Aerosol Science and Engineering (2022) 6:135–145
https://doi.org/10.1007/s41810-022-00133-w

REVIEW

Atmospheric Aerosols: Some Highlights and Highlighters, Past to Recent Years

Zainab Mushtaq[1] · Manish Sharma[2] · Pargin Bangotra[1] · Alok Sagar Gautam[3] · Sneha Gautam[4]

Received: 29 September 2021 / Revised: 29 January 2022 / Accepted: 7 March 2022 / Published online: 24 March 2022

Abstract
The severe harmful impact of atmospheric aerosols over the environment leads to create the diverse human interests and concerns. Various progressive steps were taken by researchers and scientists to understand the fundamentals, such as nucleation and growth mechanisms, formalization of particle dynamics, characterization of the mechanisms for the particle-size dispensation, detection of chemical processes for atmospheric particle sources. The increase in population growth and different manmade activities have led to change in the environmental conditions causes to pollute the distinct vicinities. Different changes in the environment such as land use pattern, increased concentration of various greenhouse gases, and Industrial pollutants change the energy balance in our climatic conditions and affect the radiation budget of earth' atmosphere. Such changes in climate and polluted environment leads to many health-related ailments to mankind. The present study outlines the recent research perspectives of atmospheric aerosols, their estimation through different modes, effects, and an overview of the current situations that need to be addressed before they become completely incorporated.

Keywords Aerosols · Particulate matter · Atmospheric environment · AOD · MODIS · MISR

Abbreviations

PM	Particulate matter
BC	Black carbon
ARF	Aerosol Radiative forcing
CO_2	Carbon dioxide
SO_2	Sulphur dioxide
CH_4	Methane
EDX	Energy dispersive energy
EC	Eliminating carbon
RH	Relative humidity
AC	Active cases
GW	Gurgaon
SSA	Single scattering albedo
WRF-Chem	Weather research and forecasting model coupled by chemistry
AOD	Aerosol optical depth
MODIS	Moderate resolution imaging spectroscopy
ARFINET	Aerosol radiative forcing network
NO_2	Nitrogen dioxide
NASA	National Aeronet and Space Administration
SEM	Scanning electron microscopy
CAE	Chinese academy of engineering
OM	Organic matter
TC	Total cases
RC	Cases of recovery
BOB	Bay of Bengal

✉ Manish Sharma
manish.sharma@bahrauniversity.edu.in

✉ Alok Sagar Gautam
phyalok@gmail.com

✉ Sneha Gautam
snehagautam@karunya.edu

[1] Atmospheric Research Laboratory, Department of Environmental Sciences, SBSR, Sharda University, Greater Noida, India

[2] Department of Physics, School of Basic Sciences, Bahra University, Shimla Hills, Shimla, HP, India

[3] Department of Physics, Hemvati Nandan Bahuguna Garhwal University, Uttarakhand, India

[4] Department of Civil Engineering, Karunya Institute of Technology and Sciences, Coimbatore, India

1 Introduction

Atmospheric aerosols are an essential part of Earth's atmosphere. Aerosols consists of solid, liquid, and gaseous of varying chemical complexity, size, and phase. They are defined as a suspension of solid or liquid particles present in a gaseous medium, scattering everywhere in the atmosphere. In general, aerosols groups include, particulate matter, sulphates, nitrates, mineral dust, sea salt, black carbon, organic carbon, etc. Further particulate matter can be characterized on the behalf of their aerodynamic diameter refers to be as Coarse (10 µm), fine (2.5 µm) and ultrafine (0.1 µm). Atmospheric aerosols can be natural or anthropogenic, having the ability to alter the balance of earth's atmosphere, and the climatic conditions (Humbal et al. 2018, 2019; Bellouin et al. 2020; Jonathan et al. 2020; Gollakota et al. 2021). Primary natural emission source involves dirt, forest fire, volcanic eruptions etc., whereas primary anthropogenic sources of air pollution are vehicular emission, burning of biomass, fuels combustion, industrial emission, petroleum refineries, etc. (Bisht et al. 2022). Natural aerosols include aerosol of sulphate formed either by emission of Sulphur dioxide from volcanic eruption or by the formation of dimethyl sulphide from phytoplankton in the oceans, particles of sea salt produced from surface of the ocean, or aerosols of mineral dust produced by the effect of wind erosion on arid ground (Erwan et al. 2014). Anthropogenic aerosols are mostly produced by the man-made activities as manufacturing, mining, transportation, and biomass burning (Ramachandran et al. 2012; Gautam et al. 2021a). Umpteen reports revealed about the degradation in visibility during the winter period is primarily due to scatter and absorbing characteristics of atmospheric aerosol (Won et al. 2020; Mukherjee and Toohey 2016). The increase in emission shows a straight impact on climate circumstances, particularly the increase in smoke, fog and cloudiness, which reduce visibility mostly during the winter season by interfering directly and indirectly, aerosols play an important role in the earth's radiation budget and atmosphere. In case of direct effect, the aerosols can scatter the solar radiations and send them back. Whereas, in indirect effect it can alter the dimension of cloud particles, thereby disturbing the Earth's energy budget. Many scientists have examined the characteristics of atmospheric aerosol and their effects over the different areas of India typically by means of surface-based aerosol measurements as given in Table 1. The field campaign such as INDOEX, ARMEX, ICARB [over Indian landmass, Arabian Sea, and Bay of Bengal (BOB)] showed the variable aerosol optical and radiative properties (Ramanathan et al. 2001; Satheesh et al. 2002; Vinoj et al. 2004; Babu et al. 2008).

Particulate matter (PM) is a combined fusion of tremendously tiny particle and water droplet. PM consists of a mixture of materials, acids (Nitrates and sulfates), natural chemicals, metals, and dust. $PM_{2.5}$ (fine) is an atmospheric pollutant that is of high concern to human health (Gautam et al. 2019). In recent years, morphology and chemical characteristics of PM have received increasing attention from the scientific community due to its impact on human health. In altering air quality and atmospheric conditions, particulate matter plays a critical role, thus it is necessary to know the structure, origin, transport and providence of aerosol particles to understand the impact of PM. $PM_{2.5}$ is considered as a main challenge for air pollution and health controlling activities around the globe as it accounts for about 4.9 million deaths throughout globe and ~ 1.2 million deaths in India in the year 2017 (Bawase et al. 2021). In recent years, morphology and chemical characteristics of PM have received increasing interest for understanding the consequence of ambient PM on the environment and human health, its mass concentration assessment, sources of its emission and transportation are compulsory (Bora et al. 2021; Gautam et al. 2016; Mishra et al. 2017; Bawase et al., 2021).The characteristics, origin and possible effects of coarse PM_{10}, fine $PM_{2.5}$ and ultra-fine $PM_{0.1}$ with diameter below 0.5 µm, improves the understanding effects of pollution across regional and global scales.

