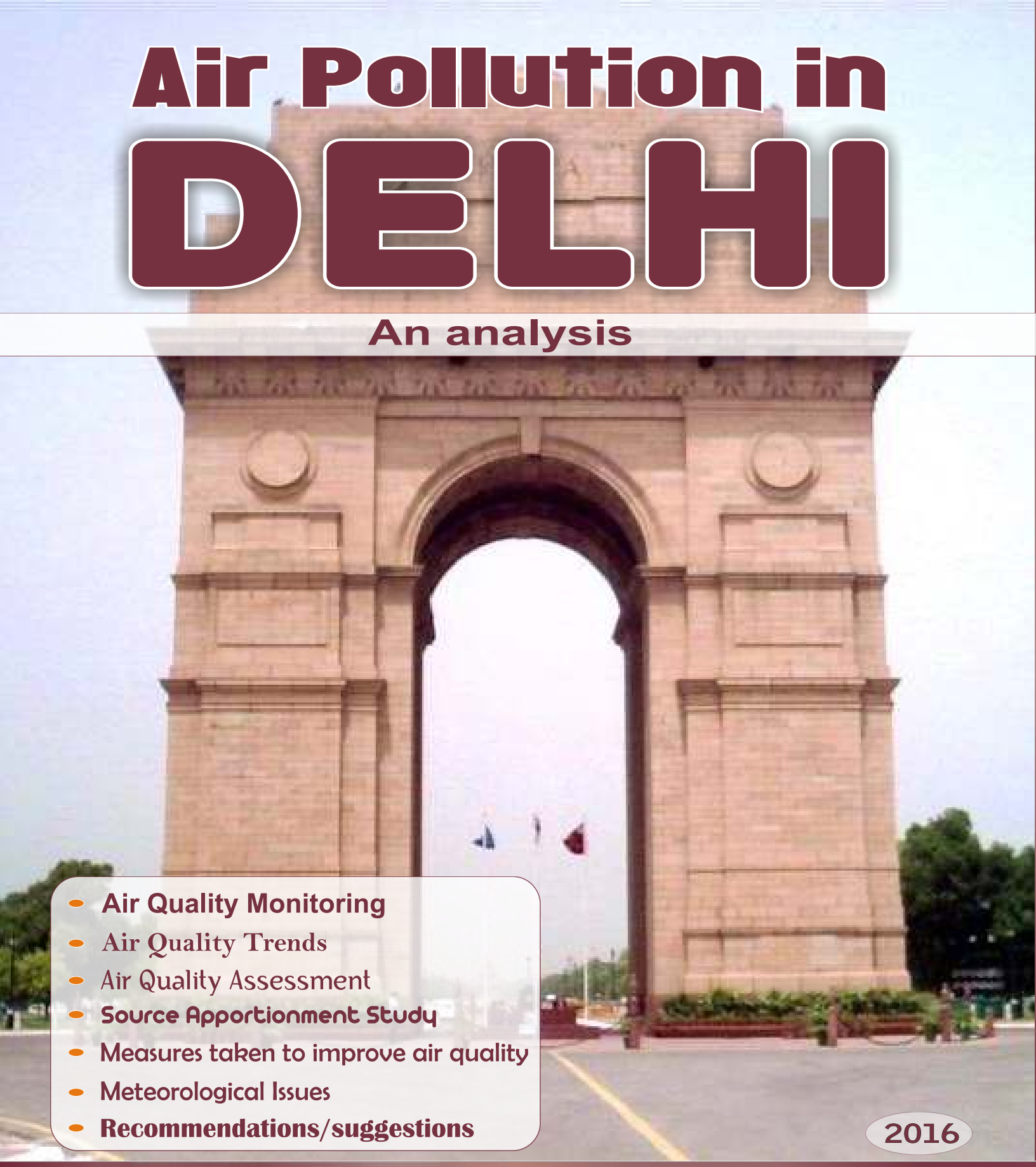
Air Pollution in DELHI

An analysis



- Air Quality Monitoring
- Air Quality Trends
- Air Quality Assessment
- Source Apportionment Study
- Measures taken to improve air quality
- Meteorological Issues
- Recommendations/suggestions

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INDEX

Air Pollution

1. Introduction

Pure air is a mixture of various gases such as nitrogen, oxygen, argon, carbon dioxide, and small amount of other gases in a fixed proportion. If the composition of air alters by any means; it is known as air pollution, which can lead to effects on human health, environment, and other living creatures. According to The Air (Prevention and Control of Pollution) Act, 1981, "air pollution is the presence of any solid, liquid, or gaseous substance in the atmosphere in such concentration as may be or tend to be injurious to human beings or other living creatures or plants or property or environment".

Air pollution has now become a serious issue of concern and many of the countries in the world such as Pakistan, Iran, India, UAE, and China *etc*. are formulating strategies to deal with it. There are a number of factors responsible for the altered composition of the ambient air which can be mainly categorised as natural causes and anthropogenic (man-made) causes.

2. Sources of air pollution

Natural sources: Natural sources of air pollution include volcanic activity, dust, sea-salt, forest fires, lightening, soil outgassing *etc.*

Anthropogenic sources: These sources include stationary point sources (*e.g.* emission from industries), mobile sources (*e.g.* vehicular emission, marine vessels, airplanes *etc.*), waste disposal landfills, open burning *etc.*

3. Air pollutants

The substances which are responsible for causing air pollution are called as air pollutants.

3.1 Classification of air pollutants

Air pollutants can be categorized by various means:

3.1.1 On the basis of source of origin

1. Natural air pollutants: Natural air pollutants are emitted from natural sources such as volcanic activity, dust, sea-salt, forest fires, lightening, soil outgassing *etc.*
2. Anthropogenic air pollutants: These pollutants include the emissions from stationary point sources (*e.g.* emission from industries), mobile sources (*e.g.* vehicular emission, marine vessels, airplanes *etc.*), waste disposal landfills, controlled burning *etc.*

3.1.2 On the basis of method of origin

1. Primary air pollutants: Those pollutants which are emitted directly from any emission source in the atmosphere are termed as primary air pollutants, *e.g.* sulphur dioxide (SO_2), carbon monoxide (CO), lead (Pb), ammonia (NH_3) *etc.*
2. Secondary air pollutants: Secondary pollutants are formed by the reactions between primary air pollutants and normal atmospheric constituents. In some of the cases, these pollutants are formed by utilizing the solar energy, *e.g.* ozone, peroxyacetylnitrate (PAN), smog *etc*.

3.1.3 On the basis of chemical composition

1. Organic air pollutants: Examples are hydrocarbons, aldehydes, ketones, amines, and alcohols *etc.*
2. Inorganic air pollutants: Examples are carbon compounds (CO and carbonates), nitrogen compounds (NO_X and NH_3), sulphur compounds (H_2S, SO_2, SO_3, H_2SO_4), halogen compounds (HF, HCl *etc.*), flyash, silica *etc.*

3.1.4 On the basis of state of matter

1. Gaseous air pollutants: Pollutants which are in the form of gas are termed as gaseous air pollutants, *e.g.* SO_2, NO_X, O_3, CO *etc.*
2. Particulate air pollutants: Particulate air pollutants or particulate matter (PM) can be defined as the microscopic solid or liquid matter suspended in the earth's atmosphere. There are various subtypes of particulate matter:

a. Total suspended particulate matter (TSPM): The concentration of particulate matter which is obtained when a high volume bulk sampling is done on a filter substrate. It includes particles of all sizes.
b. PM_{10}: These are the particles less than 10 µm in diameter
c. $PM_{2.5}$: These are the particles less than 2.5 µm in diameter
d. $PM_{1.0}$: These are the particles less than 1 µm in diameter

Particles which lie between 10µm to 2.5µm are termed as 'coarse particles' whereas particles with diameter less than 2.5µm are called as 'fine particles'. Fine particles also include ultra-fine particles of size less than 0.1 µm ($PM_{0.1}$).

