CURRICULUM VITAE

Dr. Manish Kumar
Post-Doctoral Researcher
Department of Environmental Science (Biogeochemistry Unit)
Stockholm University, Sweden
Email: manishenvi@gmail.com
Phone: +46 764498470
Google Scholar: *https://scholar.google.co.in/citations?user=9NX71dUAAAAJ&hl=en*

Research Outputs
SCI Journal Publications: **22**
Total Citations (till date): **779**
h-index: **16**
i-10 index: **18**
Cumulative Impacts: **78**
Average Impact /paper: **3.5**

Background and Motivation

I am working in the Department of Environmental Science at Stockholm University, Sweden. I am involved in the evaluation of emission inventories and socio-economic impacts of Black Carbon aerosols over India. Earlier, I was working at the Atmospheric Chemistry Department, Max Plank Institute for Chemistry, Mainz, Germany where I was involved in the evaluation and application of global chemistry-climate model simulations of aerosol composition over South Asia. I have also been associated with air quality studies over India with special emphasis on the source apportionment of fine aerosols. I would like to apply for a **Faculty Position (Assistant Professor)** at TERI University with a motivation of teaching and research, focussing on atmospheric interactions and emissions of short-lived climate forcers and their relevance to the Indian economy. The utilization of state-of-the-art remote sensing techniques and chemistry-climate models is planned for the primary scoping of circular economy in highly uncertain pollution sources in India.

Research and Teaching Interests

Emission Inventories.
Atmospheric Chemistry.
Data Science.
Remote Sensing.
Receptor Modelling.
Sustainable Development.
Value-Chain Modelling.
Environmental Statistics.
Circular Economy.

Research Experience

- **Post-Doctoral Researcher-** Department of Environmental Science, Stockholm University, Sweden, October 2019-till date.

- **Visiting Scholar-** Atmospheric Chemistry Department, Max Plank Institute for Chemistry, Mainz, Germany, October 2018- April 2019.

Education

- **Doctor of Philosophy (Ph.D.)-**Institute of Environment & Sustainable Development, Banaras Hindu University (BHU), Varanasi, India, 2013-2018.
  - **Thesis Title:** Aerosol surface and columnar properties at middle Indo-Gangetic Plains: Identifying meteorological implications and particulate source apportionment.

- **Post Graduate Diploma in Urban Environmental Management and Law-** National Law University, New Delhi, India, 2016-2017 (online mode).
  - **Thesis Title:** Inclusion of 'Cleaner Air Quality' into Clean India Mission: A way forward to urban cleanliness and planning.

- **Master of Philosophy (M.Phil.) in Environmental Science & Sustainable Development-** Banaras Hindu University (BHU), Varanasi, India, 2012-2013. CGPA: 9.21.
  - **Thesis Title:** Tropospheric Aerosols and Climate Change: A Sustainability Challenge.

- **Master of Science (M.Sc.) in Environment Management-** University School of Environment Management, GGS Indraprastha University, New Delhi, India, 2010-2012. Percentage: 78%.
  - **Thesis Title:** Spatial distribution of ambient ammonia over the national capital region of Delhi.

- **Bachelor of Science (B.Sc.) in Environment and Water Management-** Magadh University, Bodhgaya, India, 2006-2009. Percentage: 82.1%.

Academic Achievements

- **Awarded Visiting Scholarship** by Max Plank Institute for Chemistry, Mainz, Germany, October, 2018-April 2019.
- **Awarded Senior Research Fellowship (Earth Sciences)** by Council for Scientific and Industrial Research (CSIR), Govt. of India, April 2017- March 2019.
- **Qualified ICAR-NET for Lectureship in Environmental Sciences** conducted by Agricultural Scientists Recruitment Board, Govt. of India, New Delhi, October 2013.
- **Qualified UGC-NET for Lectureship in Environmental Sciences** conducted by University Grants Commission, Govt. of India, June 2012.

Professional Experience

- **Trainee Environmental Engineer-I,** Delhi Pollution Control Committee (DPCC), Department of Environment, Govt. of Delhi, India, September- November 2012.

  Responsibilities:

  i. Quality Control and statistical analysis of real-time air quality data for 6 sites in New Delhi.
  ii. Monitoring of Stack Emissions from thermal power plants within New Delhi.
  iii. Chemical analysis and quality control of air and water samples for heavy metals.

- **Project Intern, Council for Scientific and Industrial Research-National Physical Laboratory,** New Delhi on Ambient Ammonia pollution funded by Department of Science and Technology, Govt. of India, January-June, 2012.

  Responsibilities:

  i. Operation of real-time analyzers for ambient ammonia, sulfur dioxide, Ozone, Carbon monoxide, and their data analysis.
  ii. On-site monitoring of ambient PM_{10} and $PM_{2.5}$ samples through dust samplers.
  iii. Sample preparation and analysis of particulate samples for water-soluble inorganic components.
  iv. Operation of Ion Chromatograph and UV-Spectrophotometer.
  v. Study of gas-to-particle conversion mechanism through ambient ammonia.

