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An Analysis of the Annual and Seasonal Trends of Air Quality Index of Delhi

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Abstract The Air Quality Index (AQI) is an index for reporting daily air quality. A study on the annual and seasonal variations of Air Quality Index over a period of 9 years (1996–2004) based on daily averaged concentration data of criteria air pollutants has been conducted for Delhi. An attempt has been made to quantify the changes in the AQI on annual and seasonal (winter, summer, monsoon and post monsoon) basis for 9 years. Measurements for the seven monitoring sites (Nizamuddin, Ashok Vihar, Shahzada Baug, Shahadara, Janakpuri, Sirifort and ITO) in Delhi were analysed and trends were also compared amongst these sites. Maximum Operator Function method was used to compute the Air Quality Index of the above areas and percentage variations in different severity class is discussed which provides in depth analysis of the trends. The best air quality was depicted by Shahzada Baug followed by Shahdara, both of these were classified as industrial areas indicating that policy measures relating to the industries in the city during past years have helped in improving the air quality. The air quality in other areas have improved slightly in the span of nine years but still remains critical indicating continued rigorous efforts in this direction. Increased traffic density seems to have resulted into the worst air quality at ITO in the city amongst all the monitoring stations. There is a shift for the worst AQI in the city from winter to summer season in a time span of these nine years. Change of season for worst AQI from Winter to Summer may also be likely due to increased photochemical reactions playing major role with change in the nature of emissions imposed due to different control measures such as CNG implementation, significant shift to LPG in domestic sector etc. calling for a detailed study, those which started after the year 2000. After the year 2000, there is a significant increase in the Nitrogen-dioxide (NO_2) concentration at all stations. ITO which has shown continuous exponential increase in pollution levels has first time showed a declining AQI trend in the year 2004 and one of the contributing factors could have been the Delhi metro (initiated in 2002) passing through congested neighbouring areas causing traffic decongestion here. In general, the areas which are farthest from metro route viz., Siri-fort, Nizamuddin, Janakpuri etc. did not record declining AQI in 2003 onwards as happened with stations closer to Metro route such as Ashok Vihar and ITO. An attempt has been made to quantify the reasons that lead to the changes in the values of the AQI.

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1 Introduction

The majority of South Asian cities suffer from extremely high levels of urban air pollution, particularly in the form of small particles. Region-wide, urban air pollution is estimated to cause over 2,050,000 deaths and billions of cases of respiratory illnesses every year. Urban air pollution causes five times as many deaths and illnesses as malaria, and is among the largest contributors to the regional burden of disease.

Deterioration of air quality is a problem that is directly experienced by a majority of the 300 million urban Indians, who constitute about 30% of the India's population. A local survey has indicated that the incidence of respiratory diseases in Delhi is 12 times the national average, and that 30% of Delhi's population suffers from respiratory disorders due to air pollution (Kandlikar and Ramachandran 2000). For several reasons analysis of air quality data over Delhi has been undertaken in the past. Few among these could be listed as the high pollution levels, significant vehicular traffic (number of vehicles in the Delhi being about sum total of vehicles put together of other three megacities in India namely Mumbai, Chennai and Kolkatta), highest population growth amongst all mega cities with mixed land use. Paradoxically, many causative factors for urban air pollution exist in this capital city where most air pollution regulations are also implemented for the first time in the country such as unleaded fuel (1995), Bharat I and II (equivalent to EURO I, II) emission standards, conversion of all commercial vehicles and buses to CNG fuel, reduction of sulfur content in diesel and gasoline, closure of hazardous industries in the city etc. before these are implemented to other cities on the basis of Delhi's experience. Several studies in the recent past have discussed status of Delhi's air pollution based on national ambient air quality monitoring data. Kandlikar and Ramachandran (2000) described the emission estimates and impact of particulate matter on the air quality of Delhi and Mumbai. Amongst the studies dealing with annual trends for couple of years over Delhi are by Aneja et al. (2001) studied criteria pollutants over Delhi and compared the trends with US standards. Goyal and Sidhartha (2003) studied 2 years of air quality after CNG implementation in Delhi. Mouli et al. (2004) collected data on air pollutants and meteorological variables for the four cities in India including Delhi for the period July–August 2001 and proposed an air quality index. Recently, Gupta and Kumar (2006) studied trends of particulate matter in four cities of India that included three sites which are different from the seven monitoring stations of Central Pollution Control Board (CPCB) at Delhi in the present study namely Najafgarh, Town hall and Sarojini Nagar using seasonal and annual averaged data for 1991–2003 considered. The trend analysis based on annual or monthly averages are normally undertaken. However, AQI estimations undertaken here based on daily data helps in the percentage trends in each of the health category and more in-depth analysis.