India is an agricultural country, and its economy is mostly reliant on it. Haryana and Punjab produce approximately 48% of straw in the entire India, and the same amount is burned in the fields. Rice and wheat crops account for more than 90% of overall crop residue generation and burnt biomass in Punjab and Haryana (Singh et al. 2020). Due to the enormous use of pesticides, fungicides and biomass burning practices in these regions, the soil, water and air vicinities are accounted to be a threat to human beings (Bangotra et al. 2021, 2018; Mehra et al. 2015). Every year, pollutants from crop burning in these states are transported over regional air masses, causing substantial air pollution and haze episodes in the neighboring (Delhi NCR) regions (Kulkarni et al. 2020a, b; Sahu et al. 2021; Sembhi et al. 2020). Burning of Crop residue emits considerable amounts of greenhouse gases, such as carbon dioxide, nitrous oxide, and methane, all of which contribute to global climate change (Mor et al. 2022). The other air pollutants, such as carbon monoxide, ammonia, nitrogen dioxide, Sulphur dioxide, volatile organic compounds (VOCs), $PM_{2.5}$, PM_{10}, and bioaerosols, cause respiratory issues, asthma, bronchitis, cough, conjunctivitis, and a variety of skin ailments (Awasthi et al. 2010; Ravindra et al. 2019a, b; Kaur et al. 2019).

Satellite remote sensing has extremely provided an edge towards the various studies as aerosol modeling, weather forecasting, climate change and to study the worldwide pollution problems over the past two decades (Sharma et al. 2021). Owing to low spatial resolution, satellite remote sensing aerosol monitoring products are adequately accessible. However, restricted to local and universal scales, rendering them inappropriate for city-level monitoring. Sparsely dispersed regulatory control networks have often assessed pollutant concentration. With the growing availability, the installation of low-cost sensors was used to complement the regular monitoring that provides fields of concentration of air contaminants

Table 1 Earlier studies conducted over different locations

S no.	Year	Study location	Instrument used	References
1	2015–2016	Bhubaneswar (India)	MODIS, MERRA 2 reanalysis ARFINET, MICROTOPS-II	Mukherjee and Vinoj (2018)
2	2017–2016	India (28 states)	ARFINET, PREDE Sky radiometer SKYRAD-PACK software	Manoj et al. (2019)
3	2014	Delhi (India)	PREDE SKY radiometer (POM-02) data, reanalysis with SKYRAD PACK software (version 4.2), Terra and Aqua Satellite	Taneja et al. (2020)
4	2003–2017	India and Adjoining seas	MODIS and OMI UV (Aerosol Index)	Thomas et al. (2019)
5	Nov. 2016	Peshawar (Pakistan)	Fourier Transform Infra-Red (FTIR), SEM, EDX	Zeb et al. (2018)
6	Past 15 year	Singruali (India)	NASA Giovanni (Satellite data) MODIS, OMI, AIRS, CPCB	Romana et al. (2020)
7	2011	India (15 states)	MODIS,WRF-CHEM	Krishna et al. (2019)
8	2011(Jan–Dec)	Rio-de Janerio, (Brazil)	High volume sampler studies	Ventura et al. (2018)
9	2015–2020	USA	NASA Giovanni OMI-EPA (through online)	Archer et al. (2020)
10	2020	India (34 monitoring stations)	CPCB, DPCP, SAFAR (System of air quality and weather forecasting and research), IITM	Mahato et al. (2020)
11	2020	Delhi and Neighboring cities (India)	Purple Air Sensors (PMS5003, PMS1003), SPSS	Sharma and Bangotra (2020)
12	2020	Bhubaneswar (India)	Online Co-analyzer (Horiba, Ampa-370), NOx analyzer (Thermo-fisher scientific, 49i) UV photometric O_3 analyzer	Panda et al. (2021)
13	2017–2018	Jaipur, Pune, Gandhi Collage, Karunya University (India)	Aerosol Robotic Network (AERONET)	Anitha and Kumar (2020)
14	2010–2017	IGP Region (India)	MODIS, MISR, OMI, Ground-based measurement	Mangla et al. (2020)
15	May 2011	Gandhi Collage (India)	MODIS, AERONET SUN/SKY radiometer light detection/ranging Radar (LIDAR)	Dsouza and Blaise (2020)
16	2005–2019	Karlsruhe (Germany) and Skukuza (South Africa)	MODIS, AERONET	Anoruo (2020)
17	2013–2017	China	Real-time release platform for urban air quality	Wang et al. (2019)
18	1 January 2001 to 31 December 2006	Global estimation	MODIS and MISR and coincident aerosol vertical profiles from the GEOS-Chem global chemical transport model were used	Donkelaar et al. (2010)
19	August 2013–July 2015	Indo Gangetic plain (India)	Aethalometer, Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT)	Vaishya et al. (2017)

(Munir et al. 2019; Gautam et al. 2021b). At ground level, AERONET stations form a global network of sun photometers calculate more accurately Aerosol optical depth (AOD), aerosol properties and are used for satellite AOD retrieval validation and calibration (Kang et al. 2022). These satellites are, however, sparsely scattered worldwide; therefore, there is a need for better coverage of satellite retrieved AOD. Satellite remote sensing has intrinsic demand compared to ground-based aerosol observing sensors, because spatial coverage is almost continuous over wide areas and give high spatial resolution data (Zhang et al. 2021). However, most precise AOD concentration are given by sparsely spaced ground-based remote sensing, such as Aerosol Robotic network (AERONET) and Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol data to estimate the effects of aerosol on a regional and global scale.

2 Variable Characteristics of Atmospheric Aerosol

The exploration of characters of AOD and their relationship with the size and type of aerosol using a simple AOD spectral curvature method was found to be important characteristics. It was also the challenge to validate MODIS Terra and Aqua's captured data set for the best analysis. To study atmospheric aerosols' fundamental characteristics, different approaches have been used to study the satellite and ground-based measurement techniques (Fig. 1). The composition, size and shape of pollutants can differ with varying components, including acids, inorganic substances, particles of soil, and dust. Severity of the dust-based particulate matter on human health always encourages the researchers to take the challenge of calculating the connection of an extreme dust storm over an urban site in India. Atmospheric Black carbon (BC) concentration over India has been shown to check atmospheric radiative forcing (Babu et al. 2002; Dey and Tripathi 2008). BC can be shielded by radioactive cooling resulting from the dispersion of solar radiation by sulphate and additional non-absorbing aerosols, although it is a small portion of the complex aerosol system (Ramanathan and Carmichael 2008). Ramanathan and Carmichael (2008) did retrieval aerosol optical property using sky radiometer observations to see the aerosol radiative forcing (ARF). The estimation of aerosols in hazy days, especially during the winter season, is fundamental to recognize chemical and optical properties of aerosols.

To show the irregularity of aerosol loading at different time scales of the Aerosol Radiative Forcing Network (ARFINET), MICROTOPS-II, a five-channel handheld sun photometer, was primarily utilized. The AOD was extracted at five different wavelengths (308,440,500,675,870 nm) with full width and half overall bandwidth of 2–10 nm with excellent sequential resolution (30 min, depends on the condition of the sky). The long-term BC measurements over the Indian regions (28 stations) from the observatory network have been used to study the possible reasons for the trends of the data from 13 stations with more than 6 years of measurement (Manoj et al. 2019). It demonstrated the structural dispersion of BC aerosols using the analytical and organized measurements of many aerosol parameters captured by different techniques. The growing trend in AOD, the decreasing trend in BC is projected to have major climate impacts and need to be further investigated**.** The rise in the winter hazy days over the central Asia and Arabia was examined using the 15 years of satellite and model reanalysis of data sets in India and neighboring areas, to evaluate the tendency in hazy days during the dry winter seasons (Thomas et al. 2019). The superiority of absorbing aerosol over central India was confirmed by a change in UV aerosol index and AOD. The finding highlights the rapid decline in air quality in central India and highlights the effects of increased biomass burning in the background of recent climate change (Thomas et al. 2019).

