J. Ind. Geophys. Union (November 2017)
v.21, no.6, pp: 526-534

Dust storms and their influence on optical and chemical properties of aerosols along north-western Indo-Gangetic Plains

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

ABSTRACT
Dust storms are an important climatic phenomenon in the Indian subcontinent affecting air quality in the pre monsoon season. In this study, the variation in the optical and the chemical properties of mineral dust aerosols along the north-western Indo Gangetic Plains (IGP) is recorded during major dust storm events during April to June, 2015. Dustfall fluxes were measured at five sites lying on the downwind trajectory of the long-transported dust plume. The sites were - Bikaner (BK), Jaipur (JP), Hisar (HS), Delhi (DL) and Agra (AG). Five major dust storm events were identified based on the aerosol optical depth (AOD) values derived from the MODIS and OMI instruments and corroborated by the ground monitored dust fall flux measurements. An analysis of the optical properties reveals the dominance of coarse mode particles during all the events with MODIS Angstrom Exponent (AE) values lying in the range of 0.40 – 0.03 for dust events observed at the sites located in the close proximity of Thar desert. Chemical characterization of the samples showed that Ca^{2+} was the most dominating cation with flux in the range of 106.7 mg/m^2/day (at BK) to 7.4 mg/m^2/day (at DL), indicating the dominance of crustal sources in the dust aerosols. Among anions, highest flux was recorded for SO_4^{2-} and NO_3^-. NO_3^- flux was observed to increase downwind towards the sites (DL and HS) with high anthropogenic emissions. The flux Na^+ and $Cl^-$was also high during major dust events. However, it was seen to decrease downwind indicating the influence of sea salt fraction in the dust plume transported from the Arabian sea.

Key words: Dust Storms, Air quality, Optical and chemical qualities of aerosols, Aerosol optical depth, MODIS and OMI instruments, North western Indo-Gangetic Plains.

INTRODUCTION

Mineral dust aerosols play an important role in modulation of the atmospheric radiative budget (Ramanathan et al., 2001; Tegen et al., 2004; Bollasina et al., 2008), the hydrological cycle and the monsoon circulation and rainfall distribution (Gautam et al., 2009, 2011; Srivastava et al., 2010; Giles et al., 2011; Das et al., 2013; Dumka et al., 2014; Vinoj et al., 2014). The arid and the semi arid desert areas are recognized as the main source of atmospheric dust (Prospero et al., 2002; Ginoux et al., 2012; Crosbie et al., 2014) with global flux estimations of 1500–2600.

Tg yr ^{1} (Zender and Milelr, 2004). Meteorological conditions, mainly wind speed and wind direction, induce long range transport of dust thousands of kilometers from the source (Liu et al., 2012; Nastos, 2012). Dust outbreaks are known to affect air quality land use, society and biodiversity (Gou- die, 1983; Goudie and Middleton, 1992, 2006; Middleton and Gou- die, 2001; Washington et al., 2003; Engelstaedter et al., 2006; Kaskaoutis et al., 2010; Kulshrestha and Sharma, 2015). Physical characteristics like the particle size, shape and minerology (Mahowald et al., 2005) decide the optical and chemical properties of dust aerosols and are in turn determined by the sources from which the soil sediments are entrained and their chemical composition (Claquin et al., 1998; Singh et al., 2004).

The Indo-Gangetic Plains (IGP) receive dust from the sources located in Middle East, Arabia, North Africa and the Thar desert (Dey et al., 2004; Prasad and Singh, 2007; Sharma et al., 2012; Gharai et al., 2013; Aher et al., 2014). The highest frequency of dust storms in the north- western parts of India is observed in the pre-monsoon season, from April to June, under the influence of south – westerly winds (Prasad and Singh, 2007). The north-western part of IGP reports very high AOD and suspended particulate matter (SPM) levels (Sharma and Kulshrestha, 2014). As a result, dust strongly affects the aerosols characteristics over the IGP under the influence of the local pollutants.

The present study is conducted to analyze the variation in the optical as well as the chemical properties of mineral dust aerosols during major dust storm events in the north western IGP. The satellite observations are corroborated with the ground monitored data to see the change in the aerosol properties in the study region. The trajectories of the dust plume are also plotted in order to see the influence of the dust sources in the Arabian Peninsula in modulating climate and air quality over the Indian subcontinent.

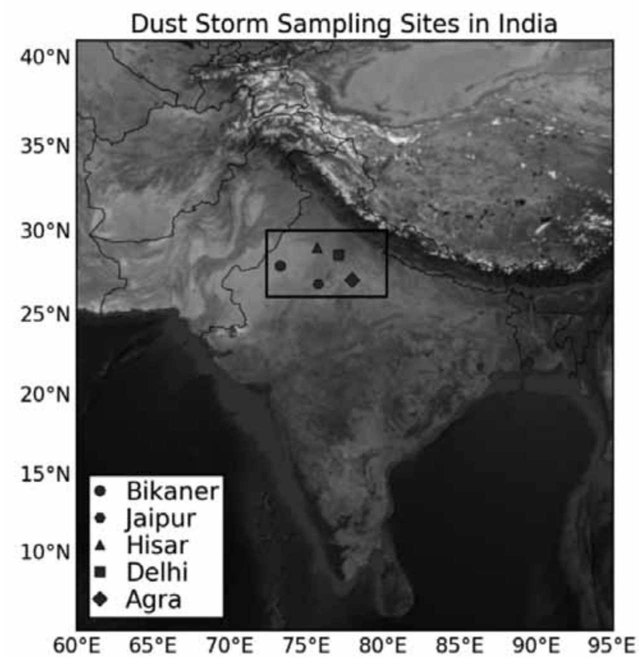


Figure 1. Study region along the north-western part of Indo-Gangetic Plains, with five sampling sites at Bikaner, Jaipur, Hisar, Delhi and Agra.