3.2 Criteria pollutants

According to the US Environmental Protection Agency (EPA), criteria pollutants are the particulate air pollutants, photochemical oxidants and ground level ozone, carbon monoxide, sulphur oxides, nitrogen oxides, and lead. These pollutants are responsible for causing serious health hazards, environmental hazards such as smog, acid rain, and property damage *etc*. These pollutants are termed as criteria pollutants because as per the Clean Air Act, 1963, US EPA sets national ambient air quality standards for them based on the human health-based and/or environmentally-based criteria (characterizations of scientific information). The sources and effects of criteria pollutants are shown in the Table 1.

Table 1: Criteria air pollutants – emission sources and major effects

Criteria pollutants	Emission sources		Major effects	
	Natural sources	**Anthropogenic sources**	**Health effects**	**Environmental effects**
Sulfur dioxide (SO_2)	Volcanic emissions	Burning of fossil fuels, metal smelting, petroleum refining *etc.*	Respiratory problems, heart and lung disorders, visual impairment	Acid rain
Nitrogen dioxide (NO_2)	Lightning, forest fires *etc.*	Burning of fossil fuels, biomass and high temperature	Pulmonary disorders, increased susceptibility to	Precursor of ozone formation in troposphere, aerosol

		combustion processes	respiratory infections	formation
Particulate matter (PM)	Windblown dust, pollen spores, photochemically produced particles	Vehicular emissions, industrial combustion processes, commercial and residential combustion, construction industries	Respiratory problems, liver fibrosis, lung/liver cancer, heart stroke, bone problems	Visibility reduction
Carbon monoxide (CO)	Animal metabolism, forest fires, volcanic activity	Burning of carbonaceus fuels, emission from IC engines	Anoxemia leading to various cardiovascular problems. Infants, pregnant women, and elderly people are at higher risk	-
Ozone (O_3)	Present in stratosphere at 10 – 50 km height	Hydrocarbons and NO_X upon reacting with sunlight results in O_3 formation	Respiratory problems, asthma, bronchitis *etc.*	O_3 in upper troposphere causes green house effects, harmful effects on plants as it interferes in photosynthesis and results in death of plant tissues since it assists in the formation of Peroxyacetylnitate (PAN)

Lead (Pb)	-	Metal processing plants, waste incineration, automobile exhausts, lead-acid batteries, industrial effluents *etc*.	Serious effects on central nervous system since it is absorbed rapidly in blood stream, anemia, toxic for soft tissues and bones	-

4. National Air Quality Monitoring Programme (NAMP)

Considering the serious impacts caused by air pollutants, their effective management becomes inevitable. Therefore, to monitor and control of various air pollutants, Central Pollution Control Board (CPCB) has been provided with various powers and functions under the Air (Prevention and Control of Pollution) Act, 1981. Subsequent to this, CPCB had launched a nationwide program *viz.* National Ambient Air Quality Monitoring Programme (NAAQM) in 1984, which has been renamed as National Air Quality Monitoring Programme (NAMP). The number of operating monitoring stations under NAMP has increased steadily to 614 by 2016 covering 254 cities across the nation (29 states and 5 UTs). Under this programme, there are 10 monitoring stations functioning in Delhi. Moreover, under the NAMP, three major pollutants *viz.* sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter (PM_{10}) have been identified for regular monitoring at all the locations. Other parameters like particulate matter ($PM_{2.5}$), carbon monoxide (CO), ammonia (NH_3), lead (Pb), ozone (O_3), benzene (C_6H_6), benzo(α)pyrene (B(α)P), arsenic (As), and nickel (Ni) are being monitored at selected locations and are slowly being added to the monitoring networks under NAMP.

5. Source apportionment study

To improve the air quality management system, there is also the need of knowing the particular source of pollution and its quantitative contribution to the ambient air quality. This can be done through the **source apportionment study**. There may be two ways for apportioning pollution, (i) A top-down approach starting with monitoring of pollution, and (ii) A bottom-up approach

starting with the activity data (like fuel consumption). Source apportionment study is based on tracking down the sources through receptor modeling and it helps in identifying the sources and extent of their contribution.

6. National Ambient Air Quality Standards (NAAQS)

To build-up a programme for the effective management of ambient air quality and to reduce the damaging effects of air pollution, development of national ambient air quality standards (NAAQS) is a pre-requisite. Central Pollution Control Board had adopted first ambient air quality standards on November 11, 1982 as per the Section 16(2) of the Air (Prevention and Control of Pollution) Act, 1981. These standards have been revised by CPCB in 1994, and later in 2009, which is shown in Table 2.

Table 2: National Ambient Air Quality Standards (NAAQS) – 2009 [1]

Pollutants	Time weighted average	Concentration in ambient air		Methods of measurement
		Industrial, residential, rural, and other areas	Ecologically sensitive area (notified by Central Government)	
Sulphur dioxide (SO_2), µg/m^3	Annual* 24 hours**	50 80	20 80	-Improved West and Gaeke -Ultraviolet fluorescence
Nitrogen dioxide (NO_2), µg/m^3	Annual* 24 hours**	40 80	30 80	-Modified Jacob & Hochheiser (Na-Arsenite) -Chemiluminescence
Particulate matter (< 10 µm) or PM_{10}, µg/m^3	Annual* 24 hours**	60 100	60 100	-Gravimetric -TOEM -Beta attenuation
Particulate matter (< 2.5 µm) or $PM_{2.5}$, µg/m^3	Annual* 24 hours**	40 60	40 60	-Gravimetric -TOEM -Beta attenuation
Ozone (O_3),	8 hours**	100	100	-UV photometric

µg/m^3	1 hour**	180	180	-Chemiluminescence -Chemical method
Lead (Pb), µg/m^3	Annual* 24 hours**	0.50 1.0	0.50 1.0	-AAS/ICP method after sampling on EPM 2000 or equivalent filter paper -ED-XRF using Teflon filter
Carbon monoxide (CO), mg/m^3	8 hours** 1 hour**	02 04	02 04	-Non Dispersive Infra Red (NDIR) spectroscopy
Ammonia (NH_3), µg/m^3	Annual* 24 hours**	100 400	100 400	-Chemiluminescence -Indophenol blue method
Benzene (C_6H_6), µg/m^3	Annual*	05	05	-Gas chromatography based continuous analyzer -Adsorption and desorption followed by GC analysis
Benzo(α)Pyrene (BaP) – particulate phase only, ng/m^3	Annual*	01	01	-Solvent extraction followed by HPLC/GC analysis
Arsenic (As), ng/m^3	Annual*	06	06	-AAS/ICP method after sampling on EPM 2000 or equivalent filter paper
Nickel (Ni), ng/m^3	Annual*	20	20	-AAS/ICP method after sampling on EPM 2000 or equivalent filter paper

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

** 24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be compiled with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note – Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigation.