- **Environmental Chemist,** Mantec Environmental Laboratory, Noida, India, April, 2009-April, 2010.

  Responsibilities:

  i. On-site and field monitoring of ambient particulates (TSPM, PM_{10}, $PM_{2.5}$), SO_2, and NOx.
  ii. Compliance monitoring of ambient air pollutants for thermal power plants, steel industries, and oil refineries.
  iii. Monitoring of stack emissions from thermal power plants, steel industries, and oil refineries.
  iv. Internal auditing of the laboratory as per IS/ISO/IEC: 17025:2005.
  v. Analysis of air, water, and soil samples for Physico-chemical and biological parameters.
  vi. Preparation of reports, quality control, and execution of Inter-laboratory comparison experiments.

Technical Skills:

- Air Quality Modelling using EPA-PMF 5.0, HYSPLIT, and Trajstat.
- GIS Softwares like ArcGIS and BEAM.
- Operation of sophisticated instruments like Ion Chromatograph, Mercury Analyzer, Aethalometer.
- Computational skills: R, Origin, ExcelStat, MATLAB software; Operating Systems: Windows.
- Knowledge of statistical software SPSS, MINITAB, and R.
- Certified Internal Auditor for Laboratory Quality Management and Internal Audit as per IS/ISO/IEC 17025:2005.

Grants/Awards/Honors/Recognitions

- **Lead-Chair**, Early Career Group Review for IPCC Sixth Assessment Report (AR6), Chapter 8 (*Water Cycle Changes*), Working Group-I (Physical Science Basis).
- **IGAC Early Career Scientist Travel Award** for attending 15th IGAC Science Conference and Early Career Short Course, 21-29 September 2018 at Takamatsu, Japan.
- **DST-International Travel Support** by Department of Science and Technology, Govt. of India to present a paper at "Asian Aerosol Conference 2017" July 02-06, 2017 at Jeju City, South Korea.
- **ICSU-International Travel Award** by International Council for Science (Asia-Pacific), Malaysia to attend the Advanced Institute on Disaster Risk Reduction with Systems Approach for Slow-Onset Climate Disasters, July 10-14, 2017 at Taipei, Taiwan.
- **CSIR-Senior Research Fellowship (2017-19),** Awarded by Council for Scientific and Industrial Research, Govt. of India.
- **IGAC Early Career Scientist Travel Award** to attend 14th IGAC Science Conference and Early Career Short Course, September 22-30, 2016 at Boulder and Breckenridge, Colorado, USA.
- **ACAM Travel Award by IGAC, USA, and ICIMOD, Nepal** to attend 2nd Workshop and Training on Atmospheric Chemistry and Asian Monsoon, June 8-12, 2015 at Asian Institute of Technology, Bangkok, Thailand.
- **Awarded Travel Grant from the World Bank** to attend an International Workshop on Statistical Methods for Environmental Data Analysis, March 4 -7, 2013, CR Rao Advanced Institute of Mathematics, Statistics and Computer Science, Hyderabad, India.

Editorial Task

- Review Editor: Frontiers in Sustainable Cities.
- Editorial Board Member: International Journal of Environmental Research and Public Health.
- Editor, Nordic Society for Aerosol Research Newsletter.
- Regular Reviewer of the following journals:
  Atmospheric Chemistry and Physics **(EGU),** Science of the Total Environment **(Elsevier),** Environmental Pollution **(Elsevier),** Atmospheric Environment **(Elsevier),** Atmospheric Research **(Elsevier),** ESPR **(Springer),** Environment, Development, and Sustainability **(Springer),** Energy, Ecology and Environment **(Springer),** Atmosphere **(MDPI)**, Energies **(MDPI)**, Applied Sciences **(MDPI)**.

Honors/Affiliations to Scientific Societies

- **Representative (South-East Asia)**, Young Earth System Scientists (YESS) Community, Germany.
- **Member, Early Career Scientists Board,** Nordic Society for Aerosol Research (NOSA), Finland.
- **Member (Organizing Committee)** Early Career Programs, 15th IGAC Science Conference, Japan.
- **Berkner Member,** American Geophysical Union (AGU), Washington, D.C, USA.
- **Life Member,** European Geosciences Union (EGU), Munich, Germany.
- **Life Member,** Nordic Society for Aerosol Research (NOSA), Sweden.
- **Life Member**, Indian Aerosol Science and Technology Association (IASTA), Mumbai, India.
- **Life Member**, Association of Environmental Analytical Chemistry of India (AEACI), Mumbai, India

Foreign visits (for research purposes):

Sweden, Germany, Switzerland, France, USA, South Korea, Japan, Nepal, Malaysia, Hong Kong, Taiwan, Thailand.

