J. Ind. Geophys. Union (April 2015)
v.19, no.2, pp:205-209

Importance of atmospheric dust in India: Future scope of research

UC Kulshrestha* and Disha Sharma
School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067 INDIA
*Corresponding Author:umeshkulshrestha@gmail.com

ABSTRACT
Abundance of soil-dust in Indian atmosphere is a natural geo-engineering tool to combat acidification and climate change. Local as well as transported dust contributes to very high loadings of particulate matter which often exceeds the prescribed limits. Alkaline nature of atmospheric dust acts as a scavenger of SO_2 and hence, SO_2 concentrations are not recorded very high in the ambient air in India. Also, atmospheric dust affects radiative forcing, cloud modification and heath of humans and plants in Indian region. This report highlights that in spite of its great regional importance, investigations about various aspects of atmospheric dust e.g. budget and inventory, long range transport and sources, combined characterization of carbon mixed aerosols and their role in radiative forcing and monsoons need dedicated systematic research efforts.

INTRODUCTION

Almost three decades back before industrial expansion, very limited number of Indian researchers was involved in aerosol science. It was the Indian Ocean Experiment (INDOEX) which changed the scenario and developed several new groups working on atmospheric aerosols in India. Soon after, programmes such as ISRO-GBP Land Campaign-I, II, Integrated Campaign on Aerosols and greenhouse gases Radiation Budget (ICARB), Atmospheric Brown Clouds (ABC-India) and Aerosol Radiative Forcing over India (ARFI) etc. were conducted, which further advanced aerosol related research where much of the emphasis was given on anthropogenic aerosols, their sources, transport, transformations and radiative effects etc. in Indian region. Now the interest of scientists has gone wider where anthropogenic as well as natural aerosols like mineral dust have also found place of investigation. Scientists have realized the importance of atmospheric dust found abundant in Indian atmosphere, which has significant direct or indirect role in atmosphere. However, one cannot ignore the fact that rapid increase in industrial and urban areas during past two decades has injected huge amount of aerosols into the atmosphere posing equally serious atmospheric implications.

In general, atmospheric aerosols are dominated by crustal components in Indian region mainly because of their origin from re-suspended soil-dust and road dust (Bhaskar and Sharma, 2008; Kulshrestha et al., 1998). Due to this reason, ambient levels of suspended particulate matter have been reported often violating the limits of National Ambient Air Quality Standards (NAAQS) (CPCB, 2012; Sharma and Kulshrestha, 2014; Kulshrestha et al., 1995). Aerosol concentrations over India have been reported three times higher than the global mean value due to higher dust loadings (Dey and Di Girolamo, 2010). Besides local contribution, much of this dust is contributed by long range transport through dust storms. Dust storms locally called `*Aandis'* are common in India during summer. The dust storm is a common phenomenon in arid and semiarid regions. It originates when a gust front passes or when winds are strong enough to remove large amounts of unconsolidated sand and soil dust from the dry surface. These dust/sand storms are most commonly caused by either thunderstorm outflows or strong pressure gradients, which cause an increase in wind velocity over a wide area. The dust can carry irritant spores, bacteria, viruses, and persistent organic pollutants (Gharai et al., 2013; Taylor, 2002; Yeo and Kim, 2002; Wu et al., 2004; Yadav et al., 2007). It can also transport nutrients to the ocean and can affect marine biomass production (Shinn and Griffin, 2000; Deckker et al., 2014). Other impacts include reduced visibility causing haze (Ramanathan et al., 2001; Srinivasan and Gadgil, 2002); reduced photosynthetically active radiation affecting crop yield (Ibrahim and Gaely, 2012).

In fact, the abundance of atmospheric dust can be considered as a boon as it controls acidification in Indian atmosphere (Kulshrestha, 2013). Calcium carbonate rich soil-dust acts as SO_2 scavenger forming calcium sulphate in the atmosphere (Kulshrestha et al., 2003). Atmospheric dust plays an important role in radiative forcing too (Ramana and Ramanathan, 2006; Satheesh et al., 2008). Some of the studies on dust storm have demonstrated the cooling of the earth's surface nullifying the warming effect of greenhouse gases to some extent (Sharma et al., 2012; Singh et al., 2004). Hence, the atmospheric dust is a natural geo-engineering tool to combat climate change in the region. The Inter-governmental Panel on Climate Change (IPCC, 2014) and the World Meteorological Organization (WMO) recognize dust as a major component of atmospheric aerosols, which are considered as essential variable in climate studies (Gharai et al., 2013).

