhan, G., Satheesh, S. K., Moorthy, K. K., and Nanjundiah, R. (2019). Simulations of black carbon over the Indian region: improvements and implications of diurnality in emissions. Atmos. Chem. Phys., 19, 8229–8241. https://doi.org/10.5194/acp-19-8229-2019.

Gu, Y., Liou, K. N., Jiang, J. H., Su, H. and Liu, X. (2012). Dust aerosol impact on North Africa climate: a GCM investigation of aerosol-cloud-radiation interactions using A-Train satellite data. Atmos. Chem. Phys., 12, 1667–1679.

Guleria, R. P., Kuniyal, J. C., Sharma, N.L. and Dhyani, P. P. (2012). Seasonal variability in aerosol optical and physical characteristics estimated using the application of the angstrom formula over Mohali in the northwestern Himalaya. India. J. Earth. Syst. Sci., 121(3), 697–710.

Gulia, S., Goyal, Nitin, Mendiratta, S., Biswas, T., Goyal, S.K. and Kumar, R. (2021). COVID 19 Lockdown - Air Quality Reflections in Indian Cities. Aerosol Air Qual. Res. 21, 200308. https://doi.org/10.4209/aaqr.200308.

Gunthe, S. S., Liu, P. and Panda, U. (2021). Enhanced aerosol particle growth sustained by high continental chlorine emission in India. Nat. Geosci. 14, 77–84. https://doi.org/10.1038/s41561-020-00677-x

Huang, J., Zhang, C. and Prospero, J. M. (2010). African dust outbreaks: A satellite perspective of temporal and spatial variability over the tropical Atlantic Ocean. J. Geophys. Res., 115, D05202, doi:10.1029/2009JD012516.

IPCC (Intergovernmental Panel on Climate Change) (2007). Climate change 2007: the physical science basis: contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Chapter 2, 129.

Jiang, J. H., Su, H., Zhai, M., Massie, S. T., Schoeberl, M. R., Colarco, P. R., Platnick, S., Gu, Y. and Liou, K. N. (2011). Influence of convection and aerosol pollution on ice cloud particle effective radius. Atmos. Chem. Phys., 11, 457–463. doi:10.5194/acp-11-457-2011.

Kant, Y., Singh, A., Mitra, D., Darshan, S.,Srikanth, P., Madhusudanacharyulu, A. S. and Murthy K. Y. N. V. (2015). Optical and radiative properties of aerosols over two locations in the North-West Part of India during premonsoon season. Adv. Meteorol., http://dx.doi.org/10.1155/2015/517434.

Kaskaoutis, D. G., Singh, R. P., Gautam, R., Sharma, M., Kosmopoulos, P. G. and Tripathi, S. N. (2012). Variability and Trends of Aerosol Properties over Kanpur, Northern India Using AERONET Data (2001-10). Environ. Res. Lett., 7(2), 024003.

Kaskaoutis, D. G., Sinha, P. R., Vinoj, V., Kosmopoulos, P. G., Tripathi, S. N., Misra, A., Sharma, M. and Singh, R. P. (2013). Aerosol properties and radiative forcing over Kanpur during severe aerosol loading conditions. Atmos. Environ., 79, 7–19.

Kiehl, J. T. and Briegleb, B. P. (1993). The relative roles of sulfate aerosols and greenhouse gases in climate forcing. Sci., 260(5106), 311–314.

Kumar, A., Singh, N. and Solanki, R. (2018a). Evaluation and utilization of MODIS and CALIPSO aerosol retrievals over a complex terrain in Himalaya. Remote Sens. Environ., 206, 139–155.

Kumar, K. R., Narasinhulu, K., Reddy, R. R., Gopal, K. R., Reddy, L. S. S., Balakrishnaiah, G., Moorthy, K. K. and Babu, S. S. (2009). Temporal and spectral characteristics of aerosol optical depths in a semi-arid region of southern India. Sci. Tot. Environ., 407, 2673–2688.

Kumar, K. T., Gadhavi, H., Jayaraman, A., Sai Suman, M. N. and Rao, V. B. (2013). Temporal and spatial variability of aerosol optical depth over South India as inferred from MODIS, J. Atmos. Sol.-Terr. Phys., 94, 71–80, doi:10.1016/j.jastp.2012.12.010.

