

## Delhi Smog 2012: Cause and Concerns

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### Abstract

Delhi, the capital city of India, has an ill repute of a polluted city specifically due to high ambient particulate concentration resulting Hazy conditions. Winter of 2012 in Delhi was characterized with high level of critical pollutants, which in general, were attributed to geographical location of the city, high vehicular and population density. The onset of winter 2012 witnessed hazy and dusty condition, which prevailed for about 20 days (October to November), which is uncommon for this period of the year. No changes in the pattern of polluting activities in Delhi city were observed, which further compelled Delhi Pollution Control Committee to find out the associated reasons. The activities in neighboring states like agricultural waste burning in Punjab and Haryana and development of cyclone on coast of Tamil Nadu during this period might be one of the factored reasons for the hazy conditions. In this study, status of pollutants like particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>), Nitrogen dioxide, Ozone, Ammonia, Sulfur dioxide and Carbon monoxide and metrological conditions were assessed and compared with 2011 data to find out the cause of extra ordinary hazy condition in Delhi, which induced panic in general population and attracted international media.

**Keywords:** Smog; Delhi; Hazy conditions; PM<sub>10</sub> and PM<sub>2.5</sub>; NO<sub>2</sub>; SO<sub>2</sub>; Ozone

### Introduction

Air pollution has received significant attention over the past several decades from both the scientific and the environmental risk management communities in India and internationally [1]. This is especially true of smog's two major components: particulate matter (PM) and ground-level ozone (O<sub>3</sub>). The primary reason for this attention has been the scientific literature, indicating the extensive impacts exerted by these pollutants on human health. Although they can also impact the environment, these impacts are less critical at the levels of smog currently experienced in Delhi, capital of the country, India.

Fast globalization, concentrated life style and automation have lead to emergence of new branches of science in the developed and developing countries. Polluted air, space, land and water are the unwanted results of the same. Compared to the rapidity of increase in pollution levels, awareness of air contamination and measures to monitor and control air quality are inadequate [2]. Pragmatic ill effects on human health and difficulty in treating air warrant due attention to continuously assess, monitor and control the ambient air quality, air being a primary source of lives. In developed countries, urban air pollution is eighth among the top 10 risk factors, and is the most important population health risk factor that cannot be significantly reduced by changes to personal behavior, arguably making it the most important risk factor for which the primary control mechanism is regulatory in nature [3].

Air pollution observed in many urban areas is commonly referred to as Smog. Smog is a yellowish fog caused by a mixture of atmospheric pollutants, and it consists mainly of fine particles and ozone. The latter is the product of complex photochemical reactions between nitrogen oxides (NO<sub>x</sub>) and volatile organic compounds (VOC), which are called "precursors" [4]. The main sources of these pollutants are motor vehicles, industrial processes and the heating of buildings. Not only does smog affect a broad swath of the population, but adverse health effects occur across the full range of ambient levels experienced in India, even very low levels. For all practical purposes, both PM and O<sub>3</sub> need to be treated as having no safe level (i.e. on a population basis,

there is no lower threshold at which there are no effects). This is likely due to the ubiquitous exposure to smog and the common nature of the illnesses and conditions affected by air pollution [5].

### Study Area

Delhi, the capital city of India, is situated in North India (28°12'-28°63' N, 75°50'-77°23' E), at an altitude of 293 m above sea level. It is surrounded by the Thar Desert of Rajasthan to the west and the hot plains of Central India to the south. The distance from the nearest ocean exceeds one thousand kilometers. The climate of Delhi is semi-arid, and is mainly influenced by its inland position and prevalence of continental air during most of the year [6]. According to the classification given by Indian Meteorological Department, Delhi has four distinct seasons: winter (December-March), pre-monsoon or summer (April-June), monsoon (July-September) and post-monsoon (October-November). Summer is long and extremely hot, with maximum temperatures of 45-48°C, and the maximum frequency of dust storms. Humidity is high only during the monsoon season, characterized by heavy rainfall, while the air is dry during the rest of the year. Normal annual rainfall is between 600 and 800 mm, with more than 80% during the monsoon season. The winter season is moderately cold, with minimum temperatures around 1-4°C. During this part of the year, conditions of atmospheric stability (low wind speed and temperature inversion) lead to the frequent accumulation of atmospheric pollutants in the lower atmospheric layer, and morning hours are often thickly foggy. Wind speeds are typically higher in the summer and the monsoon periods; they are predominantly westerly and north-westerly, and tend to be more northerly in the afternoons, except during the monsoon season,

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when they are easterly and north-easterly. Yearly mean wind speed is in the range 0.9-2.0 ms<sup>-1</sup> [7].