However, in spite of great regional significance of dust, Indian scientists have not made nationwide vigorous attempts dedicated to the study of atmospheric dust covering its chemistry, sources, role in weather modification and other atmospheric implications. Hence, through this research note, the authors want to place on record some of the identified topics about dust. We earnestly opine that these topics have future scope of research to address the issue of regional aerosol forcing and climate change.

The following five aspects of mineral dust ,which have huge knowledge gap need immediate attention of scientists-

Budget - inventory

According to AeroCom (Aerosol Comparisons between Observations and Models) programme estimates of global total dust emissions by global models range from 500 to 6000 Tg yr^{-1} with very high degree of uncertainty (Textor et al., 2006; Prospero et al., 2010; Huneeus et al., 2011). In Indian region, most of the uncertainties are contributed by dust aerosols, which have significant effect on atmospheric radiation budget because of large emissions (Dey et al., 2004). Unfortunately, most of aerosol studies reported in India represent urban areas limited to industrial and vehicular aerosol studies. Thus, the higher uncertainties are primarily due to lack of comprehensive measurements representing all types of sites including rural, background, urban, desert, forest, high altitude characteristics. Considerable uncertainties also exist in quantifying the role of dust aerosols in climate variability due to the difficulty in assessing direct and indirect effects of aerosols on clouds. Our concrete efforts in this direction may be helpful to increase the accuracy of aerosol inventory. Increasing number of study sites under various land use and topography types together with source emission studies may be the practical approaches in this regard.

Long range transport of dust aerosols

The Thar Desert centred in Western India and eastern Pakistan are the primary potential sources of dust plumes in the Indian subcontinent. Very few studies report the transport of dust in south Asia or Indian region (Badarinath et al., 2010; Begum et al., 2011; Sikka, 1997). Sikka 1997 has reported that the frequency of the dust-storm occurrence was maximum during the pre-monsoon (March–May) season, when dust aerosols are transported by southwesterly winds from the Thar Desert. However, dust storms originated in Oman and other Middle Eastern regions have also been reported contributing ambient particulates in south Asia (Begum et al., 2011). Badarinath et al 2010 have reported long-range transport of dust aerosols over the Arabian Sea and Indian region where the authors have provided an account of the alternate routes of dust storms that affect southern parts of India. Long range transport of dust and other pollutants upto Himalayan region has been reported by Kulshrestha and Kumar 2014. Impact of dust storm on Indian Himalayan foothills has been reported by Srivastava et al 2014. These workers have also presented optical properties of dust along with Lahore to Delhi airmass trajectories. Since, air has no boundaries, pollutants are transported globally from one geographic area to the other, simultaneously, depositing various biogeochemically important trace species along with mineral dust. Hence, the impact of transported dust aerosols needs to be studied in a comprehensive manner focusing upon their sources, chemistry and regional shares in order to investigate their influence on regional climate change.

CHEMICAL, PHYSICAL AND OPTICAL PROPERTIES OF CARBON MIXED DUST AEROSOLS

There are number of studies that report chemical, physical and optical properties of dust storms separately (Mani et al., 1969; Moorthy et al., 1999; Devara et al., 2002; Ramanathan et al., 2001; Madahavan et al., 2008; Badarinath et al., 2007; Satheesh et al., 2008, Babu et al., 2008; Dey et al., 2004; Ganguly et al., 2006; Dimri and Jain, 1999).But, the studies covering combined effects of these properties are not found in literature from India. Badarinath et al 2007 carried out a case study of dust storms over Hyderabad to study the impact of dust storms on solar radiation using satellite data along with ground based measurements. They used the satellite data to derive properties like aerosol index (AI) and aerosol optical depth (AOD) and concluded that diffuse to direct beam ratio is the most appropriate parameter for dust monitoring because the ratio values are not affected by solar zenith angle at the longer wavelengths. In another study reported by Prasad et al 2007, aerosol radiative forcing over the Indo-Gangetic plains has been calculated during major dust storms. Optical properties of aerosols have been studied during an unusual dust storm event over north- east India using satellite observations (Sharma et al, 2013).