2 Air Quality Index

The Air Quality Index (AQI) is an index for reporting daily air quality. It tells us how clean or polluted the air is, and what associated health effects might be a concern for us. The AQI focuses on health effects we may experience within a few hours or days after breathing polluted air. The AQI varies from 0 to 500. The higher the AQI value, the greater the level of air pollution and the greater are the health concerns. An AQI value of 100 generally corresponds to the national air quality standard for the pollutant, which is the level EPA (Environment Protection Authority) has set to protect public health in India. AQI values below 100 are generally thought of as satisfactory. When AQI values are above 100, air quality is considered to be unhealthy at first for certain sensitive groups of people, then for everyone as the AQI values get higher as detailed in Table 1.

3 Ambient Air Quality Monitoring in Delhi

The Central Pollution Control Board (CPCB; http://www.cpcb.delhi.nic.in) under it's National Air Monitoring Programme (NAMP) has been monitoring ambient air quality at seven locations viz., Nizamuddin, Ashok Vihar, Siri Fort, Janakpuri, ITO, Shahzada Bagh and Shahdara in Delhi (Fig. 1) for the past

Table 1 AQI values and the level of health concerns

Sr. no.	AQI values (when the AQI value is in this range)	Levels of health concern (air quality conditions)
1.	0 to 50	Good
2.	51 to 100	Moderate
3.	101 to 150	Unhealthy for sensitive groups
4.	151 to 200	Unhealthy
5.	201 to 300	Very unhealthy
6.	301 to 500	Hazardous

several years. The locations have been categorized on land use basis i.e. residential, industrial and traffic intersection. The stations coming under residential area are Ashok Vihar, Siri Fort, Janakpuri and Nizamuddin, under Industrial area are Shahzada Bagh and Shahdara and ITO is a traffic site junction (CPCB 2005).

4 Methodology

Maximum Operator Function method was used for calculating the AQI. This method has been used by USEPA and also by CPCB for AQI estimation. CPCB uses exceedance factor in this formula where a factor of 100 as multiple is not used. According to this method,

$$AQI = Pollutant\ Concentration * 100/Pollutant\ Standard\ Concentration.$$

The national ambient air quality standards for criteria pollutants are included in Table 2. The daily data of all the seven air sampling stations put by Central Pollution Control Board (CPCB) was procured. Air Quality Index of all the seven stations for the specified duration (1996 to 2004) was computed using 4-h or 8-h daily data. Maximum Operator Function Method was used for Air Quality Index determination. For studying the seasonal variation of the AQI values, the break-up of 12 months was taken into consideration as follows. Winter season included December, January and February months, summer season included March, April, May and June months, monsoon season included July, August and September months while post-monsoon included October and November months. Daily AQI calculated based on concentrations of criteria air pollutants at each of the seven stations were used to obtain percentages of number codes as listed in Table 1 during the desired averaging periods i.e. seasonal and annual basis for further analysis.

Fig. 1 Map of Delhi showing air quality monitoring stations

Table 2 National ambient air quality standards in as per Environment (Protection) Act, 1986 in India

Pollutants	Time-weighted average	Concentration of ambient air (in μg/m^3)		
		Industrial area	Residential rural	Sensitive area
SO_2	Annual average	80	60	15
	24 h	120	80	30
NO_2	Annual average	80	60	15
	24 h	120	80	30
SPM	Annual average	360	140	70
	24 h	500	200	100
RSPM	Annual average	120	60	50
	24 h	150	100	75