### Sampling

Sampling location was located in the urbanized part of New Delhi (28°35' N; 77°12' E). The location of the site is shown in Figure 1. No major industrial sources are located within 5 km around the site. Sampling of PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, CO, NH<sub>3</sub> and O<sub>3</sub> was carried out at three urban residential locations of New Delhi, the capital, and third largest city of India, ranks third in population among other Indian cities, estimated among 8.5 million [8].

The air monitoring stations were at following sites:

- 1) Mandir Marg
- 2) Punjabi Bagh
- 3) R. K. Puram

In this study, the ambient air quality Delhi between the second week of October and first week of November 2012 is discussed, as there was an incident of major haziness in New Delhi during that period of time.

### Methodology

The data was collected from 3 real time continuous ambient air monitoring stations established by DPCC (Table 1). This data was collected on 15 minutes average basis, and is averaged for 24 hours. PM<sub>10</sub> and PM<sub>2.5</sub> were measured using β-attenuation technique. Other parameters were measured using USEPA and CPCB standard procedures [6].

### Observations

In this study, the general parameters of atmosphere, such as Particulate Matter, Sulfur dioxide, Nitrogen dioxide; Ozone, Ammonia and Carbon monoxide were measured along with Metrological parameters like humidity, wind speed and temperature (Table 2). The monitoring data of three consecutive years (2010, 2011 and 2012) during the period of 22 October to 10 November was used. The monitoring data of three consecutive years (2010, 2011 and 2012) during the period of 22 October to 10 November was used, and is shown in Tables 3-5 and in Figures 2-5.

**Particulate Matter (PM<sub>10</sub>):** Inter-station variation was 463-530 (µg/m<sup>3</sup>) during episode period, while the maximum concentration was observed 760 at Mandir Marg on 5th Nov. 782 (µg/m<sup>3</sup>) at Punjabi Bagh

on 7th November, and 915 (µg/m<sup>3</sup>) on 30th October at R.K Puram. The gradual increases were observed at all the three stations, which reached on peak during 4th to 7 of November (Figure 6).

**Particulate Matter (PM<sub>2.5</sub>):** The average concentration of PM<sub>2.5</sub> varied from 267 to 321(µg/m<sup>3</sup>). The maximum was observed at Punjabi Bagh and minimum at R. K. Puram. The peak concentration was observed at R. K. Puram and Mandir Marg on 4<sup>th</sup> Nov; while at Punjabi Bagh on 7<sup>th</sup> November (Figure 7).

**Nitrogen dioxide:** The concentration of NO<sub>2</sub> varied from 62 to 196 (µg/m<sup>3</sup>). From 26<sup>th</sup> October onwards, value crossed 100 though NO<sub>2</sub> was low at R. K. Puram, but an increase of 100% was observed at R. K. Puram also. Though Particulate shown down ward trend from 5<sup>th</sup> on wards, but in NO<sub>2</sub> concentration showed upward trend, which was observed up to 10<sup>th</sup> November (Figure 8).

**Ozone:** Concentration of O<sub>3</sub> varied from 41 to 56 (µg/m<sup>3</sup>), which is comparable with last year's data. The higher values were observed in initial phase (Figure 9).