Role of black carbon in relation with the optical properties of aerosols during dust storms has been reported by Das and Jayaraman 2011, which is an effort to combine chemical and optical properties of aerosols. They also calculated radiative forcing caused by black carbon as a part of the dust storm and concluded that the higher aerosol induced heating in the atmosphere during premonsoon season is likely to impact the regional climate dynamics and hydrological processes. Heavy metal content of dust and its variation in relation to the prevailing metrological conditions has been reported by Yadav et al (2006). These workers have also reported different size fractions of aerosols during the dust storms tracing a course of 600 km starting from the north-western desert as a source of dust. Role of calcite aerosols in Indian region has been well established in terms of S and Ca biogeochemical cycles along with their role in acidification in developing vs industrialized regions (Kulshrestha, 2013). Even bio-aerosols have been characterized in dry freefall samples during dust storms in the north-north western region (Yadav et al., 2007). However, huge gap exists in understanding the role and linkages of dust aerosols with N and C cycles, in particular, black carbon and reactive nitrogen (Nr) vis-à-vis dust aerosols research (Singh and Kulshrestha, 2012; Kumar et al., 2014).

Dust storms and monsoon science

Recent studies have shown that natural dust affects monsoon rainfall (Lau, 2014). According to Vinoj et al (2014), monsoon season is influenced by warming induced by desert dust aerosols over the Arabian Sea and West Asia. These researchers demonstrated that rains in central India decreased within a week of dropping levels of dust aerosols over west Asia. Satheesh et al (2002) have estimated absorption of solar radiation by dust aerosols over Arabian Sea during pre monsoon season between 10 and 15 W m^{-2} ,which is more than the warming due to greenhouse gases. In a study by Mitra et al 2013, characteristics of dust storms in the north and north– western part of India have been studied using real time multi satellite observations and found that high resolution data of microwave and thermal infrared using multi-satellite observations from real time direct broadcast system have high potential to detect severe, moderate or weak dust storms. Importance of aerosols in relation with monsoons has been discussed in detail by Reddy and Reddy 2014, with an emphasis of need for more comprehensive efforts in this area. One of the difficulties scientists face is the suitability of models. To generate appropriate models, Indian researchers need to develop dust inclusive local and regional modules in order to get more reliable output.

Relation with air quality

Atmospheric dust has a strong negative correlation with air quality, which sometimes has serious human health effects. As mentioned earlier, this results in elevated levels of suspended particulate matter in ambient air, most of the time violating the limits prescribed by Indian regulatory bodies. Several studies covering cities such as Delhi, Kanpur and Patiala have demonstrated that dusty days always had remarkably higher concentrations (>150 μgm^{-3}) of PM_{10} aerosols (Mitra and Sharma, 2002; Singh et al., 2008; Sharma et al., 2012). Top ten locations for high particulate matter have been reported in north India, where suspended soil is abundant in the atmosphere (CPCB, 2012).Due to this reason, higher AOD values have been reported in north India as compared to south India (Sharma and Kulshrestha, 2014). However, studies reporting anthropogenic components such as carbon and metal contents, oxides of S and N in different size ranges have future scope in order to increase our understanding of harmful effect of dust aerosols and associated anthropogenic constituents.

SUMMARY

Abundance of mineral dust is an important feature of atmospheric environment in Indian region, which significantly affects Earth's radiation budget, monsoons and other atmospheric processes. Very high loadings of atmospheric dust in Indian region are responsible for high levels of particulate matter; violating the prescribed limits of National Ambient Air Quality Standards (NAAQS).It is well established that high levels of particulate matter have human health implications. Most of this dust is transported from distance sources through long range transport. However, local sources such as re-suspension of soil, road dust and construction activities also contribute significant fraction of atmospheric dust. It has been noticed that in spite of its local and regional significance, research attempts related to various aspects of dust and its implications are very limited. Therefore, areas such as dust source inventory, long range transport of dust, combined characterization (including chemical, physical and optical properties) of mixed aerosols and their impacts on clouds and monsoons need further in-depth research in order to improve our understanding of local and regional scale atmospheric changes.