Source: http://dpcc.delhigovt.nic.in/airstd.htm

5 Results and Discussion

The trends are compared on annual/seasonal basis for each of these sites keeping in mind the contributions for deteriorating air quality from AQI categories 4, 5 and 6, which depict unhealthy, very unhealthy and hazardous categories. As the distributions in each of these categories every year show a random pattern and different severity levels, comparison on year-to-year basis is difficult. Rationally, AQI 6 should be given more weightage than 5 and AQI 5 should get more weightage than 4 for decision making while comparing percentage distribution in each of these categories for establishing severity trends. In order to do some meaningful comparisons to derive conclusions the weights used for each AQI category is assumed similar to the category number. Thus percentage distributions in each AQI category is multiplied with the AQI category number and added. These numbers are compared from year to year basis to obtain annual as well as seasonal analysis.

5.1 Annual variations of AQI

Tables 3, 4, 5, 6, 7, 8, and 9, show percentage of occurrences of AQI in each category on annual basis at all the seven stations from 1996 to 2004.

Based on above annual trends for seven areas of Delhi i.e. Nizamuddin, Ashok Vihar, Shahzada Baug, Shahdara, Janakpuri, Sirifort and ITO are described below.

Nizamuddin Area	There was a gradual improvement in the air quality in Nizamuddin area from the year 1996 (worst amongst all the years) to 1999 but the air quality deteriorated in the year 2000 drastically. There is significant improvement in year 2001 (best amongst all the years). From then on there is more or less increasing trend in AQI and it's worsening. Considering the year 1996 as the reference year, there is an improvement in the air quality of Nizamuddin area
Ashok Vihar Area	There was a gradual improvement in the air quality in Ashok Vihar area from the year 1996 to 1998 but the air quality gradually deteriorated in the year 1999 (worst year amongst all) and 2000. Significant improvement is noticed in the year 2001 (best amongst all), which again showed maximum deterioration in 2002 at same levels as 1999. From 2002 onwards there is an improvement but AQI is not at the same level as 2002
Shahzada Baug Area	Shahzada Baug is one of the two areas with best air quality amongst all stations and in all years. The best type of air quality in the 9 years (1996–2004) was observed in the year 1997 and 1998 while the worst was in year 2000 followed by year 2002. The year to year variations are less at this site and is undertaken for comparison sake though AQI is good here
Shahdara Area	Shahdara is one of the two areas with best air quality amongst all stations and in all years. The air quality in the 9 years (1996–2004) in this area seemed to remain more or less stable and good. Year 1996 showed worst air quality followed by the years 2000 and 2002
Janakpuri	Years 1997, 1999 and 2002 shows significant deterioration of air quality at about the same levels. There is significant improvement of the same in the years 2001 and 2003. Again there is slight deterioration noted in 2004 in comparison to the year 2003
Sirifort	Years 2003 followed by 2000 shows best air quality amongst all years. Year 2004 again shows deterioration of air quality when compared to 2003 levels
ITO	The best type of air quality in the 7 years (1998–2004) was observed in the year 1999 and the worst was in the years 2002 and 2003 (both years have similar values of AQI). A gradual improvement in the air quality is seen in ITO area during 2004 in comparison to 2003 level

Considering 1996 as the reference year (1998 for ITO), there is improvement of air quality at all monitoring areas except ITO. Among all the years and all sites Shahzada Baug and Shahdara, designated as representative of industrial areas remains the best two stations with low AQI or better air quality due to measures such as closing all industries and relocating these outside the city based on supreme court directives. Similarly ITO remains the worst site amongst all the stations and during all the nine years. Year 2001 showed best air quality or significant improvement over 2000 levels for Ashok Vihar, Nizamuddin, Shahdara, Shahzada Baug, and Janakpuri. Marginal improvement in air quality at ITO and slight deterioration over Sirifort was noticed in year 2001 when compared to the year 2000 levels. Ashok

Table 3 Year-wise frequency of occurrence of AQI in each category at Nizamuddin station

Year	AQI categories					
	1	2	3	4	5	6
1996	0	12	16	22	37	13
1997	0	5	25	38	23	9
1998	1	15	27	30	25	2
1999	0	11	38	36	14	1
2000	0	14	27	20	27	12
2001	0	34	31	22	11	3
2002	3	16	27	27	22	5
2003	1	22	29	22	18	8
2004	1	12	32	25	24	6