Kumar, S., Devara, P. C. S., Sonbawne, S. and Saha, S. (2011). Sun-sky radiometer derived column integrated aerosol optical and physical properties over a tropical urban station during 2004–2009. J. Geophys. Res., 116(D10201), doi:10.1029/ 2010JD014944

Levy, H., Horowitz, L. W., Schwarzkopf, M. D., Ming, Yi., Golaz, J. C., Naik, V. and Ramaswamy, V. (2013) The roles of aerosol direct and indirect effects in past and future climate change. J. Geophys. Res., 118, 4521–4532.

Liu, P. F., Zhao, C. S., Göbel, T., Hallbauer, E., Nowak, A., Ran, L., Xu, W. Y., Deng, Z. Z., Ma, N., Mildenberger, K., Henning, S., Stratmann, F. and Wiedensohler, A. (2011). Hygroscopic properties of aerosol particles at high relative humidity and their diurnal variations in the North China Plain. Atmos. Chem. Phys., 11, 3479–3494, doi:10.5194/acp-11-3479-2011.

Lodhi, N. K., Beegum, S. N. and Singh, S. (2013). Aerosol climatology at Delhi in the western Indo-Gangetic plain: microphysics, long-term trends, and source strengths. J Geophys. Res., 118, 1361–1375.

Lohmann, U. and Feichter, J. (2005). Global indirect aerosol effects: a review. Atmos. Chem. Phys., 5,, 715–737. doi:10.5194/acp-5-715-2005.

Manoj, M. R., Satheesh, S. K., Moorthy, K. K. and Coe, H. (2020). Vertical profiles of submicron aerosol single scattering albedo over the Indian region immediately before monsoon onset and during its development: research from the SWAAMI field campaign. Atmos. Chem. Phys., 20, 4031–4046. https://doi.org/10.5194/acp-20-4031-2020, 2020.

Mishra, M. and Kulshrestha, U. C. (2021). Source Impact Analysis Using Char-EC/soot-EC Ratios in the Central Indo-Gangetic Plain (IGP) of India. Aerosol Air Qual. Res., 21(9), https://doi.org/10.4209/aaqr.200628.

Moorthy, K. K., Babu, S. S. and Satheesh, S. K. (2007). Temporal heterogeneity in aerosol characteristics and the resulting radiative impact at a tropical coastal station. Part 1: Microphysical and optical properties. Ann. Geophys., 25, 2293–2308.

More, S., Kumar, P. P., Gupta, P., Devara, P. C. S. and Aher, G. R. (2013). Comparison of aerosol products retrieved from AERONET, MICROTOPS, and MODIS over a tropical urban city, Pune, India. Aerosol Air Qual. Res., 13(1), 107–121.

Mori, T., Kondo, Y., Ohata, S., Moteki, N., Matsui, H., Oshima, N. and Iwasaki, A. (2014). Wet deposition of black carbon at a remote site in the East China Sea. J. Geophys. Res. Atmos., 119, 10485–10498. https://doi.org/10.1002/2014JD022103.

Mukherjee, T. and Vinoj, V. (2020). Atmospheric aerosol optical depth and its variability over an urban location in Eastern India. Nat. Hazards, 102, 591–605. https://doi.org/10.1007/s11069-019-03636-x

Nakata, M. (2018) "Analysis of climate change caused by aerosol-cloud-radiaton interaction", Proc. SPIE 10786, Remote Sensing of Clouds and the Atmosphere XXIII, 1078614. https://doi.org/10.1117/12.2325265.

Pachauri, T., Singla, V., Satsangi, A., Lakhani, A. and Kumari, K. M. (2013). Characterization of carbonaceous aerosols with special reference to episodic events at Agra, India. Atmos. Res., 128, 98–110.

Pandithurai, G., Dipu, S., Dani, K. K., Tiwari, S., Bisht, D. S., Devara, P. C. S. and Pinker, R. T. (2008). Aerosol Radiative Forcing during Dust Events over New Delhi, India. J. Geophys. Res., 113, D13209. doi: 10.1029/2008JD009804.