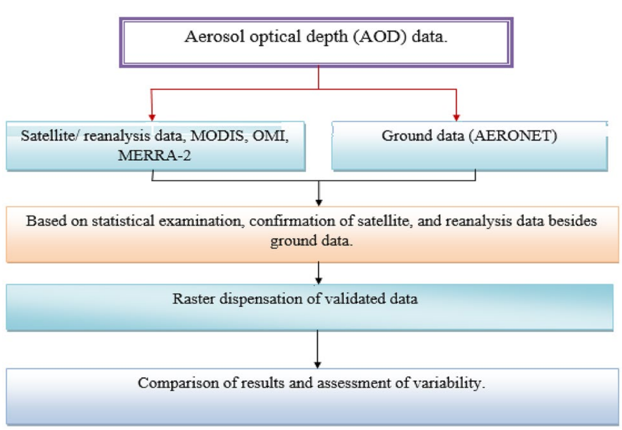
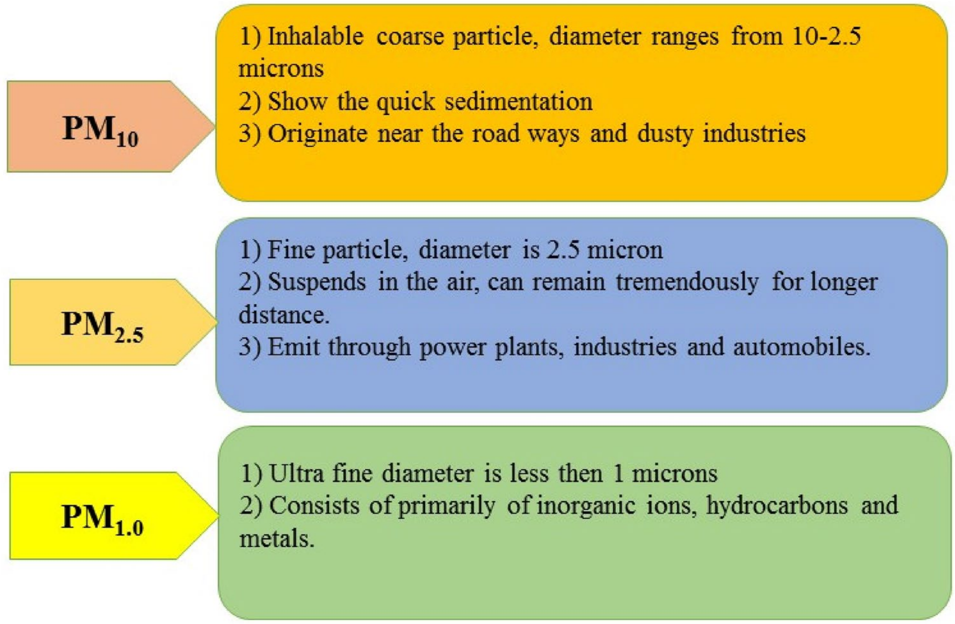


Fig. 1 AOD measurement through ground and satellite

2.1 Surface PM and Their Morphology

By smearing a drag force, the particle's morphology and chemical composition regulate its settling velocity and, therefore, disturb the particle's transportation manner (Agrawal et al. 2011; Mc Donald et al. 2004). Shape, surface roughness, and edge sharpness are morphological factors that influence a particle's scattering property (Mishra et al. 2017). The chemistry of PM is also the driving force behind PM's climatic effects (Ebert et al. 2002). Mineral dust particles make up a significant portion of atmospheric aerosols and contribute to total aerosol loading (Bora et al. 2021). The analysis of dust aerosols offers crucial information about their origin (Attiya and Jones 2020; Engelbrecht et al. 2016). To visualize the trend of trace gases, remote sensing data through satellite-based sources, i.e., Giovanni supported by the National Aeronautics and Space Administration (NASA), were used over Singruali, India (Romana et al. 2020). The severe impact of air pollution over this region is observed due to its closeness to coal-based thermal power plants. Studies claimed the effect of fly ash and gaseous pollutants, such as carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and methane (CH_4) as atmospheric pollutants. However, PM, was observed as the main containments (Fig. 2). Furthermore, to analyze the variation of trace gases for regular as well as on yearly basis statistical tools has been used to calculate the relationship among $PM_{2.5}$, metrological condition, seasonality and air basins (Sarasvathy et al. 2017). Six $PM_{2.5}$ monitors site were selected over the city of Rio de Janerio with different emission source of $PM_{2.5}$ (Copacabana, down town, Jacarepagua,

Fig. 2 Characteristics of particulate matter



Maracana, Ramos and Santacruz) in South America. These studies were based on distinct statistical techniques (PCA, HCA, Kruskal Wallis, Mann test Whitneys, etc.) for understanding the association among different levels and seasons of fine $PM_{2.5}$, metrological conditions and air basins. Some studies involve the combination of AOD recovery and simulation of MODIS from weather research and forecasting model coupled by means of chemistry (Krishna et al. 2019). AOD standards received through these satellite-based instruments were used to extract the surface $PM_{2.5}$ concentrations, to evaluate the $PM_{2.5}$ concentrations at ground level at a resolution of 36 km across India. Using Fourier transfer infrared (FTIR) spectroscopy and Scanning Electron Microscopy (SEM) with energy dispersive X-ray (EDX) spectroscopy, morphology, size and elemental composition of PM were measured by various researchers across the globe (Aggarwal et al. 2011; Bora et al. 2021; Mishra et al. 2017; Zeb et al. 2018).

2.2 Chemical Composition and Trend in PM in China During 2013–2017

The impact of anthropogenic aerosols on the direct and indirect effect contributes to the most remarkable ambiguity in assessing climate change. The most critical factor influencing uncertainties are aerosol hygroscopicity, relations among aerosol and atmospheric water vapor. In addition to climate change, relative humidity (RH) increase can significantly affect the secondary formation of particle visibility, AOD, remote sensing, measurement of aerosol loading and chemical composition of aerosols. The study of particulate matter in troposphere has become a hotspot of concern, because its influences human health, air quality and atmospheric alteration in the past few years (Ramanathan et al. 2001). Exact measurements of atmospheric particulate matter mass and chemical composition are useful in assessing the cause and origin of ambient enthalpy pollution and its relation to environmental air quality, management, and methods. Standard hourly data for $PM_{2.5}$, PM_{10}, SO_2, NO_2, and CO used by Wang et al. (2019) derived from urban air excellence national real-time platform. This information combined with data and method published by the Chinese Academy of Engineering (CAE) (CAE 2016) in the "midterm evaluation report on action plan" was used to examine the circumstances, trend of difference and pollution distinctiveness of national air quality. The main aim was to elaborate and discuss the change and development of PM of diverse size fractions of various areas through the worldwide network information. To assemble ambient PM samples simultaneously in size range of <0.43, 0.43–0.65, 0.65–1.1, 1.1–2.1, 2.1–3.3, 3.3–4.7, 4.7–5.8, 5.8–9.0 and >9.0 µm (Stage sampler "Anderson series", 20–800, USA) from 2013 to 2017 as well as to evaluate distinction among fine and coarse particles (Wang et al. 2019). According to the scientific regulations on ambient air quality index, days with a daily mean concentration of $PM_{2.5}$ above150 µg m^{-3} were selected as highly contaminated days in 74 cities and main regions from 2013 to 2017. While, the midterm assessment information on the implementation of the CAE action plan (CAE 2016) showed that the weather conditions in the main region during polluted days in 2014 and 2015 were marginally unfavorable or showed no improvement compared to those in 2013. The annual mean concentration of $PM_{2.5}$ in 338 cities was also examined from 2015 to 2017. The finding showed that in 338 cities, the $PM_{2.5}$ mean yearly concentration showed a descending movement from 2015 to 2017, with an annual decreasing rate of 7.0% (CAE 2016).