Table 5 Year-wise frequency of occurrence of AQI in each category at Shahzada Baug station

Year	AQI categories					
	1	2	3	4	5	6
1996	1	91	6	0	2	0
1997	26	72	2	0	0	0
1998	15	70	15	0	0	0
1999	19	68	12	1	0	0
2000	7	52	33	8	0	0
2001	9	71	17	3	0	0
2002	11	58	24	6	1	0
2003	17	67	13	3	0	0
2004	15	78	6	0	1	0

Vihar, Shahdara, Shahzada Baug and Janakpuri show improvement of air quality in 2003 and 2004 over 2002 levels. ITO also shows marginal improvement in the year 2004 in comparison to 2003 level. However, both Nizamuddin and Sirifort show deterioration of air quality when compared to 2003 level. The improvement on AQI in 2003 and 2004 at ITO, Ashok Vihar, Shahdara can be contributed by the metro route some distance away which was initiated in 2002 and completed in April, 2004 for line 1 of phase 1 between Shahdara Rithala route and helped in decongesting the traffic. Somehow, areas having greater distances from metro route do not show this kind of improvement in 2004 such as Siri fort and Nizamuddin. Interestingly, there are other features such as large number of completed fly overs and construction activities associated with metro and flyovers eliminating or aiding to pollution. Mixed trends in this city are generally expected from a megacity with all the development activities to evolve itself as a world class city.

5.2 Seasonal variations of AQI

Table 10 shows the following AQI trends in the four seasons (winter, summer, monsoon and post-monsoon) for the years 1996 and 2004:

5.2.1 Nizamuddin area

In the year 1996, the AQI of Nizamuddin area was comparatively worst in winter and better in monsoon. The AQI depicted the following sequence in the decreasing order: winter > post-monsoon > summer > monsoon. Decreasing order of AQI implies air quality going from worst to better in the entire text e.g., it

Table 4 Year-wise frequency of occurrence of AQI in each category at Ashok Vihar station

Year	AQI categories					
	1	2	3	4	5	6
1996	0	1	33	33	28	5
1997	0	3	39	40	18	0
1998	0	3	44	39	14	0
1999	0	2	25	42	29	2
2000	0	13	21	26	27	13
2001	0	32	32	21	14	1
2002	1	9	22	22	32	14
2003	0	8	28	24	28	12
2004	6	16	25	28	18	7

Table 6 Year-wise frequency of occurrence of AQI in each category at Shahdara station

Year	AQI categories					
	1	2	3	4	5	6
1996	12	57	24	7	0	0
1997	32	59	8	1	0	0
1998	4	84	11	1	0	0
1999	6	86	7	1	0	0
2000	24	59	11	4	1	1
2001	36	59	4	1	0	0
2002	20	56	18	5	1	0
2003	29	53	18	0	0	0
2004	28	56	14	2	0	0

Table 7 Year-wise frequency of occurrence of AQI in each category at Janakpuri station

Year	AQI categories					
	1	2	3	4	5	6
1996	0	9	29	22	37	3
1997	0	7	21	37	35	0
1998	2	3	48	20	26	1
1999	0	0	22	56	19	3
2000	0	6	41	27	23	3
2001	2	21	30	26	18	3
2002	0	8	25	21	27	19
2003	5	25	35	15	16	4
2004	4	12	30	28	25	1

means here that winter has worst air quality and monsoon has this best.

In the year 2004, the AQI of Nizamuddin area was comparatively worst in summer and better in monsoon. The AQI value followed the following sequence in the decreasing order: summer > post-monsoon > winter > monsoon.

Normally, winter have the worst air quality because of less dispersion of the pollutants but what is observed in the year 2004 was that the air quality was worst in summer.

5.2.2 Ashok Vihar area

In the year 1996, the AQI of Ashok Vihar area was comparatively worst in summer and better in monsoon. The AQI value followed the following sequence in the decreasing order: summer > winter > post-monsoon > monsoon.