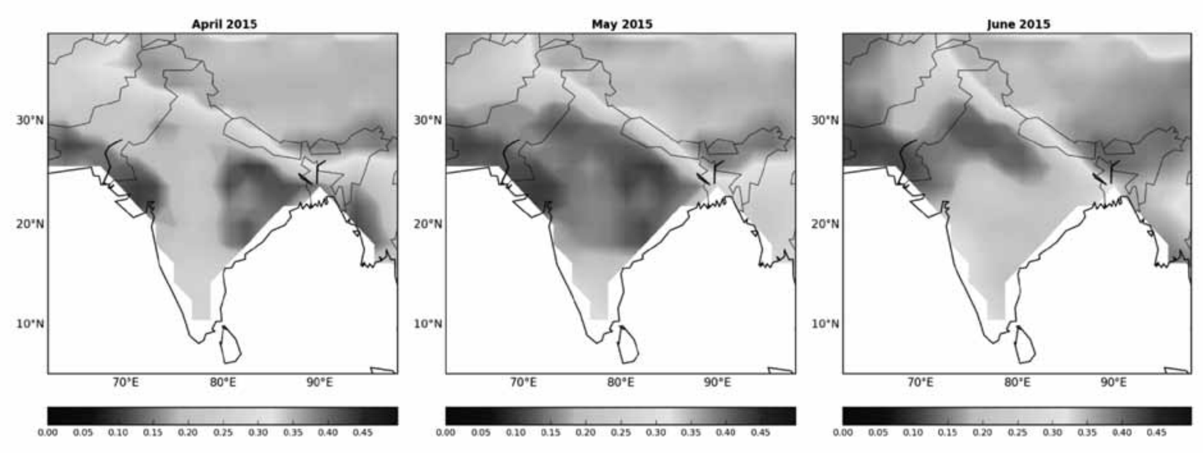


Figure 2. Monthly mean soil moisture (mm) variation over India for the month of April, May and June, 2015, respectively (NCEP reanalysis volumetric soil moisture 0 – 10 cm BGL (units: mm).

Data and Methods

Dustfall sampling

In order to sketch a complete picture of the influence of the local emissions on the trans boundary dust pollution/ plume, five sites were chosen along the downwind trajectory of dust storms, starting from Thar desert till the 'aerosol hotspots' (Lau WMO 2008), the Indo – Gangetic Plains (IGP) (Figure 1) . The first two sites, Bikaner (BK(28.01° N, 73.31 °E)) and Jaipur (JP(26.91 °N, 75.7 °E)), lie in the northwestern state of Rajasthan that marks the entry point of trans boundary dust storms in India and are in the close proximity of Thar desert. Next site along the downwind dust storm trajectory was chosen to be Hisar (HS(29.15 °N, 75.72 °E). It lies in the relatively less 'dusty' state of Haryana (table 1), however, it is characterized as a fast-developing city center. Sampling was also done in the capital city of Delhi (DL(28.70 °N, 77.10 °E) as it was vital to observe the chemical characteristics of dust aerosols in the city, which records a very high level of AOD (Sharma and Kulshrestha, 2014), other atmospheric pollutants and also influenced by dust storms. The last site chosen along IGP was Agra (AG(27.18 ° N, 78.01 °E).

The dust samples were collected from April 2015 to June 2015, which is the period when maximum number of pre monsoon dust storms are observed in the Indian subcontinent. Dry deposition flux of dust aerosols was measured by collecting dustfall on non-reactive propylene petriplates with 140mm diameter. In order to ensure sufficient dust collection, the plates were exposed for a period of two weeks for composite sampling for the entire dust storm season. For dust storm event sampling, amount of dust loading was measured by collecting samples on the day of the dust storm. The plates were placed on selected rooftops ensuring least resistance and undisturbed free flow to the free fall of dust particles for taking representative samples. This method of passive sampling of atmospheric dust has been validated in previous studies (Tiwari and Kulshrestha, 2016). The collected samples were stored and transported to lab where they were subjected to ion chromatography (IC) to measure the concentration of major anions (F^-, Cl^-, SO_4^{2-} and NO_3^-) and cations (Mg^{2+} , Ca^{2+}, K^+, NH_4^+, Na^+).

Moderate Resolution Imaging Spectroradiometer (MODIS)
MODIS is a sensor onboard Terra and Aqua satellites. It has high radiometric sensitivity (12 bit) over 36 spectral bands with wavelengths ranging from 0.41 μm to 14.4 μm. MODIS sensors measure the AOD with an estimated error of ± (0.05 + 0.15) over land (Chu et al., 2002) and 0.03 ± 0.05 over the ocean (Remer et al., 2005). The Aqua and Terra level 3 (MYD08_D3_v6 and MOD08_D3_V6) AOD daily data products from Terra and Aqua Deep Blue AOD, at .55 μm, with a spatial resolution of 10 × 10 km from 1st April to 30th June, 2015 are utilized in this study. Deep blue Angstrom Exponent (AE) for land in 0.412 – 0.47 μm range was also used. AOD and AE for the entire sampling period were obtained from MODIS, by averaging Terra and Aqua, AOD and AE values, respectively. More information can be found at https://giovanni.gsfc.nasa.gov/giovanni/.