Pandithurai, G., Pinker, R. T., Devara. P. C. S., Takamura, T. and Dani, K. K. (2007). Seasonal asymmetry in diurnal variation of aerosol optical characteristics over Pune, western India. J. Geophys. Res., 112, D08208. doi:10.1029/2006JD007803,

Pani, S. K. and Verma, S. (2013). Variability of winter and summertime aerosols over eastern India urban environment. Atmos. Res., 137, 112-124. doi:10.1016/j. atmosres.2013.09.014.

Patel, P. N. and Kumar, R. (2015). Estimation of Aerosol Characteristics and Radiative Forcing during Dust Events over Dehradun. Aerosol Air Qual. Res., 15, 2082-2093.

Pathak, B. (2015). Aerosol characteristics in North-East India using ARFINET spectral optical depth measurements. Atmos. Environ., 125, 461-473. DOI:10.1016/j.atmosenv.2015.07.038

Pathak, H. S., Satheesh, S. K., Nanjundiah, R. S., Moorthy, K. K., Lakshmivarahan, S. and Babu, S. N. S. (2019). Assessment of regional aerosol radiative effects under the SWAAMI campaign – Part 1: Quality-enhanced estimation of columnar aerosol extinction and absorption over the Indian subcontinent. Atmos. Chem. Phys., 19, 11865–11886, https://doi.org/10.5194/acp-19-11865-2019.

Pipal, A. S. and Satsangi, P. G. (2015). Study of carbonaceous species, morphology and sources of fine (PM2.5) and coarse (PM10) particles along with their climatic nature in India. Atmos. Res, 154, 103–115.

Prasad, A. K. and Singh, R. P. (2007). Changes in aerosol parameters during major dust storm events (2001–2005) over the Indo- Gangetic plains using AERONET and MODIS data. J. Geophys. Res., 112, D09208. doi:10.1029/200JD007778.

Prasad, A. K., Singh, R. P. and Singh, A. (2006). Seasonal climatology of aerosol optical depth over the Indian subcontinent: Trend and departures in recent years, Int. J. Remote Sens., 27(12), 2323–2329. doi:10.1080/ 01431160500043665

Ram, K., Sarin and M. M. (2009). Absorption coefficient and site-specific mass absorption efficiency of elemental carbon in aerosols over urban, rural, and high-altitude sites in India. Environ. Sci. Technol., 43, 8233-8239.

Ram, K., Sarin, M. M. and Tripathi, S. N. (2010). A 1 year record of carbonaceous aerosols from an urban site in the Indo-Gangetic plain: characterization, sources and temporal variability. J. Geophys. Res., 115, D24313. http://dx.doi.org/ 10.1029/2010JD014188.

Ram, K., Sarin, M. M. and Tripathi, S. N. (2012b). Temporal trends in atmospheric $PM_{2.5}$, PM_{10}, EC, OC, WSOC and optical properties: impact of biomass burning emissions in the indo-Gangetic plain. Environ. Sci. Technol., 43, 686–695. http://dx.doi.org/10.1021/ es202857w.

Ram, K., Singh, S., Sarin, M. M., Srivastava, A. K.and Tripathi, S. N. (2016). Variability in aerosol optical properties over an urban site, Kanpur, in the Indo-Gangetic Plain: A case study of haze and dust events. Atmos. Res., 174(175), 52–61.

Ramachandran, S. (2005). Aerosol radiative forcing over Bay of Bengal and Chennai: Comparison with maritime, continental, and urban aerosol models. J. Geophys. Res., 110, D21206. doi:10.1029/2005JD005861.

Ramachandran, S. and Kedia, S. (2012) Radiative effects of aerosols over Indo-Gangetic plain: environmental (urban vs. rural) and seasonal variations. Environ. Sci. Pollut. Res., 19(6), 2159–2171.

Ranjan, R. R., Joshi, H. P. and Iyer, K. N. (2007). Spectral variation of total column aerosol optical depth over Rajkot: a tropical semi-arid Indian station. Aero. Air Qual. Res., 7, 33–45.

Sarkar, S., Chokngamwong, R., Cervone, G., Singh, R. P. annd Kafatos, M. (2006). Variability of aerosol optical depth and aerosol forcing over India. Adv. Space Res., 37, 2153–2159.