Air Pollution in Delhi: An Analysis

Delhi, with an area of 1483 km^2 [2], is geographically located in North India within the latitude 28°24'17" and 28°53'00''N, and longitude 77°45'30'' and 77°21'30''E [3]. Delhi is jointly administered by the Central and State Government. As of 2011, Delhi inhabitates approximately 16.3 million people; thus becoming the second most populous city and second most populous urban agglomeration in India. Delhi is also the third largest urban area in the world. However, due to rapid development, Delhi is also facing serious challenges in terms of air pollution. To tackle the situation, Delhi has taken several steps to reduce the air pollution level during the last 10 years. However, more concerted efforts are still required to reduce the pollution level.

7. Air quality monitoring in Delhi

Air quality monitoring in Delhi is carried out through a number of air quality monitoring stations situated across the territory. The monitoring is undertaken by various organizations *viz.* Central Pollution Control Board (CPCB), Delhi Pollution Control Committee (DPCC), and System of Air Quality and Weather Forecasting and Research (SAFAR) of Indian Institute of Tropical Meteorology (IITM), Pune. As per the NAMP of CPCB, manual air pollution monitoring is carried out at Sarojini Nagar, Chandni Chowk, Mayapuri Industrial Area, Pritampura, Shahadra, Shahzada Bagh, Nizamuddin, Janakpuri, Siri Fort, and at ITO as traffic intersection station across the Delhi. Apart from the manual air monitoring stations, continuous ambient air quality monitoring (CAAQM) stations of CPCB are also located at 11 locations *viz.* Anand Vihar, Civil Lines, DCE, Dilshad Garden, Dwarka, IGI Airport, ITO, Mandir Marg, Punjabi Bagh, R.K. Puram, and Shadipur across the city (Figure 1). DPCC has air quality monitoring stations at 6 locations *viz.* Civil lines, Punjabi Bagh, Mandir Marg, Anand Vihar ISBT, IGI Airport, and R.K. Puram. In addition to CPCB and DPCC, there are 8 monitoring stations of SAFAR at various locations in Delhi, as shown in figure 1, to monitor the ambient air quality on real time basis. The data obtained from these stations are also used for the determination of national air quality index.

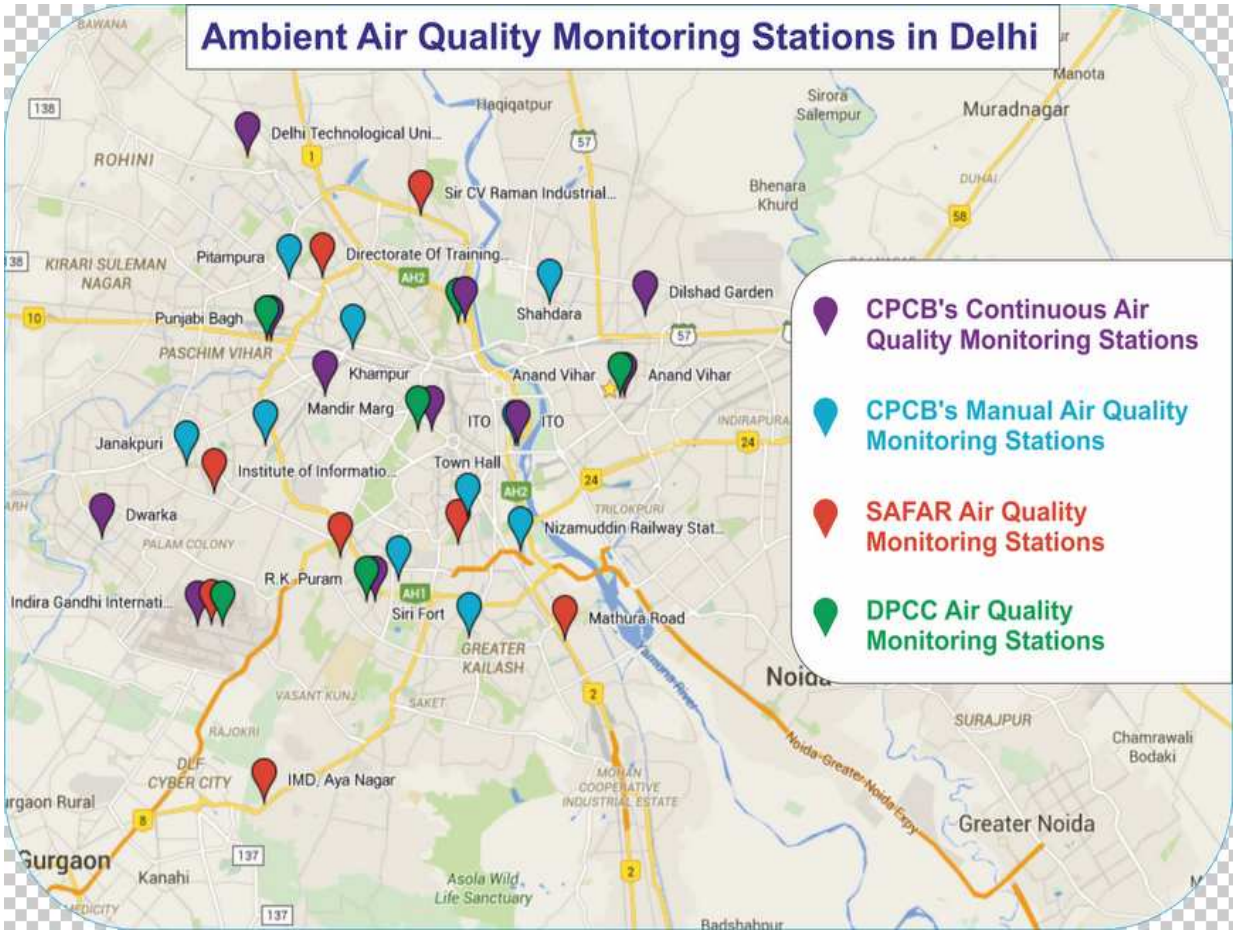

Figure 1. Air quality monitoring stations of various organizations in Delhi

8. Air quality trends in Delhi

Air quality for the three major pollutants (SO_2, NO_2, and PM) is determined to understand the trend of pollution in Delhi during recent years. On the basis of annual average concentration of pollutants, air quality trend has been seen for the years 2009 – 2015 along with the comparison with existing national ambient air quality standards (NAAQS), 2009. It can be seen in figure 2 that among the three pollutants *viz.* SO_2, NO_2, and PM_{10}, the concentration of NO_2 and PM_{10} are far exceeding the prescribed standard limits. The concentration of SO_2 is within the standard limits. However, as far as NO_2 is concerned, continuous rise in concentration was observed in past 7 years. Moreover, the problem of particulate matter (PM_{10}) is more critical. Since 2009, approximately 258 – 335% rise has been observed in PM_{10} concentration compared to the

standards. Although the concentration has been slightly lowered down since 2011, but it is still far above the safe limits.