ACKNOWLEDGEMENT

We sincerely acknowledge the support of Department of Science & Technology through PURSE funds. Author (DS) sincerely thanks Council of Scientific and Industrial Research (CSIR) for awarding her Senior Research Fellowship. We also thank Dr P R Reddy, Editor for providing useful comments and suggestions.

REFERENCES

Babu, S. S., V. S. Nair., and K. K. Moorthy 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., v.70, pp:820–834, doi:10.1016/j.jastp.2007.10.005.

Badarinath, K. V. S., Kharol S. K., Kaskaoutis D. G., and Kambezidis H. D. 2007. Case Study of Dust Storm Over Hyderabad, India: Its Impact on Solar Radiation Using

Satellite Data andGround Measurements. Science of the Total Environment v.384, pp:316–322.

Badarinath, K. V. S., Kharol S. K., Kaskaoutis D. G., Sharma A. R., Ramaswamy V., and Kambezidis H.D. 2010. Long-Range Transport of Dust Aerosols Over the Arabian Sea and Indian Region – A Case Study Using Satellite Data and Ground-Based Measurements. Global Planetary Change 72: v.164.

Begum, A., Biswas, K., Pandit, G., et al., 2011. Long range transport of soil dust and smoke pollution in the South Asian region, Atmospheric Pollution Research v.2, pp:151- 157.

Bhaskar, S., and M. Sharma 2008. Assessment and Characterization of Fugitive Road Dust Emission in Kanpur, India: A Note, Transportation Research Part D: Transport and Environment v.13, pp:400-403.

Central Pollution Control Board (CPCB) 2012. Ministry of Environment & Forests, Governmnet of India, http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php

Das S.K. and Jayaraman A., 2011. Role of black carbon in aerosol properties and radiative forcing over western India during premonsoon period, Atmospheric Research, v.102, pp: 320–334.

Deckker, P.D. and C.I. Munday 2014. Characterisation of major dust storm that traversed over eastern, Australia in September 2009; a multidisciplinary approach, Aeolian Research DOI: 10.1016/j.aeolia.2014.07.003.

Devara, P. C. S., Maheskumar R. S., Raj P. E., Pandithurai G. and Dani K. K.,2002. Recent trends in aerosol climatology and air pollution asinferred from multi-year lidar observations over a tropical urban station, International Journal of Climatology, v.22, pp:435–449, doi:10.1002/joc.745.

Dey, S., S. N. Tripathi, R. P. Singh. and B. N. Holben 2004, Influence of dust storms on aerosol optical properties over the Indo-Gangetic basin, J. Geophys. Res., v.109, D20211, doi:10.1029/2004JD004924.

Dey S.N. and Di Girolamo 2010, A climatology of aerosol optical and microphysical properties over the Indian subcontinent from 9 years 2000–2008 of Multiangle Imaging Spectroradiometer (MISR) data, J. Geophys. Res., v.115, D15204, doi:10.1029/2009JD013395.

Dimri A. P. and Jain V.K 1999, Radiative Effects of Desert Aerosols. Current Science, v.77(1), pp:163-166.

Ganguly, D., A. Jayaraman, and H. Gadhavi 2006, Physical and optical properties of aerosols over an urban location in western India: Seasonal variabilities, *J. Geophys. Res.*, v.111, D24206, doi:10.1029/2006JD007392.

Gharai, B., S. Jose, and D.V. Mahalakshmi 2013, Monitoring intense dust storms over the Indian region using satellite data – a case study, International Journal of Remote Sensing,v.34, pp:7038–7048, http://dx.doi.org/10.1080/01431161.2013.813655.

Hunneeus, N., M. Schulz, Y. Balkanski et al., 2011, Global dust model intercomparison in AeroCom phaseI,Atmos. Chem.Phys.,117781-7816,www.atmos-chem-phys.net/11/7781/2011/ doi:10.5194/acp-11-7781-2011.