**Ammonia:** The average concentration of ammonia was varied

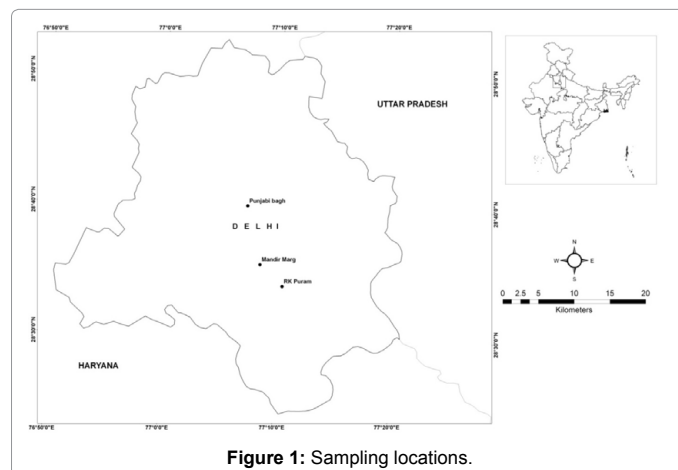


Figure 1: Sampling locations.

Sl. No.	Locations	Activities
1	Mandir Marg	Residential, Commercial
2	Punjabi Bagh	Residential
3	R. K. Puram	Residential

Table 1: Monitoring locations.

Location	Wind Speed (m/sec)				Temperature (°C)			
	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div
Mandir Marg	0.52	1.44	0.76	0.23	18.6	21.3	19.9	0.69
Punjabi Bagh	0.54	1.31	0.72	0.19	19.3	24.3	21.0	1.29
R. K. Puram	0.6	1.1	0.77	0.16	17.7	22.2	19.1	1.02

Table 2: Variation of wind speed and temperature during the study period.

Location	PM <sub>10</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				PM <sub>2.5</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				SO <sub>2</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				NO <sub>2</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)			
	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div
Mandir Marg	183	767	463	183.21	123	531	281	135.01	9	28	16	5.99	72	301	115	50.84
Punjabi Bagh	199	782	529	174.23	117	574	321	126.23	5	37	18	8.82	82	301	196	41.40
R. K. Puram	263	915	541	158.88	141	404	267	87.53	12	41	27	8.39	36	74	62	10.86
NAAQS	100				60				80				80			

Table 3: Concentration (µg/m<sup>3</sup>) of PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub> and NO<sub>2</sub> during the study period.

Location	PM <sub>10</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				PM <sub>2.5</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				SO <sub>2</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				NO <sub>2</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)			
	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div
Mandir Marg	186	581	393	87.35	97	323	226	57.67	2	25	12	7.55	40	183	80	36.32
Punjabi Bagh	252	690	496	104.33	128	465	260	90.22	6	69	22	12.56	63	176	117	30.84
R. K. Puram	301	780	516	114.54	119	560	233	95.75	2	32	10	6.25	91	215	142	37.60
NAAQS	100				60				80				80			

Table 4: Concentration (µg/m<sup>3</sup>) of PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub> and NO<sub>2</sub> during the study period (2011).

Location	PM <sub>10</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				PM <sub>2.5</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				SO <sub>2</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)				NO <sub>2</sub> (µg/m <sup>3</sup> ) (24 hrs sampling)			
	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div	Min	Max	Avg	Std Div
Mandir Marg	183	767	463	183.21	123	531	281	135.01	9	28	16	5.99	72	301	115	50.84
Punjabi Bagh	199	782	529	174.23	117	574	321	126.23	5	37	18	8.82	82	301	196	41.40
R. K. Puram	263	915	541	158.88	141	404	267	87.53	12	41	27	8.39	36	74	62	10.86
NAAQS	100				60				80				80			

Table 5: Concentration (µg/m<sup>3</sup>) of PM<sub>10</sub>, PM<sub>2.5</sub>, SO<sub>2</sub> and NO<sub>2</sub> during the study period (2012).

from 50 to 88 (µg/m<sup>3</sup>). The lowest avg. values were observed at R. K. Puram and maximum at Punjabi Bagh (Figure 10).

**Carbon monoxide:** The concentration of CO found exceeding the standard and the average value for all the three stations was 3 mg/m<sup>3</sup>. The values showed an increasing trend till first November and second peak was observed on 4<sup>th</sup> or 5<sup>th</sup> November (Figure 11).

**Sulfur dioxide:** Sulfur dioxide was always well within the limit and average varied from 16 to 27 (µg/m<sup>3</sup>) (Figure 12).