Table 8 Year-wise frequency of occurrence of AQI in each category at Sirifort station

Year	AQI categories					
	1	2	3	4	5	6
1996	0	5	36	32	22	5
1997	0	0	17	45	35	3
1998	1	3	24	36	29	7
1999	0	1	19	56	21	3
2000	0	14	42	22	18	4
2001	0	12	34	23	26	5
2002	4	4	30	26	25	11
2003	5	23	33	24	12	3
2004	1	13	34	24	21	7

Table 9 Year-wise frequency of occurrence of AQI in each category at ITO station

Year	AQI categories					
	1	2	3	4	5	6
1996	–	–	–	–	–	–
1997	–	–	–	–	–	–
1998	0	4	21	28	32	15
1999	0	6	26	21	34	13
2000	0	3	19	18	34	26
2001	0	4	19	19	32	26
2002	0	1	10	18	37	34
2003	0	2	9	15	44	30
2004	0	3	11	18	42	26

In the year 2004, the AQI of Ashok Vihar area was comparatively worst in summer and better in monsoon. The AQI value followed the following sequence in the decreasing order: summer > winter > post-monsoon > monsoon.

5.2.3 Shahzada Baug area

In the year 1996, the AQI of Shahzada Baug area was comparatively worst in winter and better in monsoon. The AQI value followed the following sequence in the decreasing order: winter > summer > monsoon = post-monsoon.

In the year 2004, the AQI of Shahzada Baug area was comparatively worst in summer and better in monsoon. The AQI value followed the following sequence in the decreasing order: summer > winter > post-monsoon > monsoon.

It should be noted that Shahzada Baug area has one of the relatively best air quality as compared with the six areas of Delhi.

5.2.4 Shahadara area

In the year 1996, the AQI of Shahadara area was comparatively worst in summer and better in monsoon. The AQI value followed the following sequence in the decreasing order: summer > winter > post-monsoon > monsoon.

In the year 2004, the AQI of Shahadara area was comparatively worst in summer and better in monsoon. The AQI value followed the following sequence in the decreasing order: summer > winter > post-monsoon > monsoon.

Table 10 Seasonal variation of the AQI of the seven areas of Delhi for the years 1996 and 2004

Area	1996	2004	Remarks
Nizamuddin	W>PM>S>M	S>PM>W>M	Overall the air quality improved. The worst AQI changed from winter in 1996 to summer in 2004
Ashok Vihar	S>W>PM>M	S>W>PM>M	Overall the air quality improved. Worst AQI is observed in summer for both years
Shahzada Baug	W>S>M=PM	S>W>PM>M	Overall the air quality improved. It shows the best air quality in the city amongst all the monitoring stations. The worst AQI changed from winter in 1996 to summer in 2004
Shahadara	S>W>PM>M	S>W>PM>M	Overall the air quality improved. Worst AQI is observed in summer for both the years
Janakpuri	W>S>PM>M	S>PM>W>M	The worst AQI changed from winter in 1996 to summer in 2004. Air quality deteriorated in summer as well as in post-monsoon season while improved in the winter and monsoon season. However, overall there is an improvement in air quality
Sirifort	PM>W>S>M	PM>S>M>W	Air quality deteriorated in all seasons except winter. Post-monsoon showed worst AQI in both years
ITO[a]	W>PM>S>M	PM>S>W>M	AQI in 1998 was worst in winter that has changed to post-monsoon in 2004. Monsoon showed the best AQI in both years. Overall there is a deterioration in air quality in all seasons

W Winter, *S* summer, *M* monsoon, *PM* post-monsoon

[a] The AQI values for the ITO area are of year 1998 instead of 1996

5.2.5 Janakpuri area

In the year 1996, the AQI of Janakpuri area was comparatively worst in summer and better in monsoon. The AQI value followed the following sequence in the decreasing order: winter > summer > post-monsoon > monsoon.

In the year 2004, the AQI of was comparatively worst in summer and better in monsoon. The AQI value followed the following sequence in the decreasing order: summer > post-monsoon > winter > monsoon.

The quality of air in Janakpuri area deteriorated in summer while post monsoon season while improved in the winter and monsoon season.

5.2.6 Sirifort area

In the year 1996, the AQI of Sirifort area was comparatively worst in post monsoon and better in monsoon. The AQI value followed the following sequence in the decreasing order: post-monsoon > winter > summer > monsoon.