Ibrahim Mohamed, M., El-Gaely Gehan 2012, Short-term effects of dust storm on physiological performance of some wild plants in Riyadh, Saudi Arabia, African Journal of Agricultural Research, v. 7(47), pp: 6305-6312. DOI: 10.5897/AJAR12.828.

Intergovernmnetal Panel on Climate Change (IPCC) Fifth Assessment Report (AR5), 2014. http://www.ipcc.ch/report/ar5/

Kulshrestha, U.C. 2013, Acid Rain, Encyclopedia of Environmental Management; S.E.Jorgensen, ed. Taylor & Francis: New York, v. 1,pp: 8-22.

Kulshrestha U C, Kumar N, Saxena A, Kumari K M and Srivastava S S., 1995. Identification of nature and source of atmospheric aerosols near Taj Mahal (Agra). Environmental Monitoring and Assessment, v.34, pp:1-11.

Kulshrestha, U.C., A. Saxena, N. Kumar, K.M. Kumari and S.S. Srivastava., 1998. Chemical composition and association of size-differentiated aerosols at a suburban site in a semi-arid tract of India, Journal of Atmospheric Chemistry, v. 29, pp:109-118.

Kulshrestha MJ, Kulshrestha U C, C Parashar D C and Vairamani M., 2003. Estimation of SO4 contribution by dry deposition of SO2 onto the dust particles in India. Atmospheric Environment, v.37 (22), pp:3057-3063.

Kulshrestha U C and Kumar B 2014. Airmass Trajectories and Long Range Transport of Pollutants: Review of Wet Deposition Scenario in South Asia. Advances in Meteorology, doi.org/10.1155/2014/596041.

Kumar, B., K. Verma and U.C. Kulshrestha 2014. Deposition and Mineralogical Characteristics of Atmospheric Dust in relation to Land Use and Land Cover Change in Delhi (India), Geography Journal, http://dx.doi.org/10.1155/2014/325612

Lau, W., 2014. Atmospheric Science: Desert dust and monsoon rain, Nature Geoscience v.7, pp: 255– 256.

Madhavan, B. L., Niranjan K., Sreekanth V., Sarin M. M., and Sudheer A. K. , 2008. Aerosol characterization during the summer monsoon period over a tropical coastal Indian station, Visakhapatnam, Journal of Geophysical Research v.113, D21208, doi:10.1029/2008JD010272.

Mani, A., Chacko O., and Hariharan S. 1969. A study of Ångström turbidity parameters from solar radiation measurements in India, Tellus,*v.* 21,pp: 829–843, doi:10.1111/j.2153-3490.1969.tb00489.

Mitra A. P. and Sharma C. (2002), Indian aerosols: present status, *Chemosphere*, v.49(9), pp:1175– 1190.

Mitra, A.K., Sharma, A.K., Soni, V.K., Kundu, P.K., 2013, Characteristics of recent dust storms over the Indian region using real time multi satellite observations from the direct bradcast receiving system at IMD, Advances in Space Research v.*51*, pp:*1195-1203*.

Moorthy, K. K., et al. 1999, Aerosol climatology over India: ISRO GBP MWR network and database, Rep. ISRO GBP SR0399, Indian Space Research. Organisation, Bangalore, India.

Prasad, A. K., and R. P. Singh 2007, Changes in aerosol parameters during major storm events 2001–2005 over the IndoGangetic Plains using AERONET and MODIS data, J. Geophys. Res., v.112, D09208, doi:10.1029/2006JD007778.

Prasad, Singh, Chauhan S.S., Srivastava, P. Singh R.P., and Singh R. (2007), Aerosol radiative forcing over the Indo-Gangetic plains during major dust storms,Atmospheric Environment v.41, pp: 6289–6301.

Prospero, J. M., Landing, W. M., and Schulz, M. 2010, African dust deposition to Florida: temporal and spatial variability and comparison to models, J. Geophys. Res.,v. 115, D13304, doi:10.1029/2009JD012773.

Ramana, M. V., and V. Ramanathan 2006, Abrupt transition from natural to anthropogenic aerosol radiative forcing: Observations at the ABCMaldives Climate Observatory, J. Geophys. Res., v.111, D20207, doi:10.1029/2006JD007063.