Ozone Monitoring Instrument (OMI)
OMI instrument is based on the NASA's Total Ozone Mapping Spectrometer(TOMS) instrument and the European Space Agency (ESA) Global Ozone Monitoring Experiment (GOME) instrument (on the ERS-2 satellite). It can distinguish between aerosol types, such as smoke, dust, and sulfates, and measures cloud pressure and coverage, which provides data to derive tropospheric ozone. The hyperspectral imaging offered by the instrument provides it the ability to measure more atmospheric constituents than TOMS and enables much better ground resolution than GOME (13 km x 25 km for OMI vs. 40 km x 320 km for GOME). AOD 500 μm values from OMI (daily, 1 degree product) were also recorded for this study, alongside MODIS AOD values.

Back trajectory and reanalysis product
Back trajectories were computed using the HYSPLIT model. The air mass back trajectories were calculated during major dust storm events, at the first site (BK), which marks the entry point of dust storms in India. In order to identify the route of local and long range transport of dust, trajectories were computed for a period of 5 days (120 hours) at three levels; 500m, 100m and 1500m. Back trajectory analysis provides important information about types of aerosols and their source region (Kaskaoutis et al., 2010). NCEP reanalysis monthly soil moisture product was also used to see the spatial and temporal variation of moisture content in the soil during the sampling period.

RESULTS AND DISCUSSION

Soil moisture analysis for the pre-monsoon dust season
Dust outflow is known to increase tremendously in the pre-monsoon months of April – June (Askary et al., 2006). It is known that the heightened dust activity is observed in arid and semi-arid regions, globally (Prospero et al., 2002). Thus, soil moisture content is an important pre-condition for triggering dust storm episodes in the region. Figure 2 shows the variation in the soil moisture content in millimeters (0 – 10 cm BGL; acquired from NCEP Reanalysis Daily Mean) over entire India. It is observed that there is a subsequent decrease in the moisture content over the northwestern part of IGP, covering the Thar desert. This explains the increase in dust emissions from the desert areas in the pre-monsoon season, from all the dust sources influencing aerosol load over India.

Aerosol optical properties and identification of dust storms
The western part of IGP experiences more dust events as compared to the eastern part in the months of May and June (Middleton, 1986). The variation of AOD at the study region was taken from the OMI and MODIS instruments (Figure 3, Table 1). Days that recorded OMI AOD_{500} and MODIS AOD_{550} (greater than 0.5) were considered as the days of the dust storm (Sharma et al., 2012). The peak AOD value recorded during the interval with high dust loadings is reported and used for correlation analysis at all the sampling sites. Five major dust events (Es) were identified from April to June. Based on satellite observations and dust fall monitoring measurements the five major dust storm events are identified on the following days; 04 April (E1), 20 April (E2), 30 April (E3), 15 May (E4) and 30 June (E5). Figures 4 a and b show the dust storms on the 3rd of April and 27th of June, 2015 using corrected reflectance images of MODIS. Most of the dust storm events occurred in the month of April and the highest AOD value recorded was greater than 2.0 and the dust fall flux measured was ~8465 mg/m^2/day in BK. For most of the events, AOD values exceeding 1 were recorded at BK and JP sites, which are under the influence of Thar desert. Dust fall flux lies in the range for these dust storm events. The observations show that dust outflow during dust storms

Table 1. Event wise AOD from MODIS and OMI, MODIS AE and dustfall flux (mg/m²/day) at the five sampling sites.

Site	Event (E)	AOD_MODIS	AOD_OMI	AE	Dustfall Flux
BK	1	2.42	-	-	8465
	2	1.34	0.80	0.40	6778
	3	1.21	0.98	0.07	5675
	4	-	-	0.03	3360
	5	1.41	-	0.32	4396
JP	1	0.75	-	1.35	2840
	2	0.45	0.73	1.24	3544
	3	0.48	0.54	0.69	2619
	4	0.50	-	1.8	3983
	5	0.39	-	1.8	-
HS	1	1.59	-	1.5	1795
	2	0.90	0.59	0.14	2006
	3	0.84	1.05	0.22	1369
	4	1.2	0.79	0.20	1184
	5	0.90	0.38	1.8	1113
DL	1	1.17	-	1.5	279
	2	0.68	0.74	0.43	734
	3	0.66	0.72	0.56	818
	4	-	0.79	0.55	378
	5	0.65	-	-	470
AG	1	0.65	-	1.79	1018
	2	0.78	1.07	1.21	3040
	3	0.75	0.61	0.69	965
	4	0.52	-	0.71	2303
	5	0.56	-	-	697

leads to elevated AOD levels downwind. However, the maximum dust loading is observed in the regions lying in the proximity of the dust source.

Table 1 shows aerosol optical characteristics during the five major dust storm events (Es) observed during the study period at all the study sites. The Angstrom Exponent (AE) is another important optical property indicative of the contribution from the fine mode particles. High values of AOD corresponding with low values of AE have been reported at some parts of the IGP (Dey et al., 2004; Singh et al., 2004; Pandithurai et al., 2008) and the Sahara region (Tanre et al., 2003). In the present study, for all the dust storm events at BK, AE value was low (<0.4) indicating the abundance of coarse mode particles, which in this case come from desert dust aerosols, both local and transported. For most of the dust storm events at all the sites, low AE values were seen.

Further, the air mass back trajectories calculated over the first site, BK, from where the long-transported dust plume enters India, shows the source of dust that enters into India (Figure 5). The dust plume is seen to pass over dust sources located in the Arabian Peninsula covering Iran, southwest Asia, Pakistan and the Thar desert. For event E5, the air mass at higher altitude transports the dust plume from north western Africa crossing the Arabian Sea to India. Thus, influence of local and distant sources is seen for all the major dust storm events in India.