International Publications (SCI Journals)

1. **Kumar, M.,** Parmar, K.S., Kumar, D.B., Mhawish, A., Banerjee, T. 2018. Long term aerosol climatology over Indo-Gangetic Plain: Trends, predictions and potential source fields, Atmospheric Environment 180:37-50.
2. **Kumar, M.,** Raju, M.P., Singh, R.S., Banerjee, T. 2017. Impact of drought and normal monsoon scenario on aerosol radiative forcing at Varanasi over middle Indo-Gangetic Plain. Journal of Aerosol Science, 113: 95–107.
3. **Kumar, M.,** Raju, M.P., Singh, R.K., Singh, A.K., Singh, R.S., Banerjee, T. 2017. Wintertime characteristics of aerosols at middle Indo-Gangetic Plain: Vertical profile, transport and radiative forcing. Atmospheric Research 183: 268–282.
4. **Kumar, M.,** Singh, R.K., Murari, V., Singh, A.K., Singh, R.S, Banerjee, T. 2016. Fireworks induced particle pollution: A spatio-temporal analysis, Atmospheric Research, 180: 78–91.
5. **Kumar, M.,** Singh, R.S., Banerjee, T. 2015. Mineral Dust: key player in the Earth system, Pure and Applied Geophysics. DOI 10.1007/s00024-015-1142-6.
6. **Kumar, M.,** Singh, R.S., Banerjee, T. 2015. Associating airborne particulates and human health: Exploring possibilities, Environment International 84:201–202.
7. **Kumar, M.,** Tiwari, S., Murari, V., Singh, A.K., Banerjee, T. 2015. Wintertime characteristics of aerosols at middle Indo-Gangetic Plain: Impacts of regional meteorology and long-range transport. Atmospheric Environment, 104:162-175.
8. Ojha, N., Sharma, A., **Kumar, M.**, Girach, I., Ansari, T., Sharma, S., Singh, N., Pozzer, A., Gunthe, S. 2020. On the widespread enhancement in the fine particulate matter across the Indo-Gangetic Plain towards winter, Scientific Reports, **10,** 5862: 1-9.
9. Srivastava, S., **Kumar, M.**, Singh, R.S., Rai, B.N., Mall, R.K., Banerjee, T. 2019. Long-term observations of black carbon aerosols at an urban location of central Indo-Gangetic Plain, South Asia, Atmosfera, 32 (2): 95-113.
10. Murari, V., **Kumar, M.**, Mhawish, A., Barman, S.C., Banerjee, T. 2017. Airborne particulate in Varanasi over middle Indo-Gangetic Plain: Variation in particulate types and meteorological influences, Environmental Monitoring and Assessment, 189: 157.
11. Singh, N., Murari, V., **Kumar, M.,** Barman, S.C., Banerjee, T. 2017. Fine particulates over South Asia: Review and meta-analysis of $PM_{2.5}$ source apportionment through receptor model. Environmental Pollution, 223:121-136.
12. Banerjee, T., **Kumar, M.,** Mall, R.K., Singh, R.S., 2017. Airing 'clean air' in Clean India Mission, Environ Sci Pollut. Res., **24,** 6399–6413.
13. Sen, A., Abdelmaksoud, A.S., Ahammed, Y, N., Alghamdi, M.A., Banerjee, T., Bhat, M.A., Chatterjee, A., Khan, A.H., Khoder, M., Kumari, K.M., Kuniyal, J.C., **Kumar, M.,** Lakhani, A et al. 2017. Variations in particulate matter over Indo-Gangetic Plains and Indo-Himalayan Range during four field campaigns in winter monsoon and summer monsoon: Role of pollution Pathways, Atmospheric Environment, 154: 200-224.
14. Murari, V., **Kumar, M.,** Singh, N., Singh, R.S. and Banerjee, T. 2015. Particulate morphology and elemental characteristics: Variability at middle Indo-Gangetic Plain, Journal of Atmospheric Chemistry J Atmos Chem 73:165–179.
15. Banerjee, T. **Kumar, M**. 2015. Unravelling Earth System for Sustainable Solution. Environ Sci Pollut Res. 22 (11):8773-8774.
16. Murari, V., **Kumar, M.,** Barman, S.C., Banerjee, T. 2015. Temporal variability of MODIS aerosol optical depth and chemical characterization of airborne particulates in Varanasi, India, Environ Sci Pollut Res (2015) 22:1329–1343.
17. Banerjee, T., Murari, V., **Kumar, M.,** Raju, M.P. 2015. Source Apportionment of Airborne Particulates through Receptor Modelling: Indian Scenario. Atmospheric Research 164–165 (2015) 167–187.
18. Sen, A., Ahamed., Y.N., Arya, B.C., Banerjee, T. Begam, G.R., Baruah, B.P, Chatterjee, A., Choudhury, A.K., Dhir, A., Das, T., Dhyan, P.P., Deb, N.C. Gadi, R., Gauns, M., Ghosh, S.K., Gupta, A., Sharma, K.C., Khan, A.H., Kumari, K.M., **Kumar, M.**, Kumar, A., Kuniyal, J.C., Lakhani, A. et al. 2014. Atmospheric Fine and Coarse Mode Aerosols at Different Environments of India and the Bay of Bengal during Winter-2014: Implications of a Coordinated Campaign. MAPAN: Journal of Metrology Society of India, 29(4):273–284.
19. Sharma, S.K., Mandal, T.K., Rohtash, **Kumar, M.,** Gupta, N.C., Saxena, M. 2014. Measurement of ambient ammonia over the National Capital Region of Delhi, India. MAPAN: Journal of Metrology Society of India, 29(3):165–173.
20. Sharma, S.K., **Kumar, M.**, Rohtash, Gupta, N.C., Saraswati, Saxena, M. and Mandal, T.K. 2014. Characteristics of Ambient Ammonia over Delhi, India. Meteorol Atmos Phys, 124:67–82.
21. Yadav, S.K., **Kumar, M.,** Sharma, Y., Shukla, P., Singh, R.S., Banerjee, T., 2017. Time resolved evolution of submicron particles during extreme fireworks, EMA, 191(9):576.
22. Mhawish, A., Sorek-Hamer, M., Chatfield, R., Banerjee, T., Bilal, M., **Kumar, M.**, Sarangi, C., Franklin, M., Chau, K., Garay, M., Kalashnikova, O. 2021. Aerosol Characteristics from Earth Observation Systems: A Comprehensive Investigation over South Asia (2000-2019), Remote Sensing of Environment, Elsevier [Article in Press].