## Results

The correlation analysis also undertaken to understand inter station correlation of different parameters. The observations were as follows:

### Correlation analysis for mandir marg

Table 6 shows the statistical correlations among PM<sub>10</sub>, PM<sub>2.5</sub>, Sulfur dioxide, Nitrogen dioxide, O<sub>3</sub>, Ammonia, Carbon monoxide, Wind Speed and Temperature. A strong correlation was observed between PM<sub>10</sub> and PM<sub>2.5</sub> (0.96), PM<sub>10</sub> and Carbon monoxide (0.83) and PM<sub>2.5</sub> and Carbon monoxide (0.80). On the other hand, negative correlation was observed between PM<sub>10</sub> and O<sub>3</sub> (-0.75) and PM<sub>2.5</sub> and O<sub>3</sub> (-0.76). The negative correlation between Wind Speed and other parameters confirms that as the wind speed was observed to be low, the pollutants remained in concentration, and were not dispersed quickly and as a result the hazy conditions (Table 6).

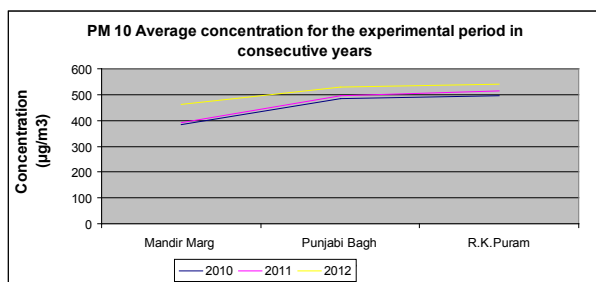


Figure 2: PM<sub>10</sub> average concentration for the experimental period in consecutive years.

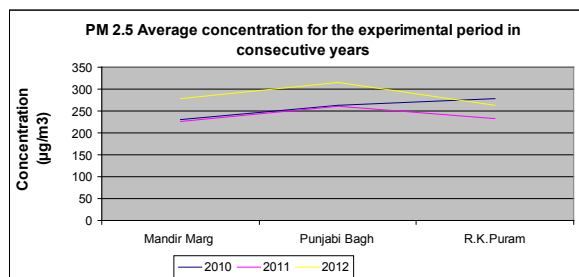


Figure 3: PM<sub>2.5</sub> average concentration for the experimental period in consecutive years.

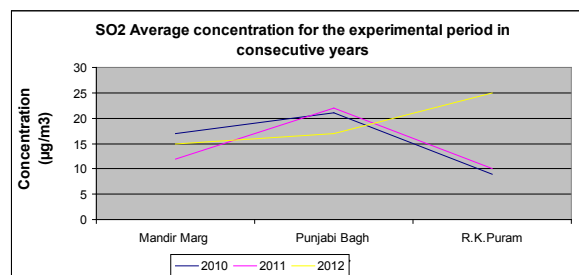


Figure 4: SO<sub>2</sub> average concentration for the experimental period in consecutive years.

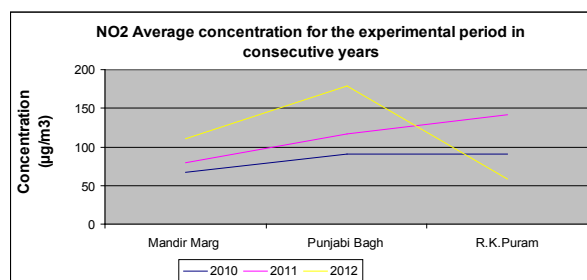


Figure 5: NO<sub>2</sub> average concentration for the experimental period in consecutive years.

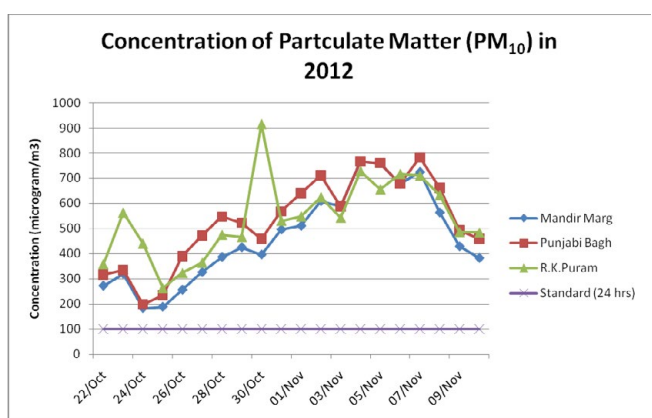


Figure 6: Concentration of Particulate Matter (PM<sub>10</sub>).