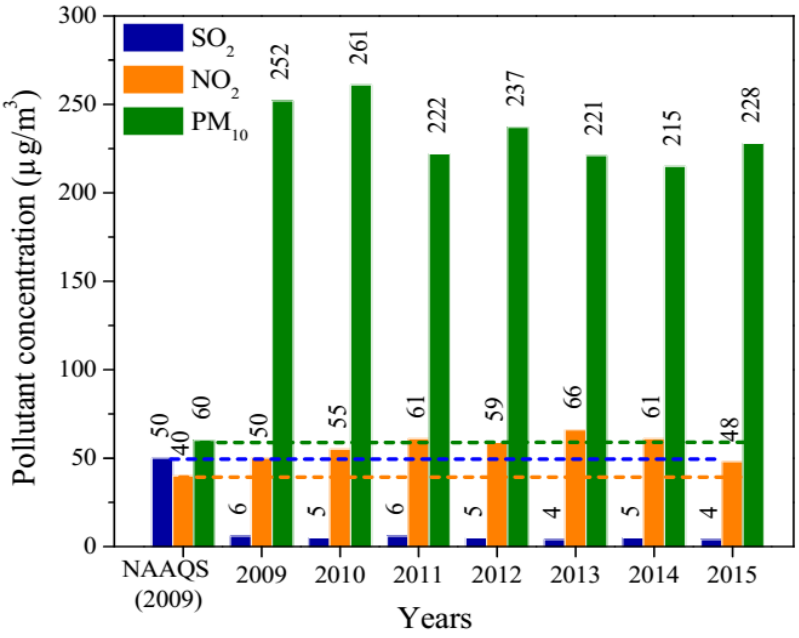

Figure 2. Air quality trends in Delhi (2009 – 2015) based on manual air quality monitoring stations *(Source:CPCB)*

Apart from the annual average data, continuous air monitoring data of Delhi is also recorded by CPCB at 11 locations, as stated above. Out of 11, the data of 8 operating monitoring stations for the period of December 1 – 10, 2015 is shown in figure 3. This graph reflects the average values of the SO_2, NO_2, and $PM_{2.5}$ concentration for the period of 10 days. Since, the standards for ambient air quality are only suitable for the data based on time weighted average of annual and 24 hours/8 hours/1 hour, the comparison of the data of 10 days average with the standards is not feasible. However, it is quite evident from the graph that concentration of NO_2 and $PM_{2.5}$ is very high. Among all the locations, NO_2 and $PM_{2.5}$ concentration is least at Dwarka. The concentration of particulate matter ($PM_{2.5}$) at all the other locations needs to be curbed down urgently as the values recorded are very high. Moreover, the concentration of SO_2 is acceptable at all the locations across Delhi.

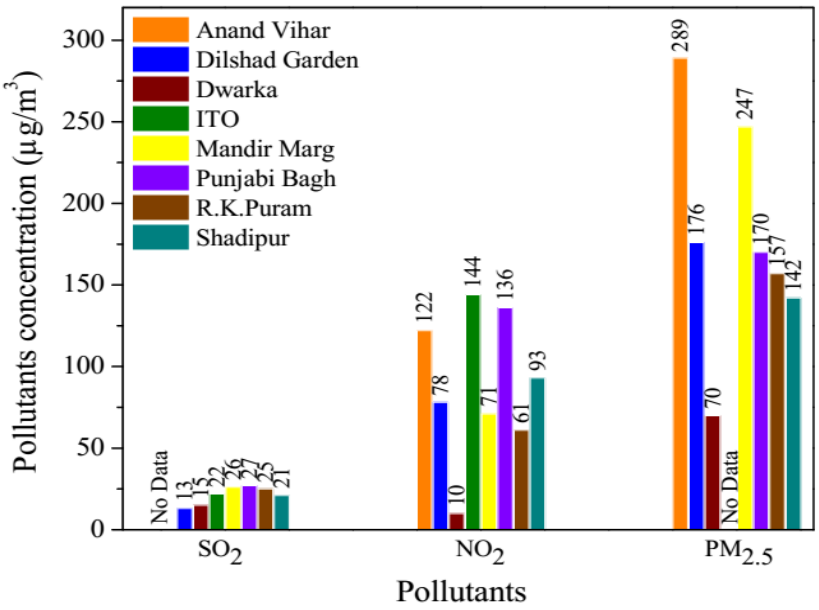

Figure 3. Air quality trends in Delhi (Dec. 1 – 10, 2015) based on the data of continuous air quality monitoring stations (*Source:CPCB)*

8.1 Air quality index (AQI) in Delhi

Air quality index (AQI) is the tool to monitor air quality in major urban cities across the country on a real – time basis and to enhance public awareness. The AQI developed is based on human exposure and health effects and may not be strictly applicable to ecologically sensitive areas. Various pollutants which are considered for AQI determination are PM_{10}, $PM_{2.5}$, NO_2, O_3, CO, SO_2, NH_3, and Pb. The data obtained from the online air quality monitoring stations is the most suitable for the AQI determination as information on AQI can be generated in real time. For the ease of understanding, colour bands are used to represent various AQI bands.

AQI	Associated health impacts
Good (0 – 50)	Minimal impact
Satisfactory (51 – 100)	Minor breathing discomfort to sensitive people
Moderately polluted (101 – 200)	Breathing discomfort to people with lungs, asthma, and heart diseases
Poor (201 – 300)	Breathing discomfort to most people on prolonged exposure
Very poor (301 – 400)	Respiratory illness on prolonged exposure
Severe (401 – 500)	Affects healthy people, and seriously impacts those with existing diseases

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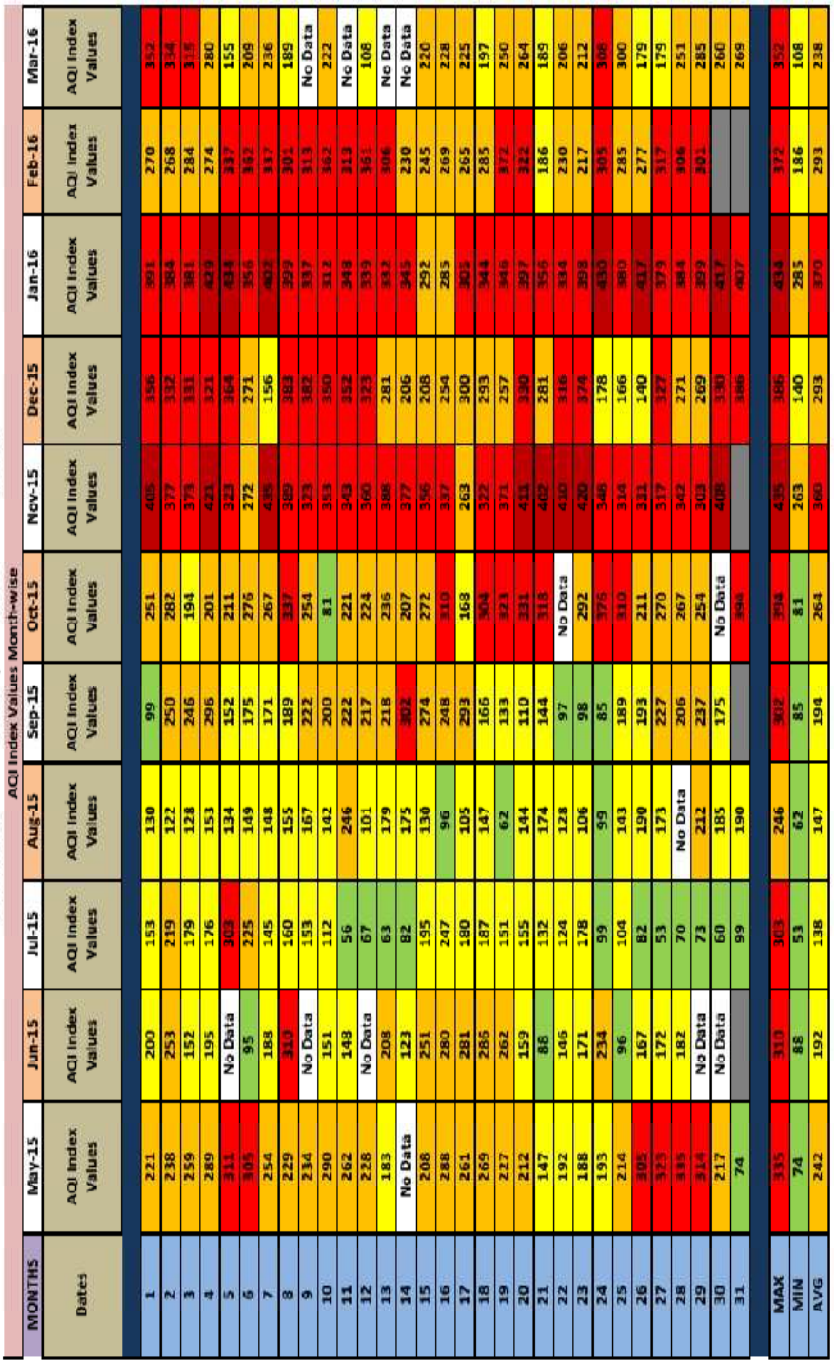