2.2.1 Trend in the Chemical Composition of $PM_{2.5}$ in the Key Regions of China

The concentration of $PM_{2.5}$ in ambient air of main urban agglomeration in china shows degree of decrease from 2013 to 2017. The certain chemical elements were decreased, such as elemental carbon (EC), organic matter (OM), sulphate (SO_4), nitrate (NO_3), ammonia (NH_4) and other minerals (Wang et al. 2019). During 2013–2017, there was a major decline in the chemical components in the fine particles in Tianjin. Decreasing rate of each component reached more than 60% during autumn and winter season with the most severe PM pollution which was consistent with the decreasing rate of $PM_{2.5}$ (34%) in the same time. The ratio of decreasing rate of major components to the minor was about 1:1.6 and the annual mass concentration of $PM_{2.5}$ and PM_{10} as well as the number of days with heavy pollution increased considerably from 2013 to 2017 (Wang et al. 2019). Still, there was also a downward trend in the mass concentration of $PM_{2.5}$ chemical components, such as EO, OM, SO_4, NO_3, and NH_4 which was consistent during the change in concentration of $PM_{2.5}$ mass throughout the similar period from 2013 to 2015, a decreasing trend was observed in coarse and fine PM concentration and decreasing rate of coarse PM was substantially larger than fine PM (Wang et al. 2019).

2.3 Estimation of Fine Particulate Matter Accumulation in the Ambient Air (AOD Measured by Satellite)

Since the mid-2000s, NASA's Terra satellite's MODIS and MISR instruments gives a general explanation of AOD, a quantification of light extinction by aerosol in atmosphere above earth's surface. However, Terra's AOD estimations offer regular details on the national allotment of column-integrated aerosol. Applicability of AOD to surface air quality is based on several variables, such as atmospheric aerosol vertical structure, configuration, size allocation, and content of water. At mid-latitudes, Donkelaar et al. (2010) established a national satellite-based approximation of surface $PM_{2.5}$ with a spatial resolution of 0.1° × 0.1°, or about 10 km 0.1°, evolve a method for incorporating MODIS, MISR and AOD into a single, more reliable AOD estimation. Estimated AOD–$PM_{2.5}$ translation factor with a global CTM, developed and related these factors to the AOD, and provided a national estimation of $PM_{2.5}$ concentrations checked with ground-based (in situ) observation through this technique. In combination with ground-based AOD retrievals, Donkelaar et al. (2010) used MODIS BRDF/Albedo product (MOD43, Selection 5, (Schaaf et al. 2002) to differentiate surface types and classify areas of highest bias in both MODIS and MISR AOD. The relation of surface albedo for various wavelengths was used to describe these surface types for every month, related to the assumptions used in the MODIS AOD retrieval.

Donkelaar et al. (2010) found that universal estimation of long-standing normal (1 January 2001 to 31 December 2006) $PM_{2.5}$ concentrations at around 10 km × 10 km resolution signifies a universal populations weighted geometric mean $PM_{2.5}$ concentrations of 20 μg m^{-3}. To boost the association of AOD versus ground-based $PM_{2.5}$ measurements, they collaborate AODs from two satellite instruments (MODIS and MISR). They have reduced the sampling error by extending the satellite data over 6 years (2001–2006). The unprecedented national spatial resolution of 0.1° × 0.1° preserves population distribution differences.

2.4 Impact on Air Quality Through Human Activities

Mean Particulate matter concentration ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) were analyzed daily for 24 h in various sites over Delhi (DEL), along with the subsequent temperature (T) and RH from 1 January 2020 to 15 may 2020 (Sharma and Bangotra 2020). The consequential daily average has been analyzed and then compare for the period prior 1 January 2020–22 March 2020, (Sharma and Bangotra 2020). The T and RH% encourage the stability of droplets into a restricted environment that can be beneficial in favor of widespread communication of virus (Chen et al. 2020), To recognize the relationship among PM, T, and RH%, as well as their synergistic impact on COVID-19 cases related to an overall number of all the cases present (TC), active cases (AC), cases of recovery (RC), and cases of death efforts were analyzed. It has also been made by DEL, taking into relation to the data for the period from 1 April 2020 to 15 May 2020**.** The effect of lockdown over Gurgaon (GW) was witnessed in $PM_{1.0}$ (21. 90 μg m^{-3}), $PM_{2.5}$ (32. 19 μg m^{-3}) and PM_{10} (34. 52 μg m^{-3}) by a dramatic decrease of 48.21%, 51.82% and 52.45%. A substantial decrease in PM contaminants throughout lockdown (23 March to 15 may 2020) was notably revealed by the study related to before and after lockdown. Substantially reduced the fine ($PM_{1.0}$ and $PM_{2.5}$) and the coarse (PM_{10}) particles at both locations due to reduction in all modes of traffic, industrial pollution and transport system (Sharma and Bangotra 2020).

To analyze the air quality situation in mid of the lockdown period over rapid shift in emission was likely to have a severe impact on air quality. Conditions can be used as routine experimentation to stimulate some of the ambient air predominant pollutants' susceptibility. NO_2 and CO level has also decreased during the lockdown period, then other contaminants. Around 40–50% enhancement of air quality is recognized only after 4 days of lockdown (Sharma and Bangotra 2020). In contrast, lower CO reductions 14%, are attributable to the control of natural atmospheric chemical parameters as well as biogenic sources relative to anthropogenic such as CO, oxides of NO_X, BC as well as O_3 were also analyzed (Panda et al. 2021). NO_2 and $PM_{2.5}$ were observed as primary and secondary contaminants released either openly in environment or by some other way through chemical reaction of the released rainfall in the BOB due to depression played major part in generating primary contaminants at the site analyzed by Panda et al. (2021). In addition, the substantial decrease in NO_2 concentration was also observed over the US at 65% of the observing sites, reducing two parts per billion (Pb) compared to the mean for the earlier 5 years in study conducted by Archer et al. 2020. The same trend was verified by NASA OMI satellite-derived NO_2 column totals, which showed an average 13% decrease across the whole country during 2020, when contracted with the average of earlier 5 years. However, the concentration of $PM_{2.5}$ at ground monitoring sites was not considerably lesser in 2020, then the previous 5 years (Fig. 3).