Chapters in Books:

1. **Kumar M**., Ojha, N., Singh, N. 2020. Atmospheric aerosols from open burning over South and South-East Asia. Asian Atmospheric Pollution, Elsevier.
2. **Kumar, M.,** Srivastava, R.K., Banerjee, T. 2016. Climatic Impacts of Aerosols: A Sustainability Challenge, Environmental Science and Engineering, STUDIUM Press, LLC, USA.
3. Ojha, N., Soni, M., **Kumar, M.**, Girach, I., Sharma, S.K., Gunthe, S.S. 2021. Air Pollution Episodes: Brief History, Mechanisms, and Outlook, Extremes in Atmospheric Processes and Phenomena: Assessment, Impacts and Mitigation, Springer-Nature.
4. Mhawish, A., Sarma, K.V., Singh, N., **Kumar M.**, Banerjee, T. 2020. Vertical Profiling of Aerosol and Aerosol Types Using Space-Borne Lidar, Measurement, Analysis and Remediation of Environmental Pollutants, Elsevier.
5. Mhawish, A, **Kumar, M.,** Banerjee, T., Mishra, A.K., Srivastava, P.K. 2016. Remote sensing of aerosols from space: Retrieval of properties and applications. Remote sensing of aerosols, clouds and precipitation, Elsevier.
6. Banerjee, T., **Kumar, M.,** Singh, N. 2016. Aerosols, Climate and Sustainability. Encyclopedia of Anthropocene.

Full length articles in Conference Proceedings:

1. **Kumar, M.,** Mhawish, A., Raju, M.P., Singh, R.S., Banerjee, T. 2016. Characteristics of black carbon aerosols during agro-residue burning seasons over middle Indo-Gangetic Plain. Proceedings of IASTA Conference, Ahmedabad, India
2. **Kumar, M.,** Singh, R.K., Kant, Y., Banerjee, T. 2014. Study of wintertime characteristics of aerosols at Varanasi using CALIPSO and MODIS products. Proceedings of IASTA Conference, Varanasi, India.
3. **Kumar, M.,** Rohtash, Gupta, N.C., Pathak, H., Saxena, M., Saraswati, Mandal, T.K., Sharma, S.K. 2012. Role of ambient ammonia in the formation of secondary aerosol over national capital region of Delhi. Proceedings of IASTA Conference, Mumbai, India.
4. Mhawish, A., Ojha, N., **Kumar, M.** 2020. Multi-sensor remote sensing of atmospheric aerosols over South Asia, GASS 2020 Proceedings, Union Radio Scientifique Internationale Conference, Rome, Italy.

Popular Science Articles:

1. Willis, M., Ishino, S., Desservettaz, M., Mbandi, A., Tzompa-Sosa, Z., **Kumar, M.**, Sakata, K. 2018. An Early Career Perspective on Fostering the Next Generation of Atmospheric Scientists in an International Community, IGAC News, Volume 63: 21-24.
2. Ishino, S., Sakata, K., Mbandi, A., **Kumar, M.**, Desservettaz, M., Willis, M., Tzompa-Sosa, Z., 2018. 2018 iCACGP/IGAC Early Career Short Course, IGAC News, Volume 63: 14-15.
3. **Kumar, M.**, Banerjee, T. सिंधु-गंगा मैदानी क्षेत्र में वायुमंडलीय एरोसोल की प्रवृति और उनके संभावित प्रभाव, Vigyan Ganga, 67-70.