Satheesh, S. K., Vinoj, V. and Moorthy, K. K. (2010). Radiative effects of aerosols at an urban location in southern India: observations versus model. Atmos. Environ., 44 (39, 5295–5304.

Schuster, G. L., Dubovik, O. and Holben, B. N. (2006). Ångström exponent and bimodal aerosol size distributions. J Geophys Res- Atmos., 111, D07207. doi:10.1029/2005JD006328.

Shannigrahi, A. S., Fukushima, T. and Ozaki, N. (2005). Comparison of different methods for measuring dry deposition fluxes of particulate matter and polycyclic aromatic hydrocarbons (PAHs) in the ambient air. Atmos. Environ., 39, 653–662.

Sharma, D., Singh, D. and Kaskaoutis, D. G. (2012). Impact of two intense dust storms on aerosol characteristics and radiative forcing over Patiala, Northwestern India. Adv. Meteorol., doi:10.1155/2012/956814.

Sharma, M., Kaskaoutis, D. G., Singh, R. P. and Singh, S. (2014). Seasonal variability of atmospheric aerosol parameters over greater Noida using ground sunphotometer observations. Aerosol Air Qual. Res., 14, 608–622. doi:10.4209/aaqr. 2013.06.0219.

Simpkins, G. (2018). Aerosol–cloud interactions. Nature Clim. Change, 8, 457. https://doi.org/10.1038/s41558-018-0195-9.

Singh, B. P., Srivastava, A. K., Tiwari, S., Singh, S., Singh, R. K., Bisht, D. S., Lal, D. M., Singh, A. K., Mall, R. K. and Srivastava M. K. (2014). Radiative Impact of Fireworks at a Tropical Indian Location: A Case Study. Adv Meteorol., http://dx.doi.org/10.1155/2014/197072.

Singh, R. P, Dey, S., Tripathi, S. N., Tare, V. and Holben, B. (2004). Variability of aerosol parameters over Kanpur city, northern India. J. Geophys. Res., 109; D23206. doi:10.1029/2004JD004966.

Singh, S., Soni, K., Bano, T., Tanwar, R. S., Nath, S. and Arya, B. C. (2010). Clearsky direct aerosol radiative forcing variations over megacity Delhi. Ann. Geophys., 28, 1157–1166.

Sinha, P. R., Dumka, U. C., Manchanda, R. K., Kaskaoutis, D. G., Sreenivasan, S., Moorthy, K. K. and Suresh, B. S. (2013). Contrasting Aerosol Characteristics and Radiative Forcing over Hyderabad, India Due to Seasonal Mesoscale and Synoptic Scale Processes. Q. J. R. Meteorolog. Soc., 139, 434–450.

Sinha, P. R., Kaskaoutis, D. G., Manchanda, R. K. and Sreenivasan, S. (2012). Characteristics of aerosols over Hyderabad, in Southern Peninsular India with the use of different techniques. Ann. Geophys., 30, 1393-1410.

Sivan, C. and Manoj, M.G. (2019). Aerosol and cloud radiative forcing over various hot spot regions in India. Adv. Space Res., 64(8), 1577-1591. https://doi.org/10.1016/j.asr.2019.07.028.

Soni, K., Singh, S., Bano, T., Tanwar, R. S., Nath, S. and Arya, B. C. (2010). Variations in single scattering albedo and Angstrom absorption exponent during different seasons at Delhi, India. Atmos. Environ., 44, 4355–4363.

Srivastava, A. K., Ram, K., Singh, S., Kumar, S. and Tiwari, S. (2015). Aerosol optical properties and radiative effects over Manora Peak in the Himalayan foothills: Seasonal variability and role of transported aerosols. Sci. Tot. Environ., 502, 287–295.

Srivastava, A. K., Singh, S., Tiwari, S. and Bisht, D. S. (2012). Contribution of anthropogenic aerosols in direct radiative forcing and atmospheric heating rate over Delhi in the Indo- Gangetic Basin. Environ. Sci. Pollut. Res., 19, 1144–1158.