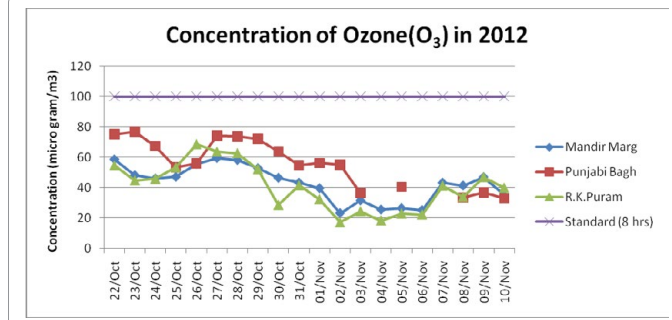


Figure 9: Concentration of Ozone.

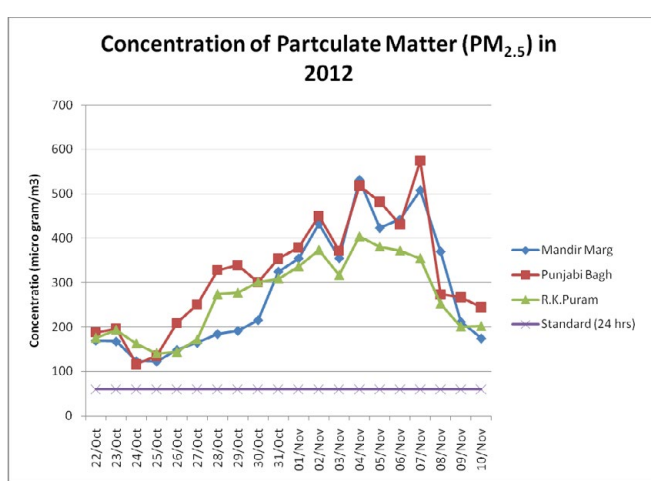


Figure 7: Concentration of Particulate Matter (PM<sub>2.5</sub>).

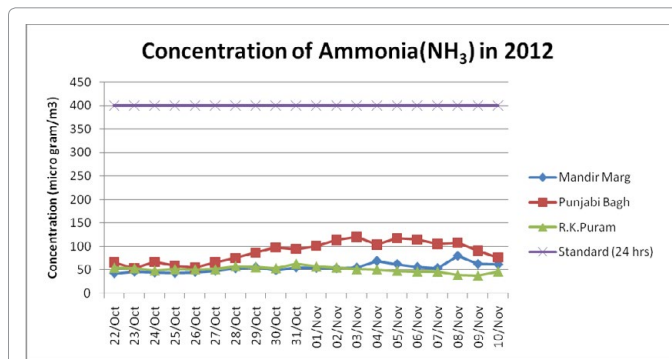


Figure 10: Concentration of Ammonia.

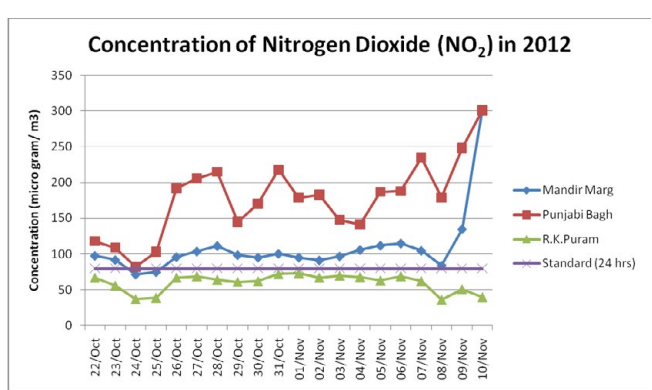


Figure 8: Concentration of Nitrogen dioxide.

