EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 11(3) (2018) 213-220
DOI 10.14456/ea.2018.49
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Haze Formation During Winter in Delhi

Jyotsna Kumar*

Ramaiah University of Applied Sciences, Bangalore, India

*Corresponding author: drkumarchem111@gmail.com
Received: February 15, 2018; Accepted: May 28, 2018

Abstract

Surging anthropogenic emissions are increasing the aerosol concentration in the atmosphere in Delhi. During winter season temporal variability is at its peak which makes atmosphere rich in toxic particles and noxious emissions. Due to atmospheric inversion pollutants get trapped in the cold air and reduce the amount of solar radiation reaching the earth's surface. Dust storm events make this problem more critical in the Indo-Gangetic Basin (IGB, which incidentally is also a host to the highest population density in India). Bio-mass burning, vehicular emissions, stationary fossil fuel combustion, rubbish burning, in-situ particle formation and wind-blown dust, all contribute to hazy conditions and visibility degradation. Visibility levels can be used as a broad-based proxy for particulate air pollution. This review discusses the contributing factors and resulting problems associated with haze formation in Delhi during winter. Recommendations for further necessary study to understand the haze and its management are made.

Keywords: Aerosol; Haze; Combustion; Volatile organic aerosol; Biomass burning

1. Introduction

Haze is a common feature of industrial and rural regions around the world. The rapid urbanization and industrialization has intensified the environmental stress, causing rise in atmospheric concentration levels of air pollutants. Megacity Delhi is located in semiarid climate zone in North India (28.38 N, 77.12 E), with population of more than 16 million and extreme climate with range of normal temperature in summer from 25 to 48°C. Delhi, as one of the most polluted cities in the world in terms of high level of particulate matter (PM) of size less than or equal to 2.5μm (PM 2.5) is facing an alarmingly high level of haze episodes (Rizwan et al., 2013). In September 2011, the World Health Organization reported that Delhi has exceeded the PM limit by 10 times.

It has been reported that per day around 3000 metric tons of air pollutants are emitted in Delhi. Among this, the major contribution i.e.

67% is by vehicular pollution followed by 12% of coal-thermal power plants. Contribution of Municipal Solid Waste (MSW) burning, in total oxides of nitrogen (NOx) load and PM 2.5 were found to be 0.2% and 3.0% respectively (Sunil *et al.,* in press; MOE and F, 2011).

Kumar et al in their studies reported that the daily average PM 2.5 concentrations at different locations in Delhi are quite high compared to the standard of national ambient air quality standards (NAAQS) (Kumar *et al.,* 2017).

The temporal variability is prominent during winter and the concentrations of particulate matter, NO_2 (nitrogen dioxide), O_3 (ozone), CO (carbon monoxide), CO_2 (carbon dioxide), SO_2 (sulphur dioxide), volatile organic compounds (VOC) are increasing mainly due to vehicular emission, greenhouse gas, industrial exhaust, burning of fossil-fuel. Overall, air becomes fully charged with particles and toxic emissions which do not disperse due to atmospheric inversion.

In winters the main challenge for the air quality of Delhi is haze pollution due to anthropogenic emitted particles in addition to dust storm events. All these are able to produce hazy conditions and reducing the sight range.

Haze, an air pollution phenomenon, causes low visibility due to high airborne particulate matter (PM), and drastically affects the air quality (Zhao *et al.,* 2013; Sun *et al.,* 2006; Okada *et al.,* 2001; Chen *et al.*, 2003; Yadav *et al.,* 2003; Lee *et al.,* 2006; Huang *et al.,* 2011; Huang *et al.,* 2014; Ji *et al.,* 2014; Tao *et al.,* 2014; Wang *et al.,* 2014; Zhang *et al.,* 2014a, 2014b; Zheng *et al.,* 2015; Rongrong *et al.,* in press).

Haze lessens the atmospheric visibility to less than 10 km due to smoke, suspended particles, vapour, volatile organic compounds, secondary organic aerosols, organic and inorganic particles found in the atmosphere (Zhang *et al.,* 2013; Behra *et al.*, 2010).

Physical interaction of light with pollution particles (smoke, dust, vapours, soot particles) and atmospheric gases, increases the absorption and scattering of atmospheric gases/aerosols. This accelerates and intensifies the process of fog and smog formation in the urban areas especially in Delhi, which is one of the highly polluted industrialized mega city in south Asia. Whenever there is a hindrance in dispersion of suspended particles, they get accumulated and concentrated, forming a low-hanging veil that impairs visibility. All this contributes to occurrence of large-scale pollution haze imposing severe risk to both aerial and surface navigation and also leading to disruption of the climate and water cycle (Figure 1 and 2) (Singh, 2017; Mitter, 2017).