Chemical characteristics of aerosols during dust storm events

In order to understand the chemical composition of the atmospheric aerosols during major dust events observed in this study, flux of major ions and cations was calculated (Figures 6 & 7). It was found that at all the sites the dominating cation was Ca^{2+} with the maximum composite value for all events recorded as 106.7, 83.5, 35.5, 7.4 and 17.5 mg/m²/day at BK, JP, HS, DL and AG respectively. The flux was seen to decrease eastwards, indicating the abundance of crustal sources in the sites

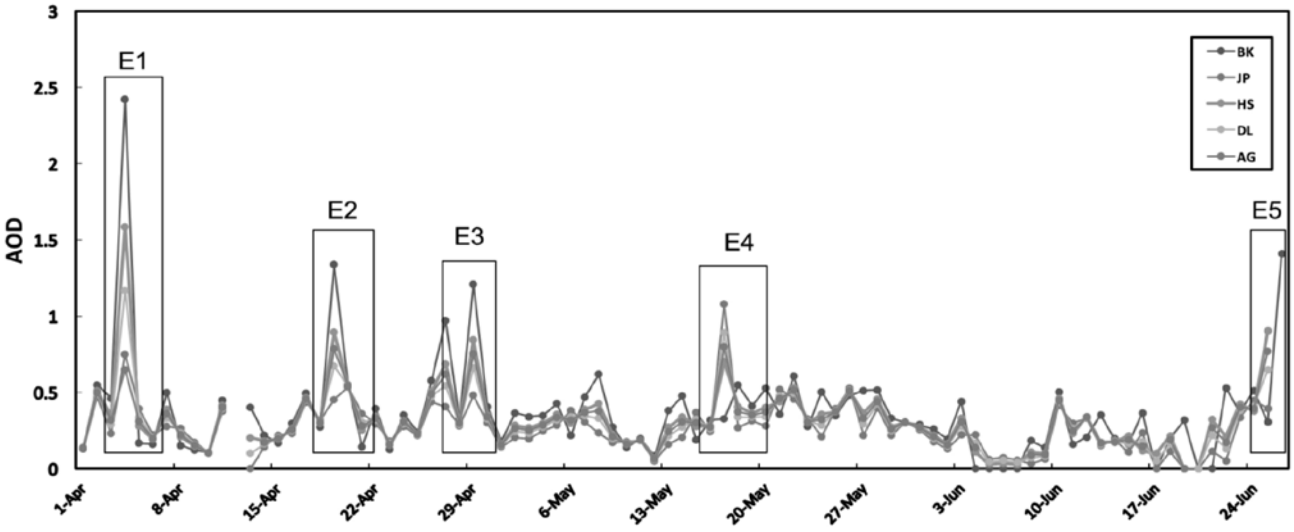


Figure 3. Day to day MODIS AOD variation from April to June, 2015 at all five sampling sites.

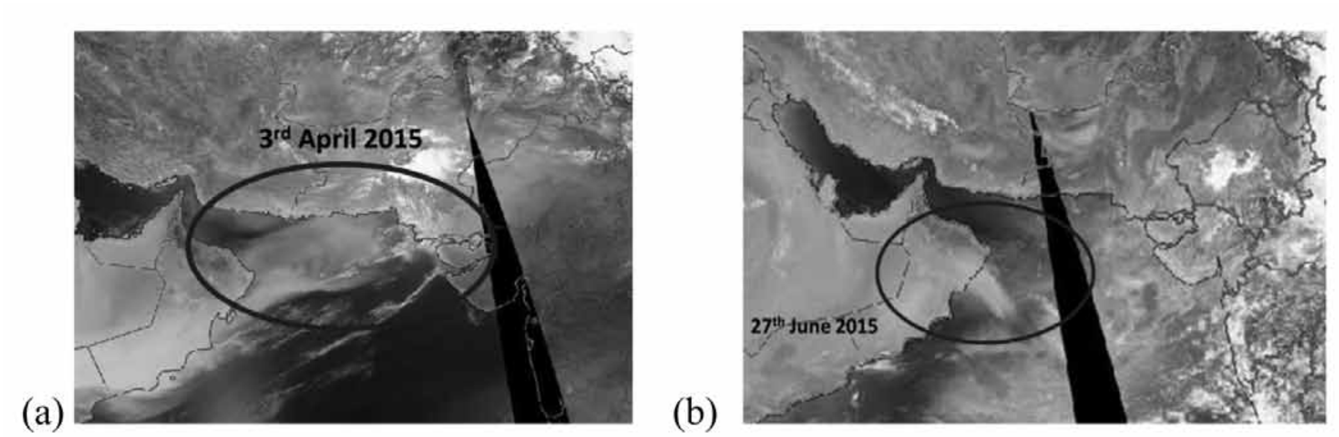


Figure 4. MODIS images a and b showing the dust storms on the 3rd April and 27th June, 2015, respectively.

lying in close proximity of the Thar desert. The second highest flux was seen for Na^+ ions at BK and JP (15.4 and 6.0 mg/m^2/day, respectively). The flux Na^+ was also seen to decrease downwind indicating the influence of sea salt fraction in the dust plume transported from the Arabian sea.

The dominance of crustal sources explains the low AE values reported for the major dust events. The dominating anions with the maximum flux values were seen to be SO_4^{2-} and NO_3^- at all the sites, during all the five dust storm events. The flux for SO_4^{2-} did not show much variation downwind. Much of this SO_4^{2-} has been reported as calcium sulphate in Indian region due to the adsorption of atmospheric SO_2 onto the $CaCO_3$ rich dust particles (Kulshrestha et al., 2003a, 2003b). Thus being acidic gas, the ambient SO_2 is effectively scavenged by the alkaline dust in the region (Kulshrestha, 2004; Kulshrestha et al., 2009).