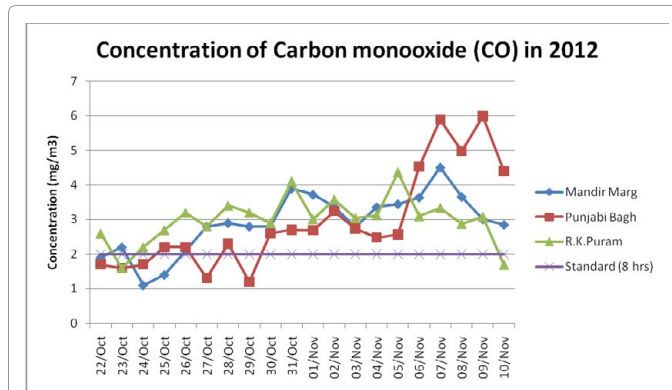


Figure 11: Concentration of Carbon monoxide.

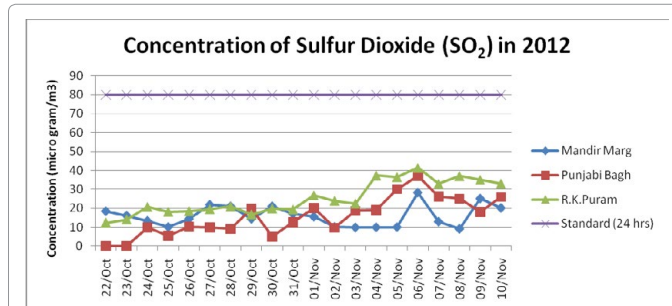


Figure 12: Concentration of Sulfur dioxide.

### Punjabi bagh

Table 7 shows the statistical correlations among PM<sub>10</sub>, PM<sub>2.5</sub>, Sulfur dioxide, Nitrogen dioxide, O<sub>3</sub>, Ammonia, Carbon monoxide, Wind Speed and Temperature. A strong correlation was observed between PM<sub>10</sub> and PM<sub>2.5</sub> (0.95), PM<sub>10</sub> and Ammonia (0.85) and PM<sub>2.5</sub> and Ammonia (0.80). On the other hand, negative correlation negative

correlation was observed between O<sub>3</sub> and Carbon monoxide (-0.80). The negative correlation between Wind Speed and other parameters



	PM <sub>10</sub>	PM <sub>2.5</sub>	NO <sub>2</sub>	SO <sub>2</sub>	CO	NH <sub>3</sub>	O <sub>3</sub>	Wind Speed	Temperature
PM <sub>10</sub>	1.00	0.96	0.03	-0.20	0.84	0.65	-0.75	-0.68	-0.13
PM <sub>2.5</sub>	0.96	1.00	-0.09	-0.29	0.80	0.57	-0.76	-0.63	-0.22
NO <sub>2</sub>	0.03	-0.09	1.00	0.34	0.13	0.26	-0.18	-0.17	0.21
SO <sub>2</sub>	-0.20	-0.29	0.34	1.00	0.04	-0.18	0.28	-0.02	0.36
CO	0.84	0.80	0.13	0.04	1.00	0.61	-0.45	-0.74	0.02
NH <sub>3</sub>	0.65	0.57	0.26	-0.18	0.61	1.00	-0.49	-0.38	-0.16
O <sub>3</sub>	-0.75	-0.76	-0.18	0.28	-0.45	-0.49	1.00	0.42	0.29
Wind Speed	-0.68	-0.63	-0.17	-0.02	-0.74	-0.38	0.42	1.00	-0.12
Temperature	-0.13	-0.22	0.21	0.36	0.02	-0.16	0.29	-0.12	1.00

Table 6: Correlation among PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, CO, NH<sub>3</sub>, O<sub>3</sub>, wind speed and temperature at Mandir Marg.