2.5 To Validate the Finding of Aerosol Observation Using Ground and Satellite-Based Measurements

Due to the dynamical characteristics of atmospheric aerosols, various properties regularly get altered. The researchers studied significant properties such as single scattering albedo (SSA), asymmetry factor, angstrom exponent (AE), real and imaginary refractive index related to aerosols over four different locations, i.e., Jaipur, Pune, Gandhi College, and Karunya University during 2017–2018 (Mangla et al. 2020). A detailed assessment was performed on aerosol optical characteristics using MODIS, MISR and OMI satellite through ground-based Aeronet observations for 8 years, i.e., 2010–2017 data (over Indo Gangetic Plains (IGP). Spatial and temporal analysis of AOD measurement based on two different satellites were also conducted by Mangla et al. (2020), as well as variability of AODs with perceptible water and cloud, validation of the finding of MODIS and AERONET with cloud and perceptible water by means of intense statistical method. The process was done by considering the chemical surface transformation of dust from the source region during its transport and studying the inner mixed particles in terms of elemental size, chemical configuration, and hygroscopic increase during transportation (Mangla et al. 2020).

2.6 Seasonal Heterogeneity and Source Allocation of Aerosol Black Carbon in a Particular Area (IGP)

Mostly the prevalent anthropogenic aerosol is light-absorbing carbon (LAC) absorb light firmly in visible wavelengths (Andreae and Gelencsér, 2006; Gautam et al. 2021c). LAC is made up of two forms of carbon: black carbon (BC) and brown carbon (BrC). For better characterization and understanding of the climatic consequences through biomass burning of aerosols, it is important to calculate their contribution to the entire BC content and recognize possible sources regions (Ambade et al. 2021). The majority of westerly winds reverse throughout the monsoon months (July–September) are experienced due to the distinctive

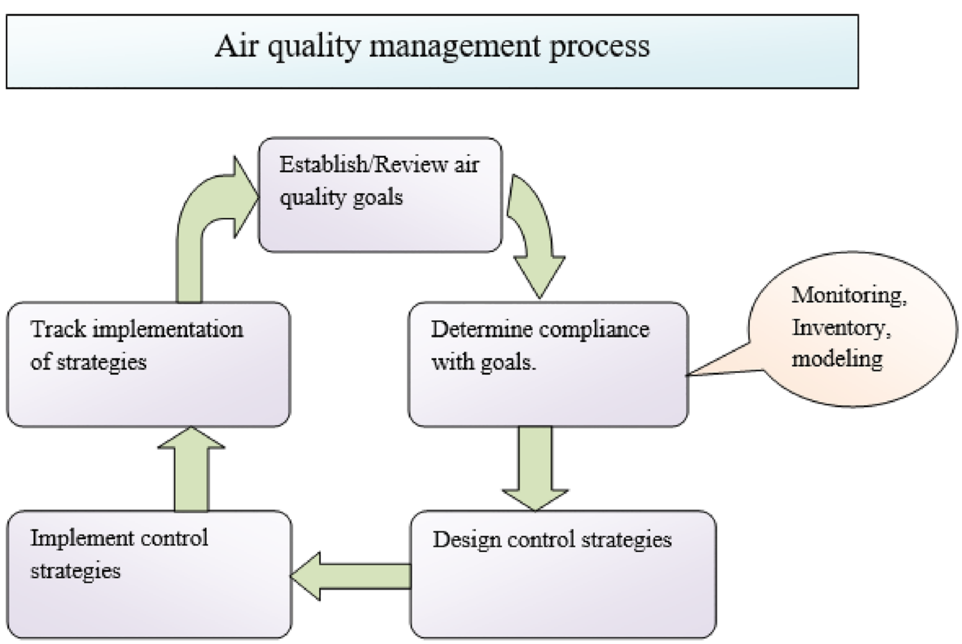


Fig. 3 Air quality management process

topography of Indo genetic diversity of source areas, shared with topography, land-use pattern, and domestic cooking practices (Rehman et al. 2011; Saud et al. 2012). Discharge from coal-fired power plants and transportation create a mixture of extremely absorbing aerosols with heavy spectral, seasonal, and diurnal variations (Prasad et al. 2006; Pandey and Venkataraman, 2014). The IGP is home to 1/7% of the world's population, analysis of absorbing aerosols, their mass quantification, physicochemical, radiative characterization, and their effects on local atmosphere are used for the period of years for aerosol light absorption records (August 2013 to July 2015) to measure the mass of absorbing aerosols over the central IGP (Vaishya et al. 2016).

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model was used to measure monthly and seasonal mean T, RH, and boundary layer height (BLH) (Vaishya et al. 2016). The highest T of 32 °C is recorded in June, just earlier than the onset of the south–west monsoon, and a lowest T of 16 °C was recorded into rain showers related to the coming monsoon, RH improves quickly from a low of 29.8% in May to a high of 93.3% in BLH over Gorakhpur has a lot of day-to-day and seasonal; because of decreased insolation due to extensive monsoonal cloud cover, the BLH reached a low of 187 ± 47 m, in August. According to a long-time regular rainfall results, the monsoon months in this area are July, August, and September, accounting for 75% of the total rainfall for years. Changes in rainfall, synoptic wind pattern, atmospheric boundary layer (ABL) height, aerosol source intensity, land use pattern are main causes of inconsistency in aerosol assimilation, affected the aerosol and trace gaseous pollution pattern. Aerosols from biomass sources account for 28% of total absorbing aerosol content throughout the winter and post monsoon seasons, compared to 16% in the pre-monsoon and monsoon seasons (Vaishya et al. 2016). Aerosols from biomass sources provide roughly twice as much to overall consuming aerosol load during winter and post-monsoon seasons as they do through pre-monsoon and monsoon seasons. Winter and post-monsoon seasons, still wind condition combine with shallow boundary layer height in the central Indo-Gangetic Plain, promote the trapping of pollutants from restricted sources, thus raising BC mass concentrations (Fig. 4). Throughout the winter and post-monsoon, limited sources of aerosols, take precedence over comprehensive transport.

3 Future Perspectives and Conclusion

A spectral variation of AOD analysis shows a strong seasonality in fine as well as in coarse mode aerosol in which the fine mode shows domination throughout the winter, while marine aerosols dominates throughout the summer monsoon period. The second-order MERRA2 reanalysis system of spectral curvature and chemical reanalysis depicted the overall time, except summer anthropogenic aerosols, such as sulphate and BC term fluctuation in CALIPSO (combined Environmental Satellite of USA and France). Aerosol profile shows that there is a growing addition of high altitude aerosols in comprise to those of the optical depth of columnar aerosol that is prevalent throughout winter, a substantial decline in ARF at surface level induced major cooling on the day of dust storm. The concentration of coarse mode particle was highest on dust day when compared to the other days. The satellite remote sensing techniques improving continuously to provide better resolution, visualization and precise measurement of pollutants and in future these remote sensing techniques may be the perfect options to replace the ground-based instruments. From last three to four decades, Ground-based measurements are more effective in measuring air quality, with two main drawbacks:

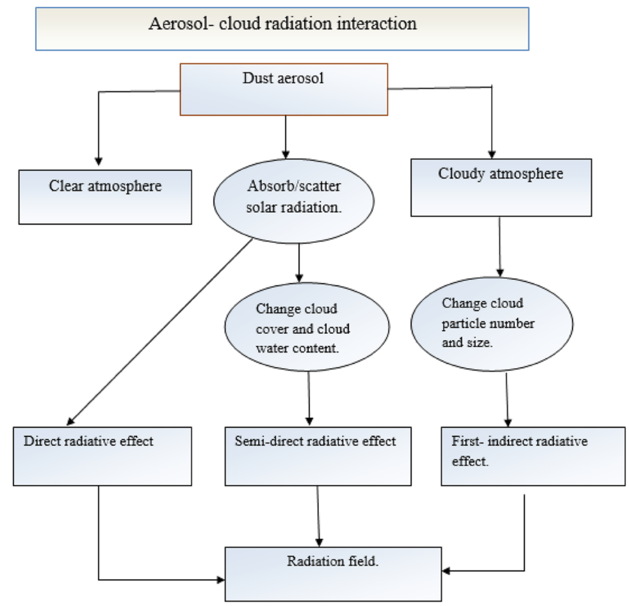


Fig. 4 **Aerosol–cloud radiation interaction**

1. The ground-based stations are located in the field sparsely and unevenly.
2. The unequal distribution of monitoring stations limits the area of analysis that can be studied.

The emission of contaminants in the megacity of Delhi have been significantly reduced fallowing the announcement of 3 weeks of lockdown. PM_{10}, $PM_{2.5}$, NO_2 and CO concentration showed a major decreasing trend, especially during the study period. The mean concentration of PM_{10} and $PM_{2.5}$ decreased by around 84% and 53.11%. For traffic and industrialized stations, decline rate of $PM_{2.5}$ is as high as around 62.61% and

59.74%. NO_2 (−52.68%) and CO (−30.35%) and additional pollutants that have revealed significant variation involving before and during lockdown time. The decrease was very low compared to the others pollutants, such as SO_2 (17.97%) and NH_3 (−12.33%). A substantial decline of primary contaminants, including NO_X (67%) and BC (47%), shows the lower traffic emission, as well as critical anthropogenic behavior, contributed to improved excellence of air throughout lockdown times Panda et al. (2021), by comparing to the same period in previous year, additional 40% drop in O_3, 50% drop in BC concentration.

The microphysical cloud and perceptible water relationship among aerosols have been analyzed at different stations with various meteorological features as per the studies of Ventura et al. (2018). The future prospect of this review is consistent with extra information of seasonal differences in previous papers on MODIS–AERONET AOD interaction. It was shown that MODIS were not offered an accountable AOD results, so the main requirement is to describe AOD involvement throughout seasons when performing MODIS atmospheric aerosol retrieval analysis. The statistical findings clearly demonstrate the underestimation of MODIS AOD. Industrialization and biomass burning of crop debris followed by primary agricultural production have contributed to SOx aerosol production in the IGP area. Surface covered dust makes it an effective way for aerosol dust surface to act as CCN and affect features of clouds. Thus, underlining the fact that AERONET, both satellite and ground-based measurement was profitably used for recognizing the property of contaminated aerosols over a wide area, particularly wherever there is limited examination and data access.

Acknowledgements Authors thanks to Sharda University, Bahra University, HNBGU, and Karunya Institute of Technology and Sciences Coimbatore for encouragement and providing the necessary infrastructure facility for this study.

Author contributions Data curation: ZM, MS, and PB. Formal analysis: ZM, MS, and PB. Funding acquisition: PB. Investigation: MS, PB, SG, and ASG. Methodology: ZM, MS, and PB. Software: ZM, MS, and PB. Supervision and validation: ASG and SG. Visualization: ZM, MS, and PB. Writing original draft: ZM, MS, PB, ASG, and SG. Writing—review and editing: MS, PB, SG, and ASG.

Funding Nil.

Availability of data and materials Not applicable.

Declarations

Conflict of interest The authors declare no competing interests.

References

Agrawal A, Upadhyay VK, Sachdeva K (2011) Study of aerosol behavior on the basis of morphological characteristics during festival events in India. Atmos Environ 45(21):3640–3644

Ambade B, Sankar TK, Panicker AS, Gautam AS, Gautam S (2021) Characterization, seasonal variation, source apportionment and health risk assessment of black carbon over an urban region of East India. Urban Clim 38(38):100896. https://doi.org/10.1016/j.uclim.2021.100896

Andreae MO, Gelencsér A (2006) Black carbon or brown carbon? The nature of light-absorbing carbonaceous aerosols. Atmos Chem Phys 6(10):3131–3148

Anitha M, Kumar LS (2020). Ground Based Remote Sensing of Aerosols Using AERONET in Indian Region. In: 2020 international conference on wireless communications signal processing and networking (WiSPNET), pp 72–77 IEEE

Anoruo (2020) Space and ground-based remote sensing comparison of seasonal interaction of aerosol-cloud-perceptible water. Atmos Environ 243:11784

Archer CL, Cervone G, Golbazi M, Al Fahel N, Hultquist C (2020) Changes in air quality and human mobility in the USA during the COVID-19 pandemic. Bull Atmos Sci Technol 1(3):491–514

Attiya AA, Jones BG (2020) Assessment of mineralogical and chemical properties of airborne dust in Iraq. SN Appl Sci 2(9):1–21

Awasthi A, Singh N, Mital S, Gupta PK, Agarwal R (2010) Effects of agriculture crop residue burning on children and young on PFTs in North West India. Sci Total Environ 408(20):4440–4445

Babu SS, Satheesh SK, Moorthy KK (2002) Aerosol radiative forcing due to enhanced black carbon at an urban site in India. Geophys Res Lett 29(18):27–31

Babu SS, Nair VS, Moorthy KK (2008) Seasonal changes in aerosol characteristics over Arabian Sea and their consequence on aerosol short-wave radiative forcing: results from ARMEX field campaign. J Atmos Sol Terr Phys 70(5):820–834

Bangotra P, Mehra R, Jakhu R, Kaur K, Pandit P, Kanse S (2018) Estimation of ^{222}Rn exhalation rate and assessment of Radiation hazardous from activity concentration of ^{226}Ra, ^{232}Th and ^{40}K. J J Geochem Explor 184(B):304–310

Bangotra P, Sharma M, Mehra R, Jakhu R, Gautam AK, Gautam S (2021) A systematic study of uranium retention in human organs and quantification of radiological and chemical doses from uranium ingestion. Environ Technol Innov 21:101360

Bawase M, Sathe Y, Khandaskar H, Thipse S (2021) Chemical composition and source attribution of PM 2.5 and PM 10 in Delhi-National Capital Region (NCR) of India: results from an extensive seasonal campaign. J Atmos Chem 78(1):35–58

Beegum SN, Moorthy KK, Babu SS (2009) Aerosol microphysics over a tropical coastal station inferred from the spectral dependence of Angstrom wavelength exponent and inversion of spectral aerosol optical depths. J Atmos Sol Terr Phys 71(17–18):1846–1857

Bellouin N, Quaas J, Gryspeerdt E, Kinne S, Stier P, Watson-Parris D, Stevens B (2020) Bounding global aerosol radiative forcing of climate change. Rev Geophys 58(1):e2019RG000660