Problem of urban haze during winters in India is the combined effect of presence of primary aerosol particles (dust, emanated soot due to construction, combustion, and industrial processes), formation of secondary inorganic ions and hygroscopic growth of secondary aerosol in the atmosphere owing to several psychophysical processes. These organic and carbon particulate matter slowly permeates the whole region. In Delhi, sources of PM 2.5 and PM 10 are abundant and heterogeneous. Table 1 shows major pollution contributors in Delhi (Shewta, 2016).

Figure 1. Heavy haze formation observed on a winter afternoon at New Delhi

Figure 2. Crippling traffic due to winter smog in Asian Mega City, New Delhi

Table 1. Major sources of pollution in Delhi and their percentage contribution

S No	Source	PM2.5	PM10
1	Brick Kilns	13%	9%
2	Construction	4%	6%
3	Diesel gen Set	5%	3%
4	Domestic	11%	7%
5	Industries	13%	9%
6	Power plant	9%	13%
7	Road dust	9%	31%
9	Waste burning	6%	4%

This changes from season to season and from day to night, for example, emission of PM will be higher during the winter due to burning of biomass for heating purposes than summers (Sahu *et al.,* 2011; Sharma *et al.,* 2016; Xuefang *et al.,* 2013).

Biomass burning contributes a lot in terms of particulate matter and atmospheric gases which have intense effects on atmospheric chemistry (Verma *et al.,* 2008; Alves *et al.,* 2010).

2. Literature Analysis

Biomass burning (anthropogenic aerosol) in the nearby regions which contribute around 26% of PM 2.5 (Kirpa *et al.,* 2012) coupled with the desert dust aerosols from the Great Indian Desert lead to a high level of aerosol loadings. Secondary inorganic aerosol (including water-soluble inorganic species such as ammonium, sulfates, nitrates) is also rising predominantly due to oxidation of SO_2 and NOx. These emanations are mainly associated with fossil fuel combustion, biomass combustion, organic aerosols from industrial emissions, biological sources, refrigerate discharge, landfill emissions, paints and organic/inorganic solvents.

According to Varshney *et al.,* (2008) the annual anthropogenic VOC emissions for India have been estimated to be 21 million metric tons (m.t.) where the majority of emissions i.e. 60% originated from combustion of biomass, nearly 20% due to oil production and distribution followed by 12% of transport and 7% of open burning of agricultural residues (Sharma *et al.,* 2015). All these factors generously contribute to enhance the scattering characteristics of aerosols.

Recently, Journal of Science of the Total Environment (Li *et al.,* 2014) stated that in New Delhi higher strong emissions of fatty acids, fatty alcohols, n-alkanes, phthalates, etc. is due to open burning of plastics and other solid wastes. Important sources of carbonaceous aerosols are biomass burning, and rapid growth in usage of motor vehicles (6.89% in New Delhi, 2014-2015).

Radiocarbon measurement of aerosols proved that biomass burning or biogenic sources contributed 79% to water-soluble organic carbon, despite of various other fossil air pollution sources (Fang *et al.,* 2015). Winter time total solid particulates (TSP) indicates that crustal material is the most abundant component of ambient particles in New Delhi accounting for 48% of particle masses, 23% organic matter and 12% secondary inorganic ions (sulfate, nitrate plus ammonium). In New Delhi, during winters, the overall average concentration of PM 2.5 is 375 μg/m^3 against the acceptable level of 60 μg/m3. PM 2.5 expose people to very high health risks (Ostro *et al.,* 2006; Pop *et al.,* 2006). These fine particles (1/30th average width of human hair) get lodged deep in the lungs. Roughly one out of three people in the world is at a higher risk of experiencing PM 2.5 related health effects. It is estimated that more than three million deaths occur globally every year due to air pollution, mainly by particulate matter (Dholakia *et al.,* 2013; Heal *et al.,* 2012; WHO, 2016).