Ramanathan, V., Crutzen, P.J., Lelieveld, J., Mitra, A.P., and Althausen, D.,Et al., 2001, Indian Ocean experiment: an integrated analysis of the climate forcing and effects of the great Indo-Asian haze. Journal of Geophysical Research-Atmospheres v.106, pp:28371-28398.

Ramanathan, V., P. J. Crutzen, J. T. Kiehl, and D. Rosenfeld 2001, Aerosols, climate, and the hydrologic cycle, Science, v.294, pp:2119– 2124.

Reddy P. R. and Reddy D V., 2014, Aerosols and Monsoon Variability, International J of Earth Sciences and Engg., 7 (Editorial note).

Satheesh, S. K., and J. Srinivasan 2002, Enhanced aerosol loading over Arabian Sea during pre-monsoon season: Natural or Anthropogenic?, Geophysical Research Letters, v.29 (18),pp:1874, doi: 10.1029 / 2002GL015687.

Satheesh, S. K., Moorthy K. K., Babu S. S., Vinoj V., and Dutt C. B. S., 2008. Climate implications of large warming by elevated aerosol over India, Geophysical Research Letters v.35, L19809, doi:10.1029/2008GL034944.

Sharma, D., D. Singh, and D.G. Kaskaoutis., 2012. Impact of Two Intense Dust Storms on Aerosol Characteristics and RadiativeForcing over Patiala, Northwestern India, Advances in Meteorology 956814, doi:10.1155/2012/956814.

Sharma, D., U.C. Kulshrestha., 2014. Spatial and Temporal Patterns of Air Pollutants in Rural and Urban Areas of India, Environmental Pollution, v.195, pp:276-81.

Shinn and Griffin., 2000. African dust and the demise of the Caribbean coral reefs, Geophysical Research Letters v.27, pp:3029–3032.

Sikka, D. R. 1997, Desert climate and its dynamics, Current Science. India, v.72,pp:35–46.

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

Singh, M., D. Singh and P. Pant 2008,Aerosol characteristics at Patiala during ICARB—2006," System Journal of Earth Science, v.117,pp: 407–411.

Singh, S., and U.C., Kulshrestha 2012, Abundance and distribution of gaseous ammonia and particulate ammonium at Delhi (India). Biogeosciences, v.9, pp:1-7.

Srinivasan, J.and S. Gadgil., 2002. Asian brown cloud - fact and fantasy. Current Science. v.83, pp:586-592.

Srivastava A.K., Soni V.K., Singh S., Kanawade V.P., Singh N., Tiwari S., and Attri S.D., 2014. An early South Asian dust storm during March 2012 and its impacts on Indian Himalayan foothills: A case study, Science of the Total Environment v.493, pp:526–534.

Taylor, D.A.,2002. Dust in the wind, Environmental Health Perspectives v.110, pp:80-87.

Textor, C., Schulz, and M., Guibert, S. 2006, Analysis and quantification of the diversities of aerosol life cycles within AeroCom, Atmos. Chem. Phys., 6, 1777–1813, doi:10.5194/acp-6-1777-2006.

Vinoj, V., et al., 2014, Short term modulation of Indian monsoon rainfall by West Asian dust, Nature Geoscience v.7, pp: 308- 313.

Wu, P.C., J.C. Tsai, F.C. Li, S.C. Lung, H.J. Su 2004 Increased levels of ambient fungal spores in Taiwan are associated with dust events from China. Atmospheric Environment v.38, pp:4879–4886.

Yadav S., Rajamani V. 2006, Air quality and trace metal chemistry of different size fractions of aerosols in N–NW India—implications for source diversity, Atmospheric Environment v.40, pp:698– 712.

Yadav S., Chauhan M.S., Sharma A. 2007, Characterisation of bio-aerosols during dust storm period in N–NW India, Atmospheric Environment.. v.41, pp:6063–6073.

Yeo, H.G., J.H. Kim 2002, SPM and Fungal spores in the ambient air of west Korea during the Asian dust (Yellow sand) period, Atmospheric Environment v.36, pp:5437–5442.