Central Pollution Control Board

Air Laboratory

Month wise Air Quality Index Values of Delhi

AQI Index Values Month-wise

MONTHS	May-15	Jun-15	Jul-15	Aug-15	Sep-15	Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16
Dates	AQI Index Values	AQI Index Values	AQI Index Values	AQI Index Values	AQI Index Values	AQI Index Values	AQI Index Values	AQI Index Values	AQI Index Values	AQI Index Values	AQI Index Values
1	221	200	153	130	99	251	405	356	991	270	352
2	238	253	219	122	250	282	377	332	384	268	334
3	259	152	179	128	246	194	373	331	381	284	318
4	289	195	176	151	296	201	421	321	429	274	280
5	311	No Data	303	134	152	211	323	364	434	337	155
6	305	95	225	149	175	276	272	271	356	362	209
7	254	188	145	148	171	267	436	156	402	317	236
8	229	310	160	155	189	337	389	383	399	301	189
9	234	No Data	153	167	222	254	373	382	337	313	No Data
10	290	151	112	142	200	81	393	360	312	362	222
11	262	148	56	246	222	221	343	352	348	313	No Data
12	228	No Data	67	101	217	224	360	323	339	361	108
13	183	208	63	179	218	236	388	281	332	306	No Data
14	No Data	123	82	175	302	207	377	206	345	230	No Data
15	268	251	195	130	274	272	396	208	292	245	220
16	288	280	247	96	248	310	337	254	285	269	228
17	261	281	180	105	293	168	263	300	302	265	225
18	269	286	187	147	166	304	322	293	344	285	197
19	227	262	151	62	133	321	371	257	346	372	250
20	212	159	155	144	110	331	411	330	397	322	264
21	147	86	132	174	144	318	402	281	355	186	185
22	192	146	124	128	97	No Data	410	316	334	230	206
23	188	171	178	106	98	292	420	374	398	217	212
24	193	234	99	99	85	376	346	178	430	305	306
25	214	96	104	143	189	310	314	166	380	285	300
26	305	167	82	190	193	211	331	140	417	277	179
27	323	172	53	171	227	270	317	327	373	317	179
28	335	182	70	No Data	206	267	342	271	384	306	251
29	314	No Data	73	212	237	254	303	269	399	301	285
30	217	No Data	60	185	175	No Data	408	330	417		260
31	74		99	190		304		386	407		269
MAX	335	310	303	246	302	394	435	386	434	372	352
MIN	74	88	53	62	85	81	263	140	285	186	108
AVG	242	192	138	147	194	264	360	293	370	293	238

Good	Satisfactory	Moderate	Poor	Very Poor	Severe
(0-50)	(51-100)	(101-200)	(201-300)	(301-400)	(>401)

As per the AQI bulletin (January 2016), $PM_{2.5}$ is the prominent pollutant in Delhi and neighbouring areas which continuously exceeds the standard [4]. In the months of May – October, the AQI shows that air quality is moderately polluted. However, after October, the situation becomes worse. The average AQI in the month of January was recorded as very poor to severe. Maximum value of $PM_{2.5}$ is recorded as 296 $\mu g/m^3$ during January 2016 (at IHBAS, Dilshad Garden) which is far above the prescribed standard limit (60 $\mu g/m^3$). There are a number of sources responsible for the particulate matter such as transport, road dust, gaseous combustion *etc*. Moreover, the sources / natural causes also get influenced by the meteorological conditions prevailing in the neighbouring areas.

9. Air quality assessment in Delhi

For the ease of understanding the pollution level, air quality can be categorised into four broad categories on the basis of exceedance factor (EF), *viz.* the ratio of annual mean concentration of a pollutant and its respective standard. Accordingly, the air pollution can be categorized into 4 types as:

- Critical pollution (C) : $EF \geq 1.5$;
- High pollution (H) : $1.0 \leq EF < 1.5$;
- Moderate pollution (M) : $0.5 \leq EF < 1.0$; and
- Low pollution (L) : $EF < 0.5$

Based on the data of SO_2, NO_2, and PM_{10}, the exceedance factors are calculated which is shown in figure 4. It is evident from the figure that pollution level for SO_2 is low. The pollution level in case of NO_2 is high along with critical in few of the years. Moreover, the pollution level crosses critical level for PM_{10} in all the years. This indicates that immediate attention is needed to curb the particulate matter.

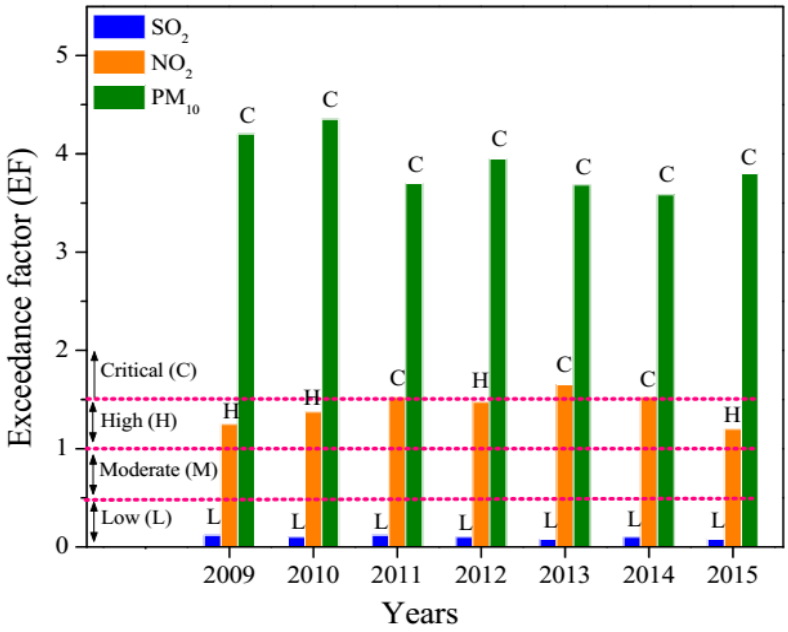


Figure 4. Pollution level based on exceedance factor (EF) of SO_2, NO_2, and PM_{10} in Delhi