This is the main reason for very low concentrations of SO_2 in ambient air in most parts of north India. However, NO_3^- flux was the highest in DL (4.7 mg/m^2/day) followed by HS (2.0 mg/m^2/day) ,which shows the dominance of anthropogenic emissions in bigger cities. Daily flux for Cl^- followed similar site wise trend as was seen in the case of Na^+ flux, further strengthening the impact of distant sources on local air quality in India.

Further, as the highest flux was reported for SO_4^{2-}, NO_3^- and Ca^{2+}, the ability of Ca2+ in neutralizing SO_4^{2-} and NO_3^- for all dust events at all sites was calculated (Figure 8). For events E1, E3 and E5 the correlation coefficient was positive. The value of Pearson Coefficient (r), at 95% significance level, is 0.70, -0.31, 0.57, -0.22 and -0.92 for the five dust events, respectively. This indicates the availability of Ca^{2+} in the dust aerosols in providing surface for neutralization of SO_4^{2-} and NO_3^-.

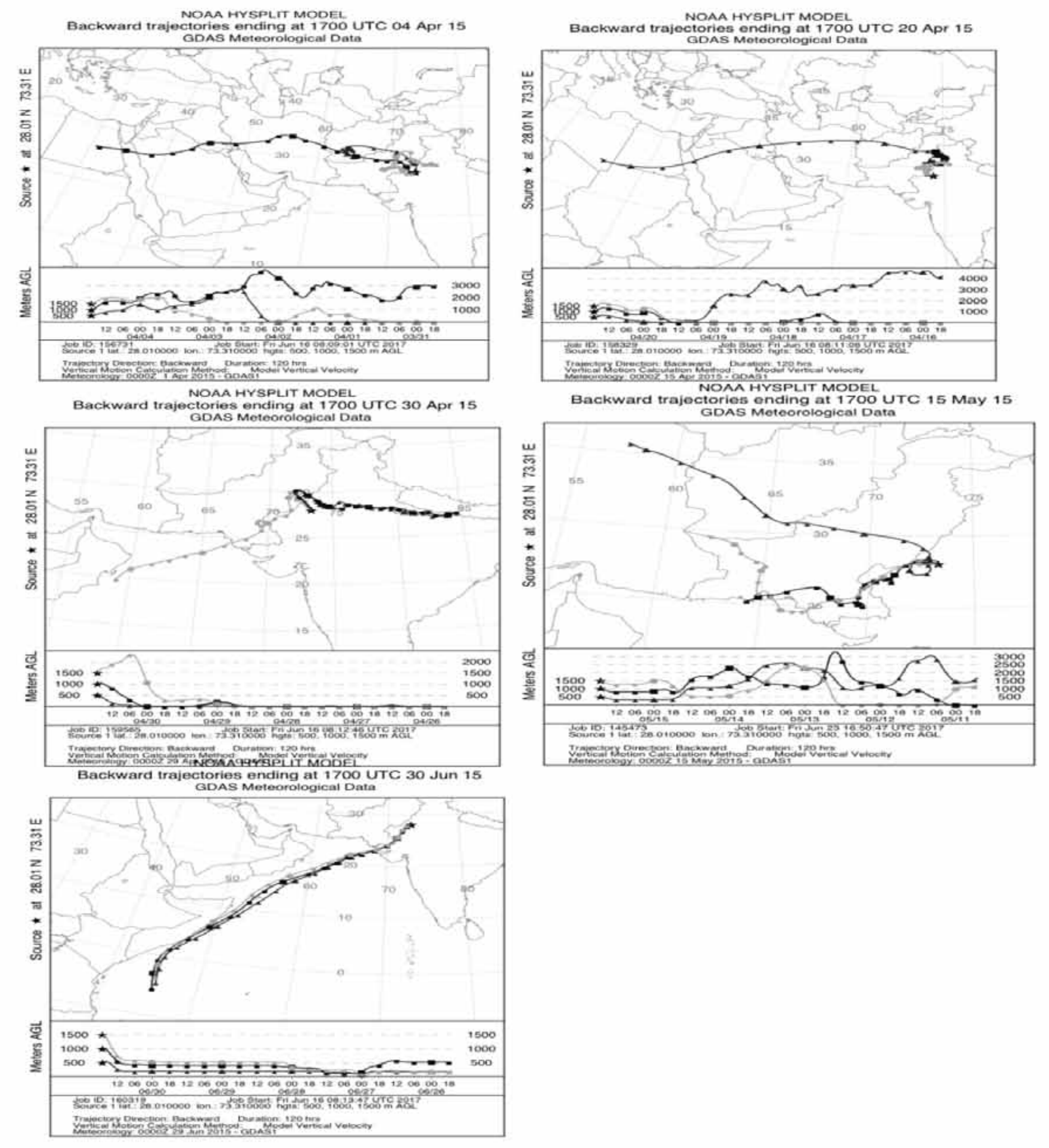
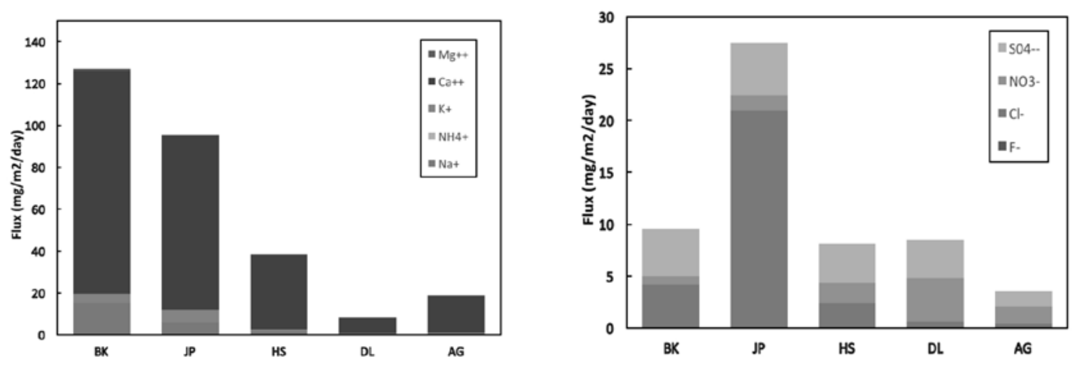