References

1. **Dr. Örjan Gustafsson**
   Professor
   Department of Environmental Science
   Stockholm University
   Email: orjan.gustafsson@aces.su.se

2. **Dr. Narendra Ojha**
   Scientist-D and Assistant Professor
   Division of Geosciences
   Physical Research Laboratory, Ahmedabad
   Email: ojha@prl.res.in

3. **Dr. Sudhir Kumar Sharma**
   Principal Scientist
   CSIR-National Physical Laboratory
   New Delhi
   Email: sudhir@nplindia.org

4. **Dr. R.S. Singh**
   Professor
   Department of Chemical Engineering and Technology
   IIT-BHU, Varanasi
   Email: rssingh.che@iitbhu.ac.in

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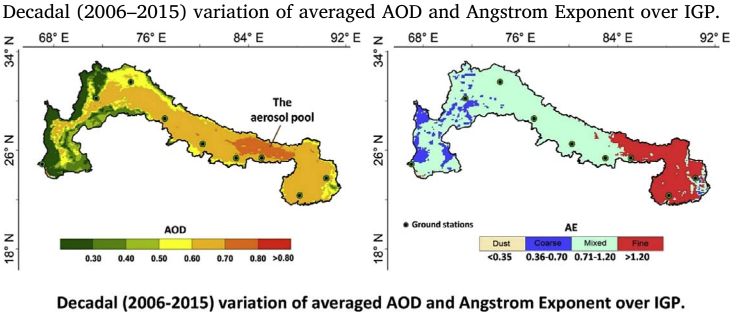
Long-term aerosol climatology over Indo-Gangetic Plain: Trend, prediction and potential source fields

M. Kumar[a], K.S. Parmar[b], D.B. Kumar[c], A. Mhawish[a], D.M. Broday[d], R.K. Mall[a,e], T. Banerjee[a,e,*]

[a] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India
[b] Department of Mathematics, Punjab Technical University, Jalandhar, Kapurthala, India
[c] School of Civil Engineering, Kalinga Institute of Industrial Technology University, Bhubaneswar, India
[d] Civil and Environmental Engineering, Technion, Haifa, Israel
[e] DST-Mahamana Centre of Excellence in Climate Change Research, Banaras Hindu University, Varanasi, India

GRAPHICAL ABSTRACT

Decadal (2006–2015) variation of averaged AOD and Angstrom Exponent over IGP.



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ABSTRACT

Long-term aerosol climatology is derived using Terra MODIS (Collection 6) enhanced Deep Blue (DB) AOD retrieval algorithm to investigate decadal trend (2006–2015) in columnar aerosol loading, future scenarios and potential source fields over the Indo-Gangetic Plain (IGP), South Asia. Satellite based aerosol climatology was analyzed in two contexts: for the entire IGP considering area weighted mean AOD and for nine individual stations located at upper (Karachi, Multan, Lahore), central (Delhi, Kanpur, Varanasi, Patna) and lower IGP (Kolkata, Dhaka). A comparatively high aerosol loading (AOD: 0.50 ± 0.25) was evident over IGP with a statistically insignificant increasing trend of 0.002 $year^{-1}$. Analysis highlights the existing spatial and temporal gradients in aerosol loading with stations over central IGP like Varanasi (decadal mean AOD ± SD; 0.67 ± 0.28) and Patna (0.65 ± 0.30) exhibit the highest AOD, followed by stations over lower IGP (Kolkata: 0.58 ± 0.21; Dhaka: 0.60 ± 0.24), with a statistically significant increasing trend (0.0174–0.0206 $year^{-1}$). In contrast, stations over upper IGP reveal a comparatively low aerosol loading, having an insignificant increasing trend. Variation in AOD across IGP is found to be mainly influenced by seasonality and topography. A distinct "aerosol pool" region over eastern part of Ganges plain is identified, where meteorology, topography, and aerosol sources favor the persistence of airborne particulates. A strong seasonality in aerosol loading and types is also witnessed, with high AOD and dominance of fine particulates over central to lower IGP, especially during post-monsoon and winter. The time series analyses by autoregressive integrated moving average (ARIMA) indicate contrasting patterns in randomness of AOD over individual stations with better performance especially over central IGP. Concentration weighted trajectory analyses identify the crucial contributions of western dry regions and partial contributions from central Highlands and north-eastern India, in regulating AOD over stations across IGP. Although our analyses provide some attributes to the observed changes in aerosol loading, we

* Corresponding author. Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, 221005, India.
E-mail addresses: tb.iesd@bhu.ac.in, tirthankaronline@gmail.com (T. Banerjee).

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SCIENTIFIC REPORTS
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On the widespread enhancement in fine particulate matter across the Indo-Gangetic Plain towards winter

Narendra Ojha[1*], Amit Sharma[2,7], Manish Kumar[3], Imran Girach[4], Tabish U. Ansari[5], Som K. Sharma[1], Narendra Singh[6], Andrea Pozzer[3] & Sachin S. Gunthe[2*]

Fine particulate matter ($PM_{2.5}$, aerodynamic diameter $\leq$2.5 µm) impacts the climate, reduces visibility and severely influences human health. The Indo-Gangetic Plain (IGP), home to about one-seventh of the world's total population and a hotspot of aerosol loading, observes strong enhancements in the $PM_{2.5}$ concentrations towards winter. We performed high-resolution (12 km $\times$ 12 km) atmospheric chemical transport modeling (WRF-Chem) for the post-monsoon to winter transition to unravel the underlying dynamics and influences of regional emissions over the region. Model, capturing the observed variations to an extent, reveals that the spatial distribution of $PM_{2.5}$ having patches of enhanced concentrations ($\geq$100 µgm^{-3}) during post-monsoon, evolves dramatically into a widespread enhancement across the IGP region during winter. A sensitivity simulation, supported by satellite observations of fires, shows that biomass-burning emissions over the northwest IGP play a crucial role during post-monsoon. Whereas, in contrast, towards winter, a large-scale decline in the air temperature, significantly shallower atmospheric boundary layer, and weaker winds lead to stagnant conditions (ventilation coefficient lower by a factor of ~4) thereby confining the anthropogenic influences closer to the surface. Such changes in the controlling processes from post-monsoon to winter transition profoundly affect the composition of the fine aerosols over the IGP region. The study highlights the need to critically consider the distinct meteorological processes of west-to-east IGP and changes in dominant sources from post-monsoon to winter in the formulation of future pollution mitigation policies.