10. Source apportionment study in Delhi

The study shows that the concentration of pollutants is continuously on the rise, especially in the case of particulate matter, where pollution level is critical. Therefore, source apportionment study for the particulate matter has been undertaken for assessing the contribution of various pollution sources for the PM_{10} and $PM_{2.5}$. In case of Delhi, the survey has been conducted by IIT Kanpur in coordination with Government of NCT of Delhi during winter and summer seasons at six characteristic locations – Dwarka (residential), Rohini (residential and industrial), Okhla (industrial), Vasantkunj (residential-cum-commercial), Dilshad garden (industrial), and Pusa road (residential-cum-commercial), for assessing the contribution of various pollution sources for the PM_{10} and $PM_{2.5}$. The idea of sampling in winter and summer months is influenced by the fact that winter conditions provide low dispersion and high concentrations of pollutants while during the summer months, meteorology gets improved leading to better dispersion conditions for pollutants. Based on the study, following information can be summarized:

PM_{10}: At all the locations, the major sources for PM_{10} during winter months are biomass burning, vehicular emission, soil and road dust, coal and flyash, secondary particles *etc*. in

different proportions. Secondary particles originate from precursor gases such as, SO_2 and NO_2. Vehicles and power plants are largely responsible for NO_2 emission, while SO_2 emission is mainly attributed by large power plants and refineries situated in the upwind direction of Delhi. Apart from this, construction materials are also responsible for PM_{10}.

During summer months, soil and road dust, coal and flyash, secondary particles, solid waste burning, and vehicular emissions are largely responsible for PM_{10}, along with minor contribution from construction activities. Role of industrial pollution in the overall concentration of PM_{10} is < 1% at all the locations.

$PM_{2.5}$: For the $PM_{2.5}$, secondary particles, vehicular emissions, biomass burning, soil and road dust, and solid waste burning are largely responsible in winter months. Moreover, coal and flyash, soil and road dust, secondary particles are the major factors responsible for $PM_{2.5}$ during summer months along with the other sources. Industrial pollution contributes to <1 – 2% at all the locations. Large amount of flyash and dust during summer months may be due to high wind speed and high temperature leading to extremely dry conditions which make dust airborne. Further, dust storms may also result in the re-suspension of flyash and road/soil dust.

11. Conclusion

Based on the above observations, it can be said that the air of Delhi is polluted *esp.* in terms of particulates. According to a study, vehicular pollution alone contributes about 72% of the total air pollution load in Delhi as estimated using emission factor and activity-based approach recommended by IPCC [5]. However, present study finds that it is not only the vehicular pollution, rather, domestic pollution, industrial emission, road dust, and garbage burning also have a large share in Delhi's total pollution load. Furthermore, construction of infrastructure including large residential complexes potentially contributes to the Delhi's air pollution load.

Study also finds that the concentration of SO_2 is well under control. This is due to phasing out of diesel driven buses, reduction of sulphur content in diesel by about 90%, and implication of Bharat Stage IV norms in vehicles of Delhi. The major cause of rising NO_2 concentration in Delhi is increased traffic load. In atmosphere, the combination of nitric oxide (NO), ozone (O_3), and hydrocarbons leads to the formation of NO_2. Therefore to minimize the NO_2 pollution, all

the three components involved in its formation needs to be targeted. To substantiate the findings, trend of increasing vehicular usage is shown in figure 5. Since 2005 – 06 to 2014 – 15, 82.75% increase can be noted in the number of registered vehicles in Delhi. Moreover, the excessive usage of cars and motor cycles are the pertinent causes for rising vehicular pollution load. This corroborates the cause of increasing NO_2 as well as particulate matter concentration. Particulate matter (PM_{10} and $PM_{2.5}$) emanates especially from the vehicular exhausts; particularly diesel vehicles, road dust, and industrial activities such as combustion processes, construction activities *etc*.

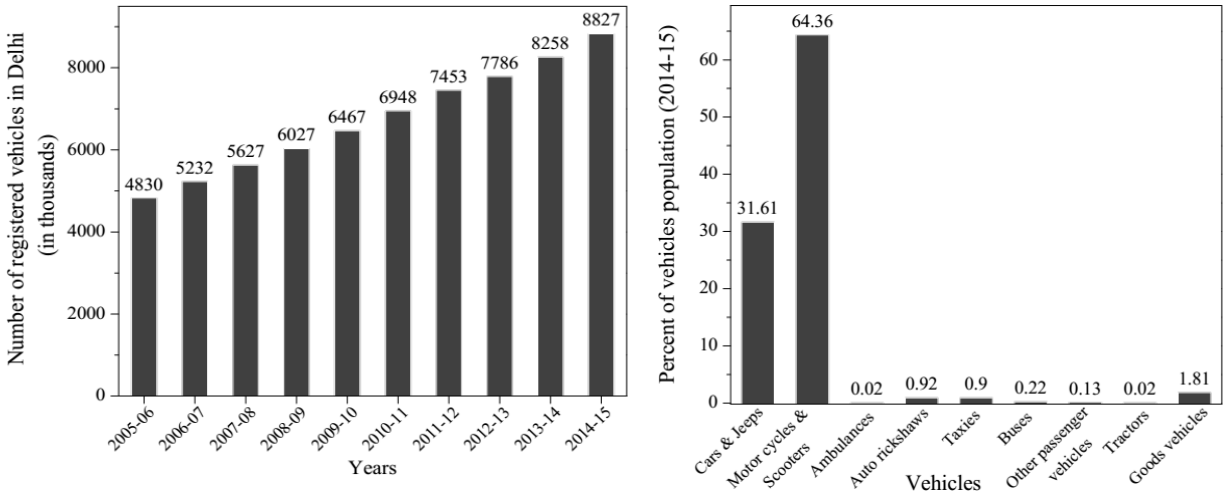


Figure 5. Traffic load in Delhi

(Source:Economic survey of Delhi 2014 – 15)

Tremendous growth of industrial sector is also responsible for pollution. As per the report of Economic Survey of Delhi 2014-15 [6], there are 8.93 lakhs total industrial establishments operating in Delhi according to 6th Economic Census 2013, which is 18.35% more than the number of establishments according to 5th Economic Census 2005. In many of the industries, installed air pollution control devices are found in idle conditions which lead to the emission of pollutants directly into the atmosphere without any filtration. Further, construction of short chimneys also restricts the polluting gases to escape into the upper layers of the atmosphere.