Bisht L, Gupta V, Singh A, Gautam AS, Gautam S (2022) Heavy metal concentration and its distribution analysis in urban road dust: a case study from most populated city of Indian state of Uttarakhand. Spatial Spatio-Temporal Epidemiol 40:100470. https://doi.org/10.1016/j.sste.2021.100470

Bora J, Deka P, Bhuyan P, Sarma KP, Hoque RR (2021) Morphology and mineralogy of ambient particulate matter over mid-Brahmaputra Valley: application of SEM–EDX, XRD, and FTIR techniques. SN Appl Sci 3(1):1–15

Chen K, Wang M, Huang C, Kinney PL, Anastas PT (2020) Air pollution reduction and mortality benefit during the COVID-19 outbreak in China. Health 4(6):210–212

Chinese Academy of Engineering (2016) Report on the implementation of the Air Pollution Prevention and Control Action Plan (Release). 2016-07-05/2019-02-01. http://www.cae.cn/cae/html/main/col96/2016-07/05/20160705161134200910514_1.html

Dey S, Tripathi SN (2008) Aerosol direct radiative effects over Kanpur in the Indo-Gangetic basin, northern India: long-term (2001–2005) observations and implications to regional climate. J Geophys Res Atmos. https://doi.org/10.1029/2007JD009029

Donkelaar AV, Martin RV, Brauer M, Kahn R, Levy R, Verduzco C, Villeneuve PJ (2010) Global estimates of ambient fine particulate matter concentrations from satellite-based aerosol optical depth: development and application. Environ Health Perspect 118(6):847–855

Dsouza ND, Blaise D (2020) Impact of aerosols on deep convective clouds using integrated remote sensing techniques. Air Qual Atmos Health 13:815–825

Ebert M, Weinbruch S, Rausch A, Gorzawski G, Helas G, Hoffmann P, Wex H (2002) Complex refractive index of aerosols during LACE 98# x2010; as derived from the analysis of individual particles. J Geophys Res Atmos 107(D21):LAC-3

Engelbrecht JP, Moosmüller H, Pincock S, Jayanty RK, Lersch T, Casuccio G (2016) Mineralogical, chemical, morphological, and optical interrelationships of mineral dust re-suspensions. Atmos Chem Phy 16(17):10809

Erwan M, Sliman B, Charlotte N, Ilya B (2014) Volcanic sulpfate aerosol formation in the troposphere. J Geophys Res 119(22):12660–12673

Gautam S, Kumar P, Yadav A, Tsai CJ (2016) A review on recent progress in observations, sources, classification and regulations of PM25 in Asian environments. Environ Sci Pollut Res 23(21):21165–21175

Gautam S, Patra AK, Kumar P (2019) Status and chemical characteristics of ambient PM25 pollutions in China: a review. Environ Sustain Dev 21(4):1649–1674

Gautam S, Patra AK, Brema J, Raj PV, Raimond K, Abraham SS, Chudugudu KR (2021a) Prediction of various sizes of particles in deep opencast copper mine using recurrent neural network: a machine learning approach. J Inst Eng India Ser A. https://doi.org/10.1007/s40030-021-00589-y

Gautam S, Sammuel C, Bhardwaj A, Esfandabadi ZC, Santosh M, Gautam AS, Joshi A, Justin A, Wessley JW, James EJ (2021b) Vertical profiling of atmospheric air pollutants in rural India: a case study on particulate matter (PM10/PM2.5/PM1), carbon dioxide, and formaldehyde. Measurement 185:110061. https://doi.org/10.1016/j.measurement.2021.110061

Gautam S, Gautam AS, Singh K, James EJ, Brema J (2021c) Investigations on the relationship among lightning, aerosol concentration, and meteorological parameters with specific reference to the wet and hot humid tropical zone of the southern parts of India. Environ Technol Innov. https://doi.org/10.1016/j.eti.2021.101414

Gollakota ARK, Gautam S, Santosh M, Sudan HA, Gandhi R, Jebadurai VS, Shu CM (2021) Bioaerosols: characterization, pathways, sampling strategies, and challenges to geo-environment and health. Gondwana Res 99:178–203. https://doi.org/10.1016/j.gr.2021.07.003

Humbal C, Gautam S, Trivedi U (2018) A review on recent progress in observations, and health effects of Bioaerosols. Environ Int 118:189–193

Humbal C, Gautam S et al (2019) Evaluating the colonization and distribution of fungal and bacterial bioaerosol in Rajkot, western India using multi-proxy approach. Air Qual Atmos Health 12(6):693–704

Kang Y, Kim M, Kang E, Cho D, Im J (2022) Improved retrievals of aerosol optical depth and fine mode fraction from GOCI geostationary satellite data using machine learning over East Asia. ISPRS J Photogramm Eng Remote 183:253–268

Kaur-Sidhu M, Ravindra K, Mor S, John S, Aggarwal AN (2019) Respiratory health status of rural women exposed to liquefied petroleum gas and solid biomass fuel emissions. Air Soil Water Res 12:1178622119874314

Krishna RK, Ghude SD, Kumar R, Beig G, Kulkarni R, Nivdange S, Chate D (2019) Surface $PM_{2.5}$ estimate using satellite-derived aerosol optical depth over India. Aerosol Air Qual Res 19(1):25–37

Kulkarni SH, Ghude SD, Jena C, Karumuri RK, Sinha B, Sinha V, Khare M (2020a) How much does large-scale crop residue burning affect the air quality in Delhi? Environ Sci Technol 54(8):4790–4799

Kulkarni S, Pal S, Ghosh KG (2020b) Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. Sci Total Environ 730:139086

Lee H, Coull BA, Bell ML, Kang C, Koutrakis P (2012) Use of satellite-based aerosol optical depth and spatial clustering for PM2.5 prediction and concentration trends in the New England region, US. In AGU fall meeting abstracts (Vol. 2012, pp. A21C-0062)

Mangla R, Indu J, Chakra SS (2020) Inter-comparison of multi-satellites and Aeronet AOD over Indian Region. Atmos Res 240:104950

Manoj MR, Satheesh SK, Moorthy KK, Gogoi MM, Babu SS (2019) Decreasing trend in black carbon aerosol over the Indian region. Geophys Res Lett 46(5):2903–2910

Mc-Donald R, Biswas P (2004) A methodology to establish the morphology of ambient aerosols. J Air Waste Manag 54(9):1069–1078

Mehra R, Bangotra P, Kaur K, Kanse S, Mishra R (2015) Estimation of attached and unattached progeny of ^{222}Rn and ^{220}Rn concentration using Deposition based progeny sensors. Radiat Prot Dosim 167(1):92

Mishra SK, Saha N, Singh S, Sharma C, Prasad MVSN, Gautam S, Kotnala RK (2017) Morphology, mineralogy and mixing of individual atmospheric particles over Kanpur (IGP): relevance of homogeneous equivalent sphere approximation in radiative models. Mapan 32(3):229–241

Mor S, Singh T, Bishnoi NR, Bhukal S, Ravindra K (2022) Understanding seasonal variation in ambient air quality and its relationship with crop residue burning activities in an agrarian state of India. Environ Sci Pollut Res 29(3):4145–4158

Mukherjee A, Toohey DW (2016) A study of aerosol properties based on observations of particulate matter from the US Embassy in Beijing, China. Earth's Future 4(8):381–395