	PM <sub>10</sub>	PM <sub>2.5</sub>	NO <sub>2</sub>	SO <sub>2</sub>	CO	NH <sub>3</sub>	O <sub>3</sub>	Wind Speed	Temperature
PM <sub>10</sub>	1.00	0.95	0.43	0.61	0.46	0.85	-0.44	-0.73	-0.64
PM <sub>2.5</sub>	0.95	1.00	0.34	0.53	0.37	0.80	-0.29	-0.72	-0.57
NO <sub>2</sub>	0.43	0.34	1.00	0.34	0.62	0.24	-0.48	-0.36	-0.41
SO <sub>2</sub>	0.61	0.53	0.34	1.00	0.55	0.58	-0.66	-0.55	-0.58
CO	0.46	0.37	0.62	0.55	1.00	0.48	-0.80	-0.27	-0.54
NH <sub>3</sub>	0.85	0.80	0.24	0.58	0.48	1.00	-0.57	-0.70	-0.64
O <sub>3</sub>	-0.44	-0.29	-0.48	-0.66	-0.80	-0.57	1.00	0.11	0.67
Wind Speed	-0.73	-0.72	-0.36	-0.55	-0.27	-0.70	0.11	1.00	0.24
Temperature	-0.64	-0.57	-0.41	-0.58	-0.54	-0.64	0.67	0.24	1.00

Table 7: Correlation among PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, CO, NH<sub>3</sub>, O<sub>3</sub>, wind speed and temperature at Punjabi Bagh.

	PM <sub>10</sub>	PM <sub>2.5</sub>	NO <sub>2</sub>	SO <sub>2</sub>	CO	NH <sub>3</sub>	O <sub>3</sub>	Wind Speed	Temperature
PM <sub>10</sub>	1.00	0.77	0.21	0.51	0.24	-0.13	-0.76	-0.29	-0.43
PM <sub>2.5</sub>	0.77	1.00	0.52	0.54	0.60	0.12	-0.80	-0.55	-0.49
NO <sub>2</sub>	0.21	0.52	1.00	-0.12	0.52	0.56	-0.15	-0.68	0.17
SO <sub>2</sub>	0.51	0.54	-0.12	1.00	0.24	-0.66	-0.58	-0.36	-0.73
CO	0.24	0.60	0.52	0.24	1.00	0.21	-0.23	-0.61	-0.40
NH <sub>3</sub>	-0.13	0.12	0.56	-0.66	0.21	1.00	0.13	-0.14	0.42
O <sub>3</sub>	-0.76	-0.80	-0.15	-0.58	-0.23	0.13	1.00	0.23	0.45
Wind Speed	-0.29	-0.55	-0.68	-0.36	-0.61	-0.14	0.23	1.00	0.26
Temperature	-0.43	-0.49	0.17	-0.73	-0.40	0.42	0.45	0.26	1.00

Table 8: Correlation among PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, CO, NH<sub>3</sub>, O<sub>3</sub>, wind speed and temperature at R. K. Puram.

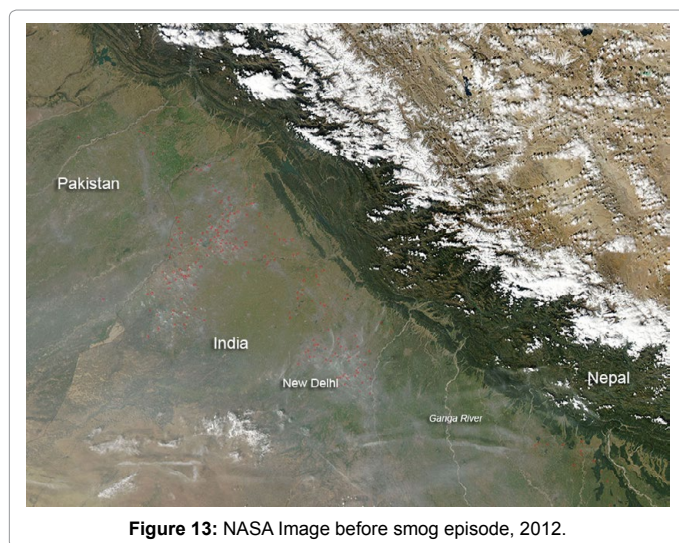


Figure 13: NASA Image before smog episode, 2012.