Figure 5. Back trajectory analysis for the five dust storm events at Bikaner.



Figures 6 & 7. Total flux of major cations and anions at all the sampling sites during all five dust storm events.

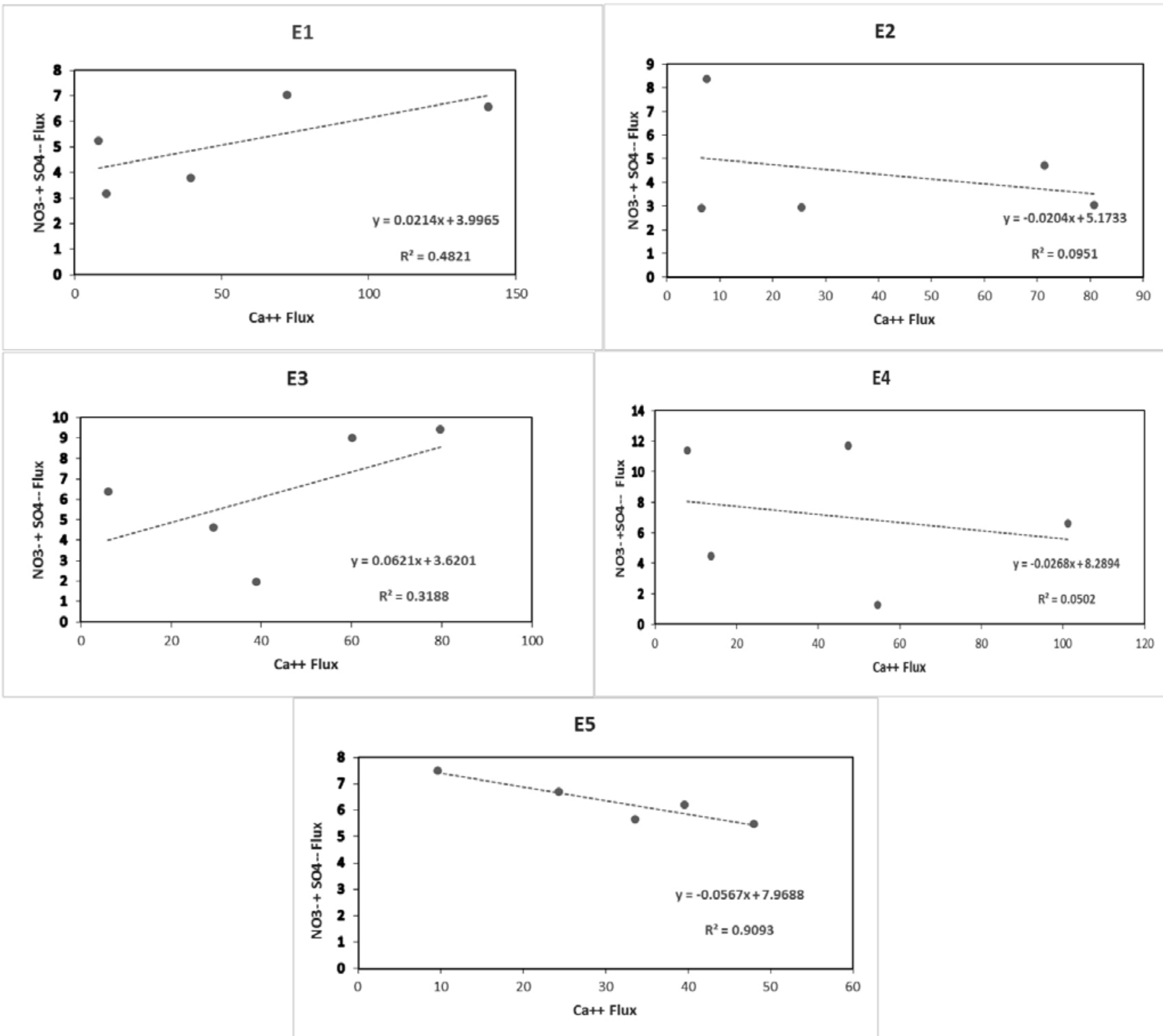


Figure 8. Correlation between Ca^{2+} and SO_4^{2-} and NO_3^- at the sampling sites for all the dust storm events.

CONCLUSIONS

In this study, we identified five major dust storm events based on the AOD values (>0.5) derived from the MODIS and OMI instruments and corroborated by the ground monitored dust fall flux measurements at the sampling locations. An analysis of the optical properties shows the dominance of coarse mode particles during all the events with low MODIS AE values recorded for dust events observed at the sites located in the close proximity of Thar desert. Back trajectory analysis showed the influence of dust sources in the north-west Africa and the Middle East on the air quality observed over the IGP. Chemical characterization of the dust fall samples showed that Ca^{2+} was the most dominating cation indicating the dominance of crustal sources at all the sites. The highest flux was recorded for SO_4^{2-} and NO_3^-. The NO_3^- flux was observed to increase downwind towards the sites (DL, HS) with high anthropogenic emissions. The fluxes of Na^+ and Cl^- were also high during major dust events. However, they were seen to decrease downwind indicating the influence of sea salt fraction in the dust plume transported from the Arabian sea.