The Indo-Gangetic Plain (IGP) region is considered to be a global hotspot of elevated aerosol loading, and is among few regions of the world, which have been experiencing enhancements[1–4]. Atmospheric processes occurring in this region have been shown to affect atmospheric composition, chemistry and climate over regional as well as global scales[5–8]. Fine particulate matter ($PM_{2.5}$) in this region is estimated to cause severe health implications including premature mortalities[9–12]. Numerous efforts based on *in-situ* and satellite-based observations have revealed strong enhancements in the $PM_{2.5}$ over this region towards winter, typically every year[13–16]. $PM_{2.5}$ concentrations over the IGP region are observed to exceed the standards of World Health Organization (WHO) as well as the National Ambient Air Quality Standards (NAAQS) of India, attributed to the combined effects from a variety of anthropogenic and biomass-burning emissions and meteorological conditions[17–24]. The accumulation of aerosols in this region is further supported by the topography of Himalaya that extends from northwest to southeast and forms a corridor along the IGP.

The changes in meteorology and atmospheric dynamics can offset the benefits availed from reduction in anthropogenic emissions. Such meteorological influences, besides the elevated emission source strengths and upwind biomass-burning, highly complicate the detailed understanding of aerosol behavior over the IGP[18,22–24]. The implementation of an odd-even scheme for vehicular traffic aiming to reduce its emissions in Delhi, India's capital territory, did not lead to a significant improvement in the air quality[25,26], which highlighs the crucial

[1]Space and Atmospheric Sciences division, Physical Research Laboratory, Ahmedabad, India. [2]EWRE Division, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, India. [3]Atmospheric Chemistry Department, Max Planck Institute for Chemistry, Mainz, Germany. [4]Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, India. [5]Lancaster Environment Centre, Lancaster University, Lancaster, UK. [6]Aryabhatta Research Institute of observational sciencES (ARIES), Nainital, India. [7]Present address: Laboratory for Atmospheric Research, Washington State University, Pullman, USA. *email: ojha@prl.res.in; s.gunthe@iitm.ac.in

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Wintertime characteristics of aerosols over middle Indo-Gangetic Plain: Vertical profile, transport and radiative forcing☆

M. Kumar [a], M.P. Raju [b], R.K. Singh [c], A.K. Singh [d], R.S. Singh [e], T. Banerjee [a,*]

[a] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India
[b] National Centre for Medium Range Weather Forecasting, Noida, India
[c] International Center for Agriculture Research in the Dry Areas, New Delhi, India
[d] Atmospheric Research Laboratory, Department of Physics, Banaras Hindu University, Varanasi, India
[e] Department of Chemical Engineering and Technology, Indian Institute of Technology (BHU), Varanasi, India

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Trans-boundary

ABSTRACT

Winter-specific characteristics of airborne particulates over middle Indo-Gangetic Plain (IGP) were evaluated in terms of aerosol chemical and micro-physical properties under three-dimensional domain. Emphases were made for the first time to identify intra-seasonal variations of aerosols sources, horizontal and vertical transport, effects of regional meteorology and estimating composite aerosol short-wave radiative forcing over an urban region (25°10′–25°19′N; 82°54′–83°4′E) at middle-IGP. Space-borne passive (Aqua and Terra MODIS, Aura OMI) and active sensor (CALIPSO-CALIOP) based observations were concurrently used with ground based aerosol mass measurement for entire winter and pre-summer months (December, 1, 2014 to March, 31, 2015). Exceptionally high aerosol mass loading was recorded for both PM_{10} ($267.6 \pm 107.0\ \mu g\ m^{-3}$) and $PM_{2.5}$ ($150.2 \pm 89.4\ \mu g\ m^{-3}$) typically exceeding national standard. Aerosol type was mostly dominated by fine particulates (particulate ratio: 0.61) during pre to mid-winter episodes before being converted to mixed aerosol types (ratio: 0.41–0.53). Time series analysis of aerosols mass typically identified three dissimilar aerosol loading episodes with varying attributes, well resemble to that of previous year's observation representing its persisting nature. Black carbon ($9.4 \pm 3.7\ \mu g\ m^{-3}$) was found to constitute significant proportion of fine particulates (2–27%) with a strong diurnal profile. Secondary inorganic ions also accounted a fraction of particulates ($PM_{2.5}$: 22.5%; PM_{10}: 26.9%) having SO_4^{-2}, NO_3^- and NH_4^+ constituting major proportion. Satellite retrieved MODIS-AOD (0.01–2.30) and fine mode fractions (FMF: 0.01–1.00) identified intra-seasonal variation with transport of aerosols from upper to middle-IGP through continental westerly. Varying statistical association of columnar and surface aerosol loading both in terms of fine (r; $PM_{2.5}$: MODIS-AOD: 0.51) and coarse particulates (PM_{10}: MODIS-AOD: 0.53) was found influenced by local meteorology (boundary layer and humidity) and aerosol vertical profile. A gradual increase in aerosol vertical profile (surface to 4.9 km) was evident with dominance of polluted continental, polluted dust and smoke at lower altitude. Presence of mineral dusts in higher altitude during later phase was linked with its transboundary transport, originating from western dry regions. Conclusively, winter-specific short-wave aerosol radiative forcing revealed an ATM warming effect (31–47 W m^{-2}) while cooling both at TOA (−20 to −32 W m^{-2}) and SUF (−51 to −80 W m^{-2}) with significant level of intra-seasonal variations in heating rates (0.86–1.32 K day^{-1}).