Satellite images and data of several investigators for the period of December to February reveal the presence of persistent aerosol haze layers over northern India along the southern edge of Himalayan region and above the Indo-Gangetic plain extending across Bangladesh onto the Bay of Bengal. The

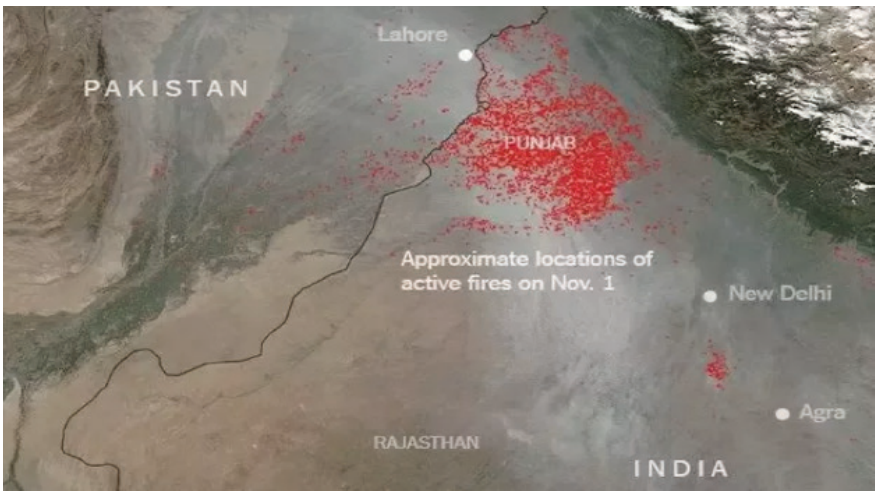

Figure 4. NASA image showing red (fire) spots near and around Delhi in November 2012

problem is more critical in the Indo-Gangetic Basin (IGB), where frequent fog formation leading to very low visibility is aided by high aerosol concentration (Tiwari *et al.,* 2011). Images released in 2012 by the United States NASA (National Aeronautics and Space Administration) (figure 4) suggest a thick blanket of aerosols and fire spots mainly over northern Indian states including Delhi during winter time. The large area covered with red dots in figure 4 suggest fire due to crop/biomass burning.

In Kanpur, another major city in Gangetic basin, contribution of secondary organic aerosols (SOA) is about 17% of total PM 2.5 (Behra *et al.,* 2010). This suggests that VOCs emission need to be controlled, both in and outside New Delhi, as it can lead to formation of SOA from VOC sources at a distance farther from the receptor.

3. Conclusion

In India the expected emission of VOCs is about 22.5 million metric tons by 2025, stressing the urgent need of developing effective VOC emission control approach in the near future. To understand the impact of smoke, aerosols emitted after the biomass burning on the local and regional climate system, identification of different categories of biomass burning and their contributions in several modes especially weather wise is essential. Since increase in PM mass concentration increases the adverse effects of PM on human health it has become more and more important to find out the sources of PM and the development of effective PM emission reduction strategies. The motto should be to first catch the problem at source point by using clean and green fuels.

In industries more emphasis should be laid on the green methodology and energy efficient processes. Since air pollution is not bound by geographical boundaries strict rules and regulation are the need of the hour on the

emission of gases from the industries and vehicles, and stringent control on backyard bio mass burning.

Apart from regulatory measures, usage of smokeless fuels, proper maintenance of roads and vehicles, optimization of technology for the development of low emission and energy efficient vehicles, advancement and adaptation of electric vehicle technology, properly planned and systematic management of traffic are few points to be considered.

To provide more lung space government and people should promote more and more green plantation in and around the susceptible regions.

For the mitigation of haze formation more research studies are necessary to characterize physical properties, chemical compositions, and secondary formation processes of urban non-fossil emissions. As SOA sources are still unknown and their formation include complex chemistry, multiphase processing they deserve concrete investigation and research.

References

Alves CA, Goncalves C, Evtyugina M, Pio CA, Mirante F, Puxbaum H. Particulate organic compounds emitted from experimental wildland fires in a Mediterranean ecosystem. Atmospheric Environment 2010; 44: 2750-2759.

Arora S, https://www.quora.com/Why-does-Delhi-have-so-much-smog-recently. 2016.

Behera SN, Sharma M. Reconstructing primary and secondary components of $PM_{2.5}$ composition for an urban atmosphere. Aerosol Science and Technology 2010; 44 (11): 983-992.

Chen Y, Schleicher N, Chen YZ, Chai FH, Norra S. The influence of governmental mitigation measures on contamination characteristics of $PM_{2.5}$ in Beijing. Science of Total Environment 2014; 490: 647–658.