ACKNOWLEDGEMENTS

We thank the Department of Science and Technology (DST) PURSE Fund for providing resources for successful completion of this project. D.S. sincerely thanks the CSIR for SRF funds to carry out this research. We are also thankful to GIOVANNI NASA and MODIS websites for enabling access to satellite data used in this project. We thank Dr. Prasenjiit Acharya for objective evaluation of the manuscript. Thanks are also due to Chief Editor for his constant support and proper editing.

Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

REFERENCES

Aher, G.R., Pawar, G.V., Gupta, P., and Devara, P.C.S., 2014. Effect of major dust storm on optical, physical, and radiative properties of aerosols over coastal and urban environments in Western India. Int. J. Remote Sens., v.35, no.3, pp: 871-903.

Askary, El-, H., Gautam, R., Singh, R., and Kafatos, M., 2006. Dust storms detection over the Indo-Gangetic basin using multi sensor data. Adv. Space Res., v.37, no.4, pp: 728-733.

Bollasina, M., Nigam, S., and Lau, K.-M., 2008. Absorbing aerosols and summer monsoon evolution over South Asia: an observational portrayal. J. Clim., v.21, no.13, pp: 3221-3239. http://dx.doi.org/10.1175/2007JCLI2094.1

Chu, D.A., Kaufman, Y.J., Ichoku, C., Remer, L.A., Tanre □, D., and Holben, B.N., 2002. Validation of MODIS aerosol optical depth retrieval over land. Geophysical Research Letters, v.29, no.12, pp: 1-2.

Claquin, T., Schulz, M., Balkanski, Y., and Boucher, O., 1998. Uncertainties in assessing radiative forcing by mineral dust. TellusB, v.50, pp: 491-505.

Crosbie, E., Sorooshian, A., Monfared, N.A., Shingler, T., and Esmaili, O., 2014. A multi- year aerosol characterization for the greater Tehran area using satellite, surface, and modeling data. Atmosphere,v.5, no.2, pp: 178-197.

Das, S., Dey, S., Dash, S.K., and Basil, G., 2013. Examining mineral dust transport over the Indian subcontinent using the regional climate model, RegCM4.1. Atmos. Res. http://dx.doi.org/10.1016/j.atmosres.2013.07.019.

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

Dumka, U.C., Tripathi, S.N., Misra, A., Giles, D.M., Eck, T.F., Sagar, R., and Holben, B.N., 2014. Latitudinal variation of aerosol properties from Indo-Gangetic Plain to central Himalayan foothills during TIGERZ campaign. J. Geophys. Res. Atmos., http://dx.doi.org/10.1002/2013JD021040., v.119.

Engelstaedter, S., Tegen, I., and Washington, R., 2006. North African dust emissions and transport. Earth Science. Rev., v.79, pp: 73-100.

Gautam, R., Hsu, N.C., Lau, K.-M., and Kafatos, M., 2009. Aerosol and rainfall variability over the Indian monsoon region: distributions, trends and coupling. Ann. Geophys., http://dx.doi.org/10.5194/angeo-27-3691-2009., v.27, pp: 3691-3703

Gautam, et al., 2011. Accumulation of aerosols over the Indo-Gangetic Plains and southern slopes of the Himalayas: distribution, properties and radiative effects.

Giles, D.M., et al., 2011. Aerosol properties over the Indo-Gangetic Plain: a mesoscale perspective from the TIGERZ experiment. J. Geophys. Res. D18203. http:// dx.doi.org/10.1029/2011JD015809., v.116.

Ginoux, P., Prospero, J.M., Gill, T.E., Hsu, C., and Zhao, M., 2012. Global scale attribution of anthropogenic and natural dust sources and their emission rates based on MODIS Deep Blue aerosol products. Rev. Geophys. 50, RG3005. http://dx.doi.org/10.1029/2012RG000388.

Gharai, B., Jose, S., Mahalakshmi, D.V., 2013. Monitoring intense dust storms over the Indian region using satellite data – a case study. Int. J. Remote Sens., v.34, no.20, pp: 7038-7048.

Goudie, A.S., 1983. Dust storms in space and time. Prog. Phys. Geogr., v.7, pp: 502-530.

Goudie, A.S., and Middleton, N.J., 1992. The changing frequency of dust storms through time. Climate Change, v.20, pp: 197-223.

Goudie, A.S., and Middleton, N.J., 2006. Desert dust in the global system, Springer.

Kaskaoutis, D.G., Kalapureddy, M.C.R., Krishna Moorthy, K., Devara, P.C.S., Nastos, P.T., Kosmopoulos, P.G., and Kambezidis, H.D., 2010. Heterogeneity in pre- monsoon aerosol types over the Arabian Sea deduced from shipboard measurements of spectral AODs. Atmos. Chem. Phys., v.10, pp: 4893-4908.

Kulshrestha, U.C., Kulshrestha, M.J., Sekar, R., Sastry, G.S.R., and Vairamani, M., 2003a. Chemical characteristics of rainwater at an urban site of south-central India. Atmospheric Environment, http://doi.org/10.1016/S1352-2310(03)00266-8., v.37, no. 21, pp: 3019-3026.

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

Kulshrestha Umesh, 2004. Atmospheric dust- a significant scavenger of SO_2 in India. Seminar lecture delivered at International Meteorological Institute, Stockholm University, Sweden on March 17, 2004.