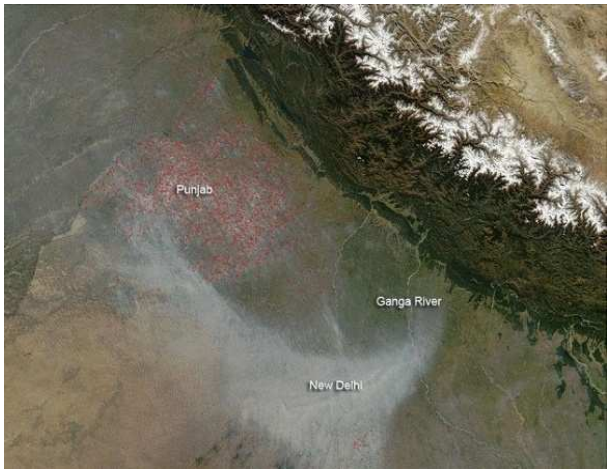
Traffic congestion on the roads, although underestimated, is another very important factor as far as air pollution is concerned. As it is evident from figure 5, cars and jeeps are responsible for a major share of Delhi's vehicular load, their congestion on the roads create nuisance. Moreover, 4-wheelers also need a lot of space for parking. This further reduces the space on the roads

leading to high frequency of traffic jams. To reduce the pollution at traffic intersection points, time clocks have been installed at most of the points in the city. But it has been observed that hardly any vehicle owner switches off the engine during that period. Thus fuel is continuously burned at a fixed place which further adds up in the atmospheric pollution load.

Meteorological issues

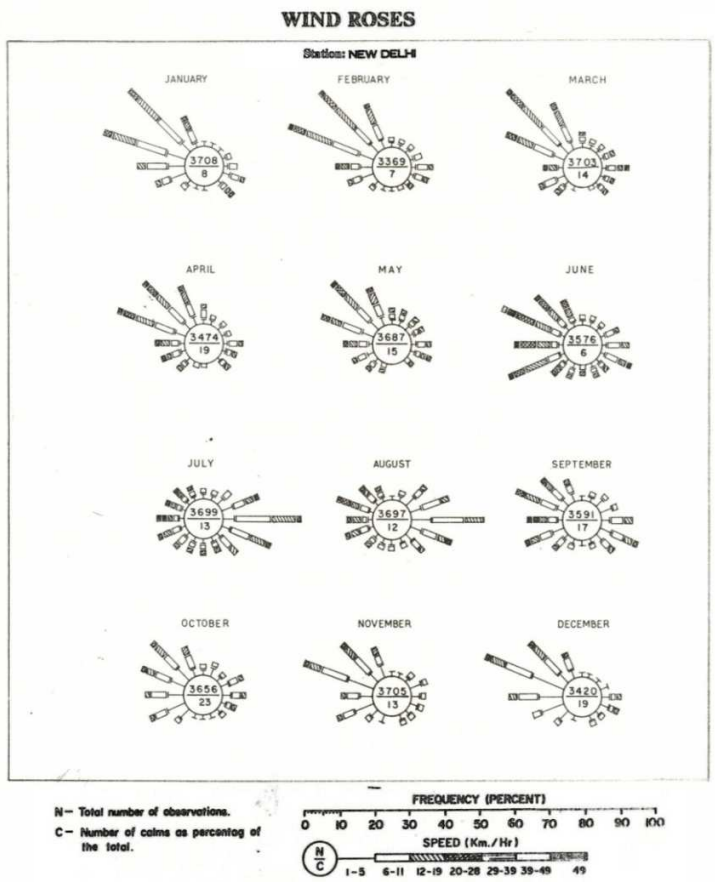
Apart from the vehicular and industrial emissions, local climatic and seasonal factors also affect the air quality of Delhi. Delhi, being a land-locked territory, is unable to dilute its emission using the moderating effects of sea; the opportunity availed by other metropolitan cities, such as Mumbai, Kolkata, and Chennai. Surrounded by the regions of varied climate, Delhi also represents a great variability in the seasonal patterns. At its west, there is Great Indian desert (Thar desert) of Rajasthan while in the north and east direction there are cool hilly regions. At its south, there are central hot plains. Thus, Delhi is located in the subtropical belt with extremely scorching summers, moderate rainfall, and chilling winters.

The winters are extremely important in Delhi as it is dominated by cold, dry air, and ground based inversion with low wind conditions, which are responsible for increasing concentration of pollutants [7, 8]. High concentration of pollutants is trapped close to earth's surface bacause a layer of warm air acts as a lid on top of this layer. Moreover, dense smog formation during winter months has also been witnessed in Delhi, the reason of which is vehicular pollution as well as the prevailing meteorological conditions in the months of December and January. Similarly, wind pattern also affects the weather conditions. According to a study, during the autumn and winter months, approximately 500 million tons of crop residues are burnt in Indo-Gangetic plains [9]. The image in figure 6 (a) shows the biomass burning in the state of Punjab. The wind blows from India's north and north-west to the east direction during winters as depicted from the wind-rose diagram of Delhi (Figure 6 b). This ultimately results in combination of pollution and fog, leading to heavy smog formation in Delhi *esp.* during winters. In summers, although there is no inversion phenomenon, still the air quality gets deteriorated because of the increased concentration of PM_{10}, which is due to dust. However, it becomes toxic due to the coating of polluted emissions from various sources. Nevertheless, during rainy season pollution level goes down due to dust suspension. Thus, air pollution in Delhi is a trans-boundary and climate induced phenomenon.



(a) Image showing the biomass burning in Punjab (red dots show the fires and plume)

Source: NASA



(b) Wind-rose diagram of Delhi

Source: Indian Meteorological Department, Ministry of Earth Sciences

Figure 6. Effect of meteorological conditions on the air quality of Delhi

12. Measures adopted to improve the air quality of Delhi

12.1 Recent initiatives

12.1.1. Odd even scheme

An initiative (on trial basis) has been taken by Govt. of NCT of Delhi to curb the air pollution by applying 'Odd-even scheme' on the 4-wheelers plying on the roads (exempting a few) from Jan. 1st – 15th and Apr. 15th – 30th, 2016. The scheme proposed to run the vehicles as per their registration numbers on alternate days. Vehicles having registration number ending with an odd digit were allowed to run on the odd dates and *vice-versa*. The ultimate aim of the scheme was to reduce the number of vehicles from the roads of Delhi.

To assess the effect of this scheme on the air quality of Delhi, an analysis was done using the data collected by CPCB from 8 operational CAAQMS (4 of CPCB and 4 of DPCC) and 7 manual stations of CPCB [10]. The pollutants studied include PM_{10}, $PM_{2.5}$, SO_2, benzene, O_3, NO_2, and CO. The study reveals that during the odd-even period, there was marked increase in the pollutants concentration as compared to 'pre – odd even period', for *e.g.* there can be seen 13 – 39% rise in PM_{10} concentration, 52 – 70% rise in $PM_{2.5}$, and 37 – 80% rise in NO_2 concentration [10]. Other pollutants were also found to be increasing. No definite reason could be determined for this, however, unclear trend and wide fluctuations of air pollutants can be attributed to the meteorological factors and emissions from pollution sources other than transportation. Moreover, the odd-even scheme effect might also be diluted due to coverage of very few vehicles under this scheme.