1. Introduction

Airborne particulates have enormous potential in modifying atmospheric heat budget either by absorbing/scattering insolation (Dey and Tripathi, 2007), altering cloud microphysical properties (Gettelman et al., 2013) and thereby, regulating regional climate and hydrological cycle (Ji et al., 2011). Characteristic features of airborne particulates are highly heterogeneous and regulated by meteorology (Banerjee et al., 2011a; Kumar et al., 2015a, 2016); regional topography (Ramanathan and Ramana, 2005) and emission sources (Badarinath et al., 2009; Banerjee et al., 2011b). Global distributions of aerosols are typically region specific due to its relatively shorter lifespan and thereby, aerosols pose a strong regional signature (Banerjee et al., 2015). Globally there are few isolated regions which are well recognized of having considerably high aerosol loading with unique region specific characteristics, notably Indo-Gangetic Plain (IGP) of South Asia, South-East Asia, tropical regions of Africa (Ji et

☆ Capsule: Intra-seasonal variations in aerosol radiative forcing was found regulated by aerosol sources, transport and aerosol constituents over middle-IGP.

* Corresponding author at: Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi 221005, India.
E-mail addresses: tb.iesd@bhu.ac.in, tirthankaronline@gmail.com (T. Banerjee).

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Impact of drought and normal monsoon scenarios on aerosol induced radiative forcing and atmospheric heating in Varanasi over middle Indo-Gangetic Plain

Manish Kumar[a], M.P. Raju[b], R.S. Singh[c,d], Tirthankar Banerjee[a,d,*]

[a] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India
[b] National Centre for Medium Range Weather Forecasting, Noida, India
[c] Department of Chemical Engineering and Technology, Indian Institute of Technology (BHU), Varanasi, India
[d] DST-Mahamana Centre of Excellence in Climate Change Research, Banaras Hindu University, Varanasi, India

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ABSTRACT

Observations on aerosols with specific emphasis to black carbon (BC) are reported for an urban site over middle Indo-Gangetic Plain (IGP), South Asia. Emphases are made to evaluate variation in BC concentrations during typical monsoon season (June-September, JJAS) from 2009 to 2011, and to recognize its impact on aerosol radiative forcing (ARF) and atmospheric heating. Almost entire Indian sub-continent experienced a drought year in 2009 before achieving a normal monsoon in 2010 and 2011. The ground monitoring station in Varanasi over middle-IGP experienced minimum monsoonal rain during 2009 drought year (total monsoon rain: 437.3 mm), which gradually increased during 2010 (deficit monsoon, 613.4 mm), before achieving a normal monsoon in year 2011 (1207.0 mm). The BC mass loading during drought year was relatively high (mean ± SD: 7.0 ± 3.3; range: 5.3–8.8 $\mu g\ m^{-3}$) compared to 2010 (4.9 ± 2.1, 3.7–5.8 $\mu g\ m^{-3}$) and 2011 (4.6 ± 2.1, 3.2–5.2 $\mu g\ m^{-3}$). The increase in BC aerosols especially during drought year was associated to lower wind speed and reduced rate of wet removal, which potentially enhanced BC loading in comparison to years with normal monsoon. Columnar aerosol loading in terms of aerosol optical depth (AOD) was retrieved from space-borne MODerate resolution Imaging Spectroradiometer (MODIS) sensor on-board Terra satellite. It has revealed high AOD over Varanasi during drought (2009: 1.03 ± 0.15) and deficit monsoon (2010: 1.07 ± 0.53) before being reduced during 2011 (0.89 ± 0.20). Conclusively, a radiative transfer model was run to estimate the ARF for composite aerosols for both surface (SUF), atmosphere (ATM) and top of the atmosphere (TOA). The 2009 drought year was found to have reasonably higher ATM and SUF forcing (ATM: 105; SUF: − 122 $W\ m^{-2}$) in comparison to deficit (ATM: 61; SUF: − 88 $W\ m^{-2}$) and normal (ATM: 67; SUF: − 89 $W\ m^{-2}$) monsoon scenarios. The lower atmosphere heating rates during 2009 monsoon was also recorded to be as high as 2.9 $K\ day^{-1}$ in comparison to 2010 (1.7 $K\ day^{-1}$) and 2011 (1.9 $K\ day^{-1}$). Such findings provide meaningful outcomes in terms of climatic effects of BC aerosols and their associated inference on Indian summer monsoon.