Kulshrestha, U.C., Reddy, L.A.K., Satyanarayana, J., and Kulshrestha, M.J., 2009. Real-time wet scavenging of major chemical constituents of aerosols and role of rain intensity in Indian region. Atmospheric Environment, v.43, no.32, pp: 5123-5127.

Kulshrestha, U. C., and Disha Sharma, 2015. Importance of atmospheric dust in air: Future scope of research, Journal of Indian Geophysical Union, v.19, no.2, pp: 205-209.

Liu, D., Wang, Y., Wang, Z., and Zhou, J., 2012. The three-dimensional structure of transatlantic African dust transport: a new perspective from CALIPSO LIDAR measurements. Adv. Meteorol. 1, 9. http://dx.doi.org/10.1155/2012/850704. Article ID 850704.

Mahowald, N., Baker, A., Bergametti, G., Brooks, N., Duce, R., Jickells, T., Kubilay, N., Prospero, J., and Tegen, I., 2005. Atmospheric global dust cycle and iron inputs to the ocean. Global Biogeoch. Cycles 19, GB4025, doi: 10.1029/2004GB002402.

Middleton, N. J., 1986. "Dust storms in the Middle East," Journal of Arid Environments, v.10, no. 2, pp: 83-96.

Middleton, N.J., and Goudie, A.S., 2001. Saharan dust: sources and trajectories. Trans.Inst. Br. Geogr., v.26, pp: 165-181.

Nastos, P.T., 2012. Meteorological patterns associated with intense Saharan dust outbreaks over Greece in winter. Adv. Meteorol. http://dx.doi.org/10.1155/ 2012/828301, ID 828301.

Pandithurai, G., Dipu, S., and Dani, K.K., et al., 2008. "Aerosol radiative forcing during dust events over New Delhi, India," Journal of Geophysical Research D, Article IDD13209, v.113, 13 pages.

Prasad A.K., and Singh, R.P., 2007. "Changes in aerosol parameters during major dust storm events (2001–2005) over the Indo-Gangetic basin using AERONET and MODIS data," Journal of Geophysical Research, Article ID D09208, v.112.

Prospero, J.M., Ginoux, P., Torres, O., Nicholson, S.E., and Grill, T.E., 2002. Environmental characterization of global sources of atmospheric soil dust identified with the Nimbus 7 total ozone mapping spectrometer (TOMS) absorbing aerosol product. Rev. Geophys. 1002. http://dx.doi.org/10.1029/2000RG000095, v.40, pp: 32655- 32657.

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

Remer, L.A., Tanr´e, D., Mattoo, S., Chu, D.A., Martins, J.V., Li, R.-R., Cichoku, C., Levy, R.C., Kleidman, R.G., Eck, T.F., Vermote, E., and Holben, B.N., 2005. The MODIS aerosol algorithm, products, and validation. Journal of the Atmospheric Sciences, v.62, pp: 947-973.

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

Sharma, D., and Kulshrestha, U.C., 2014.Spatial and temporal patterns of air pollutants in rural and urban areas of India, Environmental Pollution, http://dx.doi.org/10.1016/j.envpol.2014.08.026.

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

Srivastava, M.K., Srivastava, S.K., Saha, A., Tiwari, S., Singh, S., Dumka, U.C., Singh, B.P., and Singh, N.P., 2010. Aerosol optical properties over Delhi and Manora Peak during a rare dust event in early April 2005. Int. J. Remote Sens., v.32, no.23, pp: 7939-7954.

Tanre, D., Haywood, J., and Pelon, J., et al., 2003. "Measurement and modeling of the Saharan dust radiative impact: overview of the Saharan Dust Experiment (SHADE)," Journal of Geophysical Research, v.108, no.D18, Article ID D8574.

Tegen, I., Werner, M., Harrison, S.P., and Kohfeld, K.E., 2004. Relative importance of climate and land use in determining present and future global soil dust emission. Geophys. Res. Lett. L05105. http://dx.doi.org/10.1029/ 2003GL019216., v.31.

Vinoj, V., Rasch, P.J., Wang, H., Yoon, J.-H., Ma, P.-L., Landu, K., and Singh, B., 2014. Shorter modulation of Indian summer monsoon rainfall by West Asian dust. Nat. Geosci. http://dx.doi.org/10.1038/NGEO2107.

Washington, R., Todd, M.C., Middleton, N.J., and Goudie, A.S., 2003. Dust-storm source areas determined by the total ozone monitoring spectrometer and surface observations. Ann. Assoc. Am. Geogr., v.93, pp: 297-313.

Zender, C.S., Miller, R.L., and Tegen, I., 2004. Quantifying mineral dust mass budgets: Terminology, constraints, and current estimates. EOS Trans., v.85, no.48, pp: 509-512.

Received on: 3.7.17; Revised on: 21.7.17; Accepted on: 30.7.17

"These dust storms.... Poor farmer spent a lifetime fixin' his farm and everything, goes out and looks down at it, and it's up above him". -HYPERLINK "http://www.azquotes.com/author/12553-Will_Rogers"*Will Rogers (1879 – 1935) was a motion picture actor and social commentator.*

***

"The storm took place at sundown; it lasted through the night,
When we looked out next morning, we saw a terrible sight
We saw outside our window where wheat fields they had grown
Was now a ripping ocean of dust the wind had blown".

- Woody Guthrie (1912 –1967) was an American singer

***

"Travelling, you realize that differences are lost: each city takes to resembling all cities, places exchange their form, order, distances, a shapeless dust cloud invades the continents".

- Italo Calvino (1923 – 1985) was an Italian journalist