Dholakia HH, Purohit P, Rao S, Garg A. Impact of current policies on future air quality and health outcomes in Delhi, India. Atmospheric Environment 2013; 75: 241–248.

Fang C, Zhang YL. Tightening non-fossil emissions control: A potential opportunity for $PM_{2.5}$ mitigation in China. In: Proceedings of National Academy of Science U.S.A. 2015; 112(12): 1402.

Heal MR, Kumar P, Harrison RM, Particles, air quality, policy and health. Chemical Society Reviews 2012; 41: 6606–6630.

Huang LK, Yuan CS, Wang GZ, Wang K. Chemical characteristics and source apportionment of PM_{10} during a brown haze episode in Harbin, China. Particuology 2011; 9: 32–38.

Huang RJ, Zhang Y, Bozzetti C, Ho KF, Cao JJ, Han Y, Daellenbach KR, Slowik J.G, Platt SM, Canonaco, F, Zotter P, Wolf R, Pieber SM, Bruns EA, Crippa M, Ciarelli G, Piazzalunga A, Schwikowski M, Abbaszade G, Schnelle-Kreis, J, Zimmermann R, An Z, Szidat S, Baltensperger U, Haddad IE, Prevot ASH. High secondary aerosol contribution to particulate pollution during haze events in China. Nature 2014; 514: 218–222.

Ji DS, Li L, Wang YS, Zhang JK, Cheng MT, Sun Y, Liu ZR, Wang L, Tang G, Hu B, Chao N, Wen T, Miao H. The heaviest particulate air-pollution episodes occurred in northern China in January, 2013: insights gained from observation. Atmospheric Environment 2014; 92: 546–556.

Kirpa R, Sarin MM, Tripathi SN. Temporal trends in atmospheric $PM_{2.5}$, PM_{10}, elemental carbon, organic carbon, water-soluble organic carbon, and optical properties: Impact of biomass burning emissions in the Indo-Gangetic plain. Enviornmental Science and Technology 2012; 46: 686-695.

Kumar P, Gulia, S, Harrison, RM, Khare, M. The influence of odd–even car trial on fine and coarse particles in Delhi. Environmental Pollution 2017; 225: 20–30.

Lee KH, Kim YJ, Kim MJ. Characteristics of aerosol observed during two severe haze events over Korea in June and October 2004. Atmospheric Environment 2006; 40: 5146–5155.

Li J, Wang G, Aggarwal SG, Huang Y, Ren ZY. Comparison of abundances, compositions and sources of elements, inorganic ions and organic compounds in atmospheric aerosols compositions from Xi'an and New Delhi, two megacities in China and India. Science of Total Environment 2014; 476–477: 485–495.

Mitter S, https://www.cntraveller.in/story/just-how-bad-is-the-smog-in-delhi/#s-custnikon-d850-the-perfectionists-partner. 2017.

Okada K, Ikegami M, Zaizen Y, Makino Y, Jensen JB, Gras JL. The mixture state of individual aerosol particles in the 1997 Indonesian haze episode. Journal of Aerosol Science 2001; 32: 1269–1279.

Ostro B, Broadwin R, Green S, Feng WY, Lipsett M. Fine particulate air pollution and mortality in nine California counties: results from CALFINE. Environmental Health Perspectives 2006; 114 (1): 29–33.

Pope CA, Dockery DW. Health effects of fine particulate air pollution: lines that connect. Journal of Air and Waste Management Association 2006; 56 (6): 709–742.

Rizwan SA, Baridalyne N, Sanjeev KG. Air pollution in Delhi: Its Magnitude and Effects on Health. Indian Journal of Community Medicine 2013; 38 (1): 4-8.

Rongrong S, Klaus S, Jürgen S-K, Longyi S, Stefan N, Utz K, Bernhard M, Gülcin A, Thorsten S, Ralf Z, Stefan E. Seasonal variability and source distribution of haze particles from a continuous one-year study in Beijing, Atmospheric Pollution Research (in press)

Sahu SK, Beig G, Parkh NS. Emissions inventory of anthropogenic $PM_{2.5}$ and PM_{10} in Delhi during Commonwealth games 2010. Atmospheric Environment 2011; 45: 6180–6190.

Sharma M, Dikshit O. Comprehensive Study on Air Pollution and Green House Gases. (GHGs) in Delhi. Final Report, Prepared by IIT Kanpur, sponsored by Delhi Pollution Control Committee, New Delhi, 2016.