Srivastava, A. K., Soni, V. K., Singh, S., Kanawade, V. P., Singh, N., Tiwari, S. and Attri, S. D. (2014). An early South Asian dust storm during March 2012 and its impacts on Indian Himalayan foothills: A case study. Sci. Total Environ., 493, 526–34.

Srivastava, A. K., Tiwari, S., Devara, P. C. S., Bisht, D. S., Manoj K. Srivastava, Tripathi, S. N., Goloub, P. and Holben, B. (2011). Pre-monsoon aerosol characteristics over the Indo-Gangetic Basin: implications to climatic impact. Ann. Geophys., 29, 789-804. doi:10.5194/angeo-29-789-2011.

Suman, M. N. S., Gadhavi, H., Kiran, V. R., Jayaraman, A. and Rao, S. V. B. (2013). Role of coarse and fine mode aerosols in MODIS AOD retrieval: a case study. Atmos. Meas. Tech. Diss., 6, 9109–9132.

Suresh, T. and Desa, E. (2005). Seasonal variations of aerosol over Dona Paula, a coastal site on the west coast of India. Atmos. Environ., 39, 3471–3480, doi:10.1016/j.atmosenv.2005.01.063.

Tai, A. Y., Chen, L. A., Wang, X., Chow, J.C. and Watson, J.G. (2017). Atmospheric deposition of particles at a sensitive alpine lake: Size-segregated daily and annual fluxes from passive sampling techniques. Sci. Total Environ., 579, 1736–1744.

Takamura, T., Sugimoto, N., Shimizu, A., Uchiyama, A., Yamazaki, A., Aoki, K., Nakajima, T., Sohn, B. J. and Takenaka, H. (2007). Aerosol radiative characteristics at Gosan, Korea, during the atmospheric brown cloud East Asian regional experiment 2005. J. Geophys. Res., 112, 22–36.

Tiwari, S. and Singh, A. K. (2013a). Variability of aerosol parameters derived from ground and satellite measurements over Varanasi located in Indo-Gangetic Basin. Aerosol Air Qual. Res., 13, 627–638.

Tiwari, S., Hopke, P. K., Attri, S. D., Soni, V. K. and Singh, A. K. (2016). Variability in optical properties of atmospheric aerosols and their frequency distribution over a mega city ‘New Delhi’, India. Environ. Sci. Pollut. Res. Int., 23(9), 8781–93. doi:10.1007/s11356-016-6060-3.

Tiwari, S., Pandithurai, G., Attri, S. D., Srivastava, A. K., Soni, V. K., Bisht, D. S., Kumar, V. A. and Srivastava, M. K. (2015). Aerosol optical properties and their relationship with meteorological parameters during wintertime in Delhi, India. Atmos. Res., 153, 465–479.

Tiwari, S., Srivastava, A. K. and Singh, A. K. (2013). Heterogeneity in pre- monsoon aerosol characteristics over the Indo-Gangetic basin. Atmos. Environ., 77, 738–747.

Tiwari, S., Srivastava, A. K., Singh, A. K. and Singh, S. (2015a). Identification of aerosol types over Indo-Gangetic Basin: implications to optical properties and associated radiative forcing. Environ. Sci. Pollut. Res., 12(22), 12246-12260. doi:10.1007/s11356-015-4495-6.

Vaishya, A., Babu, S. N. S. , Jayachandran, V., Gogoi, M.M., Lakshmi, N. B., Moorthy, K. K. and Satheesh, S. K. (2018). Large contrast in the vertical distribution of aerosol optical properties and radiative effects across the Indo-Gangetic Plain during the SWAAMI–RAWEX campaign. Atmos. Chem. Phys., 18, 17669–17685. https://doi.org/10.5194/acp-18-17669-2018.

Verma, S., Prakash, D., Ricaud, P., Payra, S., Attié, J. L. and Soni, M. (2015). A new classification of aerosol sources and types as measured over Jaipur, India. AAQR, 15, 985–993, doi: 10.4209/aaqr.2014.07.0143.

Vinod K. A., Jagatheeswari A., Muneeswaran S., Palanivelraja S. and Chockalingam, M. P. (2020). Aerosol Optical Depth and Black Carbon Concentration along the Coast of Bay of Bengal. IJRTE, 8(5), 1493-1496.