Mukherjee T, Vinoj V (2018) Atmospheric aerosol optical depth and its variability over an urban location in Eastern India. Nat Hazards 102(2):591–605

Munir S, Mayfield M, Coca D, Jubb SA (2019) Structuring an integrated air quality monitoring network in large urban areas–discussing the purpose, criteria and deployment strategy. Atmos Environs X 2:100027

Panda S, Mallik C, Nath J, Das T, Ramasamy B (2021) A study on variation of atmospheric pollutants over Bhubaneswar during imposition of nationwide lockdown in India for the COVID-19 pandemic. Air Qual Atmos Health 14(1):97–108

Pandey A, Venkataraman C (2014) Estimating emissions from the Indian transport sector with on-road fleet composition and traffic volume. Atmos Environ 98:123–133

Prasad AK, Singh RP, Kafatos M (2006) Influence of coal based thermal power plants on aerosol optical properties in the Indo-Gangetic basin. Geophys Res Lett. https://doi.org/10.1029/2005GL023801

Ramachandran S, Srivastava R, Kedia S, Rajesh TA (2012) Contribution of natural and anthropogenic aerosols to optical properties and radiative effects over an urban location. Environ Res Lett 7(3):034028

Ramanathan V, Crutzen PJ, Lelieveld J, Mitra AP, Althausen D, Anderson J, Valero FPJ (2001) Indian Ocean experiment: an integrated analysis of the climate forcing and effects of the great Indo-Asian haze. J Geophys Res Atmos 106(D22):28371–28398

Ravindra K, Sing T, Mor S, Singh V, Mandal TK, Bhatti MS, Gahlawat SK, Dhankhar R, Mor S, Beig G (2019a) Real-time monitoring of air pollutants in seven cities of North India during crop residue burning and their relationship with meteorology and transboundary movement of air. Sci Total Environ Sci 690:717–729

Ravindra K, Singh T, Mor S (2019b) Emissions of air pollutants from primary crop residue burning in India and their mitigation strategies for cleaner emissions. J Clean Prod 208:261–273

Rehman IH, Ahmed T, Praveen PS, Kar A, Ramanathan V (2011) Black carbon emissions from biomass and fossil fuels in rural India. Atmos Chem Phys 11(14):7289–7299

Romana HK, Singh RP, Shukla DP (2020) Long term air quality analysis in reference to thermal power plants using satellite data In Singrauli Region, India. Int Arch Photogram Remote XLIII-B3-2020:829–834

Sahu SK, Mangaraj P, Beig G, Samal A, Pradhan C, Dash S, Tyagi B (2021) Quantifying the high resolution seasonal emission of air pollutants from crop residue burning in India. Environ Pollut 286:117165

Sarasvathy K, Luciana ML, Kumar RS (2017) Comparison of sine, hysteresis, SVPWM and predictive PWM techniques for shunt active power filter. In: 2017 IEEE international conference on electrical, instrumentation and communication engineering (ICEICE), pp 1–7 IEEE

Satheesh SK, Ramanathan V, Holben BN, Moorthy KK, Loeb NG, Maring H, Savoie D (2002) Physical, chemical, and radiative properties of Indian Ocean aerosols. J Geophys Res 107(10):1029

Saud T, Gautam R, Mandal TK, Gadi R, Singh DP, Sharma SK, Saxena M (2012) Emission estimates of organic and elemental carbon from household biomass fuel used over the Indo-Gangetic Plain (IGP), India. Atmos Environ 61:212–220

Schaaf CB, Gao F, Strahler AH, Lucht W, Li X, Tsang T (2002) First operation BRDF, albedo nadir relectance products from MODIS. Remote Sens Environ 83:135–148

Sembhi H, Wooster M, Zhang T, Sharma S, Singh N, Agarwal S, Khaiwal R (2020) Post-monsoon air quality degradation across Northern India: assessing the impact of policy-related shifts in timing and amount of crop residue burnt. Environ Res Lett 15(10):104067

Sharma M, Bangotra P (2020) Lockdown impact on particulate matter and role of meteorological parameters in the transmission of Covid-19. Nat Environ Pollut Technol 19(4):1627–1636

Sharma M, Bangotra P, Gautam AK, Gautam S (2021) Sensitivity of Normalized Difference Vegetation Index (NDVI) to Land Surface Temperature, Soil Moisture and Precipitation over District Gautam Buddh Nagar, UP. Stoch Environ Res Risk Assess. https://doi.org/10.1007/s00477-021-02066-1

Shonk JKP, Turner AG, Amulya C, Wilcox LJ, Dittus AJ, Hawkins ED (2020) Uncertainty in aerosol radiative forcing impacts the simulated global monsoon in the 20th century. Atmos Chem Phys 20(23):14903–14915

Singh T, Biswas A, Mor S, Ravindra K, Singh V, Mor S (2020) A high-resolution emission inventory of air pollutants from primary crop residue burning over Northern India based on VIIRS thermal anomalies. Environ Pollut 266:115132

Taneja K, Ahmad S, Ahmad K, Attri SD (2020) Impact assessment of a severe dust storm on atmospheric aerosols over an urban site in India. Curr Sci 118(5):737–749

Thomas A, Sarangi C, Kanawade VP (2019) Recent increase in winter hazy days over Central India and the Arabian Sea. Sci Rep 9(1):1–10

Usman F, Zeb B, Alam K, Huang Z, Shah A, Ahmad I, Ullah S (2022) In-depth analysis of physicochemical properties of particulate matter (PM_{10}, $PM_{2.5}$ and PM_1) and its characterization through FTIR, XRD and SEM–EDX Techniques in the Foothills of the Hindu Kush Region of Northern Pakistan. Atm 13(1):124

Vaishya A, Singh P, Rastogi S, Babu SS (2017) Aerosol black carbon quantification in the central Indo-Gangetic Plain: seasonal heterogeneity and source apportionment. Atmos Res 185:13–21

Ventura LMB, de Oliveira PF, Soares LM, Luna AS, Gioda A (2018) Evaluation of air quality in a mega city using statistics tools. Meteorol Atmos Phys 130(3):361–370

Vinoj V, Babu SS, Satheesh SK, Moorthy K, Kaufman YJ (2004) Radiative forcing by aerosols over the Bay of Bengal region derived from shipborne, island-based, and satellite (Moderate-Resolution Imaging Spectroradiometer) observations. J Geophys Res Atmos. https://doi.org/10.1029/2003JD004329

Wang Y, Li W, Gao W, Liu Z, Tian S, Shen R, Zhang Y (2019) Trends in particulate matter and its chemical compositions in China from 2013–2017. Sci China Earth Sci 62(12):1857–1871

Won WS, Oh R, Lee W, Kim KY, Ku S, Su PC, Yoon YJ (2020) Impact of fine particulate matter on visibility at Incheon International Airport, South Korea. Aerosol Air Qual Res 20(5):1048–1061

Zeb B, Khan A, Armin S, Thomas B, Ahmad I, Imran S (2018) On the morphology and composition of particulate matter in an urban environment. Aerosol Air Qual Res 18:1431–1447

Zhang Y, Li Z, Bai K, Wei Y, Xie Y, Zhang Y, Li D (2021) Satellite remote sensing of atmospheric particulate matter mass concentration: advances, challenges, and perspectives. Fundam Res 1(3):240–258