12.1.2. Court directions

A number of directions under Section 18(1)(b) of the Air (Prevention and Control of Pollution) Act, 1981 regarding prevention, control or abatement of air pollution and improvement of ambient air quality in Delhi and National Capital Region (NCR) were issued to U.P. Pollution Control Board, Haryana Pollution Control Board, Delhi Pollution Control Committee, and Jhalana Institutional Area, Jaipur, Rajasthan on Dec. 29th, 2015. The directions included various significant issues such as control of vehicular emission, control of road dust and other fugitive

emission, control of air pollution from biomass burning, control of industrial air pollution, control of air pollution from construction and demolition activities, *etc*.

12.1.3. A control room has been set up in CPCB to facilitate review of levels of air pollution and monitoring ambient air quality in Delhi and National Capital Region (NCR).

12.1.4. Prohibition on entry of overloaded and non-destined trucks in Delhi and imposition of 'Green Tax'.

12.1.5. The Delhi Government has launched car-free day campaign '*Ab Bus Karein*' since 22nd October 2015 to be observed on 22nd day of every month.

12.1.6. Air Quality Index (AQI)

To reduce the health impacts of the pollutants, dissemination of the information related to air quality is also equally important so that the preventive measures can be adopted. In view of this, CPCB and the Ministry of Environment, Forest, and Climate Change (MoEF & CC) initiated the project on national Air Quality Index (AQI) to strengthen air quality information dissemination system for larger public awareness and their participation on air quality management [11]. The index was launched by Hon'ble Prime Minister in April 2015 starting with 14 cities. At present, AQI is determined at 23 locations across the country, including Delhi, Faridabad, and Gurgaon.

12.1.7. For the on-line continuous (24x7) air pollution monitoring, out of 2800 major industries, 920 industries have installed the devices; and others are in process of installation.

12.2. Other initiatives

12.2.1. Stringent provision for ash content in coal for thermal power plants.

12.2.2 Stringent industrial emission standards formulated and notified for public / stakeholders' comments.

12.2.3. Construction of Eastern and Western Expressways for by-passing non-destined traffic to Delhi has been given high priority for completion.

12.2.4. Regular co-ordination meetings to discuss air pollution control in NCR adopting air-shed approach.

12.2.5. Revision of rules for handling and management of municipal waste.

12.2.6. Revision of rules pertaining to construction and demolition waste.

12.2.7. Ban on burning of leaves/ biomass in Delhi.

12.2.8. Fuel quality standards (Bharat Stage – I, II, III, and IV) are introduced.

12.2.9. Pollution under control (PUC) certificate with three month validity is introduced.

12.2.10. Introduction of compressed natural gas (CNG) for commercial vehicles phased out from 1998.

12.2.11. Metro rail transit system for rapid mass transport is introduced.

12.2.12. Construction of fly-over and sub-ways for smooth flow of traffic.

12.2.13. Time clocks installations at red lights.

12.2.14. Route diversion of inter-state buses.

12.2.15. Benzene (a carcinogen) in gasoline reduced from 5% (April 1996) to 1% (November 2000).

12.2.16. Sulphur content in diesel reduced from 0.5% (April 1996) to 0.05% in April 2000.

12.2.17. Restrictions imposed in operation of goods vehicles during day time from August 1999.

12.2.18. Unleaded petrol introduced in NCR in September 1998.

12.2.19. Catalytic converter in passenger cars introduced in April 1995.

13. Recommendations/suggestions to improve the air quality of Delhi

Even after taking a number of initiatives, the pollution in Delhi is rising to a great extent. To tackle the problems and to reduce health risks generated due to air pollution, immediate steps need to be taken. Therefore, following issues need to be judiciously addressed at the earliest.

1. For the development of the country, establishment of new industrial units can not be downgraded; however, effective control measures of pollution, and proper installation of air pollution control devices and their smooth functioning must be ensured before the establishment of any industry. After the establishment of industry, proper functioning of the installed controlling units must also be ensured.
2. Emission from construction industries / activities can be minimized by adopting best practices such as; use of water sprays for dust suppression, creating ridges to prevent dust, compaction of disturbed soil, prevention of dumping of earth materials along road side *etc*.
3. Restrictions may be imposed over the number of vehicles owned by an/a individual/family.

4. Fines should be imposed for the parking of vehicles on the roads.
5. Provision of parking space in any commercial establishment/shopping mall/parks/residential apartments should be mandatory.
6. There should be strict restrictions on old polluting vehicles and subsidies may be given on the vehicles running on cleaner fuels.
7. There should be strict checking of PUC certificates.
8. There should be uniformity in the fuel quality standards used across the country.
9. There should be more space for pedestrians and two wheeler vehicles on the roads.
10. Up-gradation of public transport is necessary by improving service quality, enhancing the number of buses, and better road management.
11. Improvement in traffic signal co-ordination for continuous traffic flow to reduce traffic jam and idling time can also help to minimize pollution.
12. Corporate firms/ government offices may draw up an action plan to have bus/cab service for their employees with reasonable rates.
13. Idea of working in different shifts for corporate firms / government offices to minimize traffic at peak hours can be introduced.
14. Strict rules should be imposed for proper dumping and disposal of solid waste, since unregulated burning results in pile-up of smoke and particulate matter in concentrated form at one place. Regular functioning of all the installed solid waste treatment facilities must also be ensured.
15. Vegetation cover should be increased along the highways, road dividers, and busy traffic intersection points.
16. Mass awareness should be increased through electronic and print media for all age groups towards sustaining the environment and to reduce pollution. Public should also be motivated for the use of public transport.
17. Research and development for the battery-run buses/cars *etc.* needs to be promoted.

References:

1. The Gazatte of India, Part III – Section 4, NAAQS CPCB Notification, 2009.
2. Economic survey of Delhi (2004), Planning Department, Government of National Capital Territory of Delhi, 6th level, New Delhi (India).
3. Air quality trends and action plan for control of air pollution from seventeen cities, CPCB – NAAQM Series (NAAQMS/29/2006 – 07).
4. Air quality bulletin – January 2016, Air Lab, CPCB, available at http://www.cpcb.nic.in/AQI_Bulletin_Jan2016_AirLab.pdf.
5. Sindhwani R. and Goyal P. (2014), Assessment of traffic-generated gaseous and particulate matter emissions and trends over Delhi (2000 – 2010), Atmospheric Pollution Research, 5, 438 – 446.
6. Economic survey of Delhi report 2014 – 15.
7. Anfossi D., Brusasca G., and Tinarelli G. (1990), Simulation of atmospheric diffusion in low windspeed meandering conditions by a Monte Carlo dispersion model, II Nuovo Cimento C, 13(6), 995 – 1006.
8. Air quality status and trends in India, CPCB – NAAQM Series (NAAQMS/14/1999 – 2000).
9. Sharma A.R., Kharol S.K., Badrinath K.V.S., and Singh D. (2010), Impact of agriculture crop residue burning on atmospheric aerosol loading – a study over Punjab state, India, Annales Geophysicae, 28, 367 – 379.
10. Assessment of impact of Odd – Even Scheme on air quality of Delhi, CPCB, available at http://cpcbenvis.nic.in/pdf/CPCB%20Report%20on%20Odd-Even%20Scheme.pdf and http://cpcbenvis.nic.in/pdf/CPCB%20Report%20on%20Odd-Even%20Scheme(15th-30th%20April%202016)%20in%20Delhi%20-%20Phase%20II.pdf.
11. National air quality index, CPCB – CUP Series (CUPS/82/2014 – 15).

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