Sharma S, Goel A, Gupta D, Kumar MA, Arabinda K, Seema C, Satoru K, Zbigniew K. Emission inventory of non-methane volatile organic compounds from anthropogenic sources in India. Atmospheric Environment 2015; 102: 209-219.

Singh S, http://www.newspatrolling.com/ima-declares-emergency-as-pollution-reaches-unprecedented-levels-in-delhi/. 2017

Singh Y. Pollution in Delhi : A Chronic Problem. https://www.jagranjosh.com/current-affairs/pollution-in-delhi-a-chronic-problem-1510211965-1. 2017

Sun YL, Zhuang GS, Tang AH, Wang Y, An ZS. Chemical characteristics of $PM_{2.5}$ and PM_{10} in haze-fog episodes in Beijing. Environmental Science and Technology 2006; 40: 3148–3155.

Sunil G, Abhishek M, Mukesh K, Quantitative evaluation of source interventions for urban air quality improvement - A case study of Delhi city. Atmospheric Pollution Research (In press).

Tao M, Chen L, Xiong X, Zhang M, Ma P, Tao J, Wang Z. Formation process of the widespread extreme haze pollution over northern China in January 2013: implications for regional air quality and climate. Atmospheric Environment 2014; 98: 417–425.

Tiwari S, Payra S, Mohan M, Verma S, Bisht DS. Visibility degradation during foggy period due to anthropogenic urban aerosol at Delhi, India. Atmospheric Pollution Research 2011; 2: 116-120.

Varshney CK, Padhy PK. Emissions of total volatile organic compounds from anthropogenic sources in India. Journal of Industral Ecology 2008; 2(4): 93–105.

Verma S, Venkataraman C, Boucher O. Origin of surface and columnar Indian Ocean Experiment (INDOEX) aerosols using source- and region-tagged emissions transport in a general circulation model. Journal of Geophysical Research-Atmospheres. 2008; 113: D24211.

Wang YS, Yao L, Wang LL, Liu ZR, Ji DS, Tang GQ, Zhang JK, Sun Y, Hu B, Xin JY. Mechanism for the formation of the January 2013 heavy haze pollution episode over central and eastern China. Science China Earth Sciences 2014; 57: 14–25.

White Paper on Pollution in Delhi with an Action Plan, Ministry of Environment and Forests, Government of India, http://envfor.nic.in/divisions/cpoll/delpolln.html. 1997.

WHO (World Health Organization). Ambient air pollution: a global assessment of exposure and burden of disease. http://who.int/phe/publications/airpollution- global-assessment/en/. 2016.

Xuefang S, Zhisheng Z, Chuenyu C, Guenter E. Source categories and contribution of biomass smoke to organic aerosol over the southeastern Tibetan Plateau. Atmospheric Environment 2013; 78:113-123.

Yadav AK, Kumar K, Kasim AMHA, Singh MP, Parida SK, Sharan M. Visibility and incidence of respiratory diseases during the 1998 haze episode in Brunei Darussalam. Pure and Applied Geophysics 2003; 160: 265–277.

Zhang F, Chen J, Qiu T, Yin L, Chen X, Yu J. Pollution characteristics of $PM_{2.5}$ during a typical haze episode in Xiamen, China. Atmospheric and Climate Sciences 2013; 3: 427-439.

Zhang JK, Sun Y, Liu ZR, Ji DS, Hu B, Liu Q, Wang YS. Characterization of submicron aerosols during a month of serious pollution in Beijing, 2013. Atmospheric Chemistry and Physics 2014a; 14: 2887–2903.

Zhang RH, Li Q, Zhang RN. Meteorological conditions for the persistent severe fog and haze event over eastern China in January 2013. Science China Earth Sciences 2014b; 57(1): 26–35.

Zhao XJ, Zhao PS, Xu J, Meng W, Pu WW, Dong F, He D, Shi QF. Analysis of a winter regional haze event and its formation mechanism in the North China Plain. Atmospheric Chemistry and Physics 2013; 13: 5685–5696.

Zheng GJ, Duan FK, Su H, Ma YL, Cheng Y, Zheng B, Zhang Q, Huang T, Kimoto, T, Chang D, Pöschl U, Cheng YF, He KB. Exploring the severe winter haze in Beijing: the impact of synoptic weather, regional transport and heterogeneous reactions. Atmospheric Chemistry and Physics 2015; 15, 2969–2983.