Capsule: BC induced aerosol radiative forcing during 2009 drought year was higher in comparison to deficit (2010) and normal (2011) monsoon scenarios over middle IGP.

* Corresponding author.
E-mail addresses: tb.iesd@bhu.ac.in, tirthankaronline@gmail.com (T. Banerjee).

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Fireworks induced particle pollution: A spatio-temporal analysis☆

M. Kumar [a], R.K. Singh [b], V. Murari [a], A.K. Singh [c], R.S. Singh [d], T. Banerjee [a,]*

[a] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi, India
[b] International Center for Agriculture Research in the Dry Areas, New Delhi, India
[c] Atmospheric Research Laboratory, Department of Physics, Banaras Hindu University, Varanasi, India
[d] Department of Chemical Engineering and Technology, Indian Institute of Technology (BHU), Varanasi, India

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ABSTRACT

Diwali-specific firework induced particle pollution was measured in terms of aerosol mass loading, type, optical properties and vertical distribution. Entire nation exhibited an increase in particulate concentrations specifically in Indo-Gangetic Plain (IGP). Aerosol surface mass loading at middle IGP revealed an increase of 56–121% during festival days in comparison to their background concentrations. Space-borne measurements (Aqua and Terra-MODIS) typically identified IGP with moderate to high AOD (0.3–0.8) during pre-festive days which transmutes to very high AOD (0.4–1.8) during Diwali-day with accumulation of aerosol fine mode fractions (0.3–1.0). Most of the aerosol surface monitoring stations exhibited increase in $PM_{2.5}$ especially on Diwali-day while PM_{10} exhibited increase on subsequent days. Elemental compositions strongly support K, Ba, Sr, Cd, S and P to be considered as firework tracers. The upper and middle IGP revealed dominance of absorbing aerosols (OMI-AI: 0.80–1.40) while CALIPSO altitude-orbit-cross-section profiles established the presence of polluted dust which eventually modified with association of smoke and polluted continental during extreme fireworks. Diwali-specific these observations have implications on associating fireworks induced particle pollution and human health while inclusion of these observations should improve regional air quality model.

1. Introduction

Regional distribution of airborne particulates, its composition, morphology and mixing states are highly heterogeneous which link particulates to multi-lateral negative impacts (Kumar et al., 2015a; Banerjee et al., 2011a, 2011b, 2015). Many of the factors that regulate a particle's chemical behaviour are region specific while some extraneous effects may also induce additional uncertainties by injecting multiple foreign elements into the regional environment. These external effects used to transform the entire aerosol-climate system into a far more complicated and uncertain one (Devara et al., 2015). One localized impact is pyrotechnic displays that modify local environment by introducing sudden flush of particulates and associated toxins, sometimes on a regional, and often extends to national scale. Collective impact of fireworks therefore, definitely be considered as an episodic pollution event as it poses potential to modify chemical nature of aerosols (Vecchi et al., 2008). Thus create the scope of initiating a comprehensive campaign on firework induced particle pollution at middle IGP for recognizing the origin of aerosols and its spatio-temporal distribution.

There are a number of instances when extensive pyrotechnic displays are made for recreational purpose most notably during New Year's Eve (e.g. Sydney), Lantern Festival (China), Bonfire Night (UK), Independence Day (e.g. USA), Bastille Day (France) and Diwali (India). These festive events possibly introduce a number of foreign species to lower troposphere and therefore, were subject to intense scientific investigation. There is ample evidence of the link between firework emissions and associated degraded environment most notably in United States (Licudine et al., 2012); Milan (Vecchi et al., 2008); Mainz (Drewnick et al., 2006); Delhi (Perrino et al., 2011); China (Wang et al., 2007); Spain (Moreno et al., 2007) and Pune (Devara et al., 2015). In most instances attempts were specifically made to explore variation in aerosol mass loading and chemical characteristics while there were only a few efforts (Devara et al., 2015; Vyas and Saraswat, 2012) to associate mass loading with aerosol optical properties and vertical distribution. Additionally, previous studies focused solely on exploring regional atmosphere without integrating particulate spatial nature which seems extremely relevant in identifying particulate flux and its potential impacts.

For the present analysis, efforts were made to identify the impacts of Diwali-specific pyrotechnic displays on the environment through concurrent measurements of both in situ aerosol physico-chemical

☆ Capsule: Polluted and dust aerosols in the entire Indo-Gangetic Plain were modified through Diwali-specific firework emissions with an association of smoke and polluted continental aerosol.

* Corresponding author at: Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi 221005, India.
E-mail addresses: tb.iesd@bhu.ac.in, tirthankaronline@gmail.com (T. Banerjee).

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