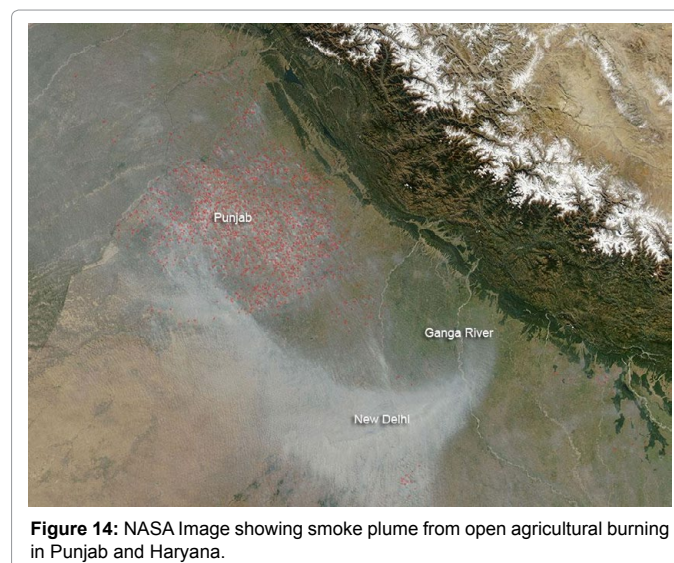


Figure 14: NASA Image showing smoke plume from open agricultural burning in Punjab and Haryana.

has the same reason as that of for Mandir Marg station (Table 7).

### R. K. puram

Table 8 shows the statistical correlations among PM<sub>10</sub>, PM<sub>2.5</sub>, Sulfur dioxide, Nitrogen dioxide, O<sub>3</sub>, Ammonia, Carbon monoxide, Wind

Speed and Temperature. A strong correlation was observed between PM<sub>10</sub> and PM<sub>2.5</sub> (0.77). On the other hand, negative correlation negative correlation was observed between O<sub>3</sub> and PM<sub>10</sub> (-0.76) and O<sub>3</sub> and PM<sub>2.5</sub> (-0.80). The negative correlation between Wind Speed and other

parameters has the same reason as that of for Mandir Marg station (Table 8).

## Discussion

The comparison of the concentration of different parameters from 22<sup>nd</sup> to 26<sup>th</sup> of October is comparable with the data for the same period in year 2010 and 2011. Particulate concentration (PM<sub>10</sub> and PM<sub>2.5</sub>) showed an increasing trend from 26<sup>th</sup> October to November 6<sup>th</sup>. In gaseous pollutants, NO<sub>2</sub> and CO also showed the same trend. While Ozone and Ammonia showed downward trend from 24<sup>th</sup> October. During this period, no sudden activity was observed in Delhi, which may be attributed to increase of particulates in ambient air. The agricultural waste burning, which is normal practice in Haryana and Punjab, may be a cause (Figure 8 and 9). The image released by NASA in public domain clearly shows the agricultural fire in Gangetic plain. The Figure 13 shows agricultural fire through the Delhi area has no smoke, but after development of a cyclone at Tamil Nadu coast caused movement of smoke towards Delhi, which is clearly visible in form of plume. To understand the reasons for an abnormal hazy conditions in Delhi, ambient air data from 22<sup>nd</sup> October to 10<sup>th</sup> November 2012, was compared with the data of 2011. The hazy condition is normal for Delhi, but only December and January months, when inversion is acute and temperature difference between day and night temperature in below 10°C with very low wind speed. The hazy conditions developed in year 2012 maybe correlated with biomass burning and cyclonic development during this period in down southern part of Indian subcontinent.

The Image shows the clouds of ash just above Delhi city the cloud trapped above Delhi due to formation of cyclone and corresponding anti-cyclone. The calm condition in Delhi during the period also correlates to the situation. The positive correlation between particulate and CO also indicates the particulate and CO both is from same source. Past IMD data and Satellite imageries of 2000-2012 show that there were

similar prolonged fog/smog/haze conditions over Delhi and adjoining NW India, in association with crossing of cyclones during December 1998, November 2008 and December 2011. During November 2008, there were 21 days of prolonged occurrence of fog/smog/haze, with three spells in association with three cyclones “Rashmi” “Khi-Muk” and “Nisha”. During last week of December 2011, Cyclone “Thane” crossed Tamil Nadu coast and created similar atmospheric conditions. It indicates that the smog episodes in Delhi is a cumulative effect of formation of cyclonic conditions due to cyclone “Nilam” and open agricultural burning in the region (Figure 14).

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