In the year 2004, the AQI of Sirifort area was comparatively worst in post monsoon and better in winter. The AQI value followed the following sequence in the decreasing order: post-monsoon > summer > monsoon > winter.

5.2.7 ITO area

In the year 1998, the AQI of ITO area was comparatively worst in winter and better in monsoon. The AQI value followed the following sequence in the decreasing order: post-monsoon > winter > summer > monsoon.

In the year 2004, the AQI of ITO area was comparatively worst in post monsoon and better in winter. The AQI value followed the following sequence in the decreasing order: post-monsoon > winter > summer > monsoon.

Figures 2 and 3 show seasons having the worst air quality during 1996–1999 and 2000–2004 respectively. Increase of percentages of worst air quality during summer season from 27 to 46 and decrease from 35 to 11 in winter season in these figures reflect that tendency of encountering worst pollution is changing towards summer season during the course of time. This could perhaps be due to changing emission patterns and increased role of photochemical reactions taking part during summer season. Tables 11 and 12 show the worst and best seasons respectively from air quality point of view at seven sites in Delhi from 1996–2004. As can be seen in Tables 12 here, winter has been showing the worst air quality with maximum up to three sites till 1999.

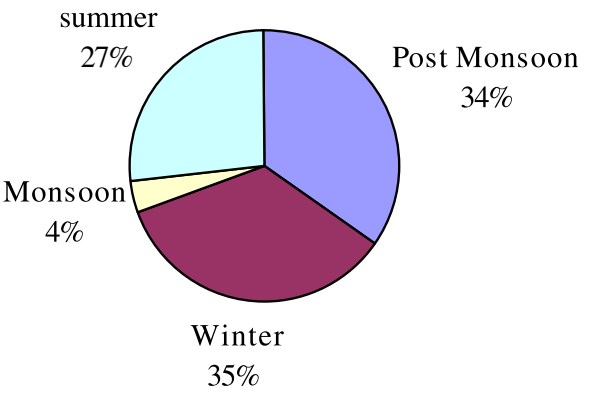

Fig. 2 Season-wise percentage distribution of worst air quality in Delhi during 1996–1999

However, from 2000–2004, only in 2001 and 2003, one of the seven site has shown winter as the worst season and it is mostly summer and post-monsoon seasons which are showing the worst air quality in most cases and the year 2004 shows summer as the worst season at five sites with remaining two sites showing the post-monsoon as the worst season from air quality point of view. An increase of post-monsoon season showing worst air quality represented by October and November months in Delhi can be explained by the facts that reasonably high values of mixing height and solar radiation (Mohan 1985; Mohan and Sharma 1987) facilitate possibilities of photochemical activities as is the case with the summer months.

Overall the following conclusions are drawn from the above annual and seasonal analysis:

(1) There is improvement in the air quality of the most of the areas during the study period. The best estimated air quality is in Shahzada Baug followed by Shahadara. The next category of stations having somewhat similar pollution levels are Nizamuddin, Ashok Vihar, Sirifort and Janakpuri where air quality is still critical and continuous efforts are required to further improve the same.

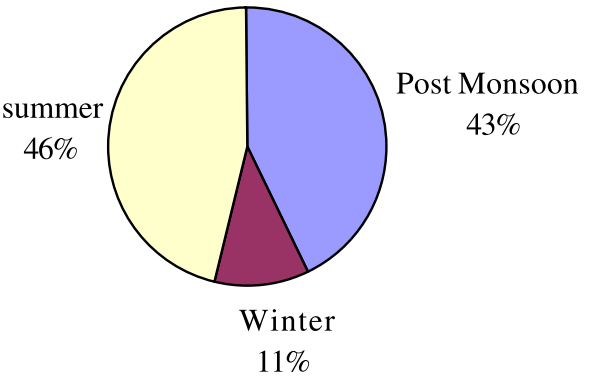

Fig. 3 Season-wise percentage distribution of worst air quality in Delhi during 2000–2004

(2) ITO showed the worst AQI in the city throughout the study period because of being a busy traffic junction and a thermal power plant not far away from this place. Though worst air quality at ITO was in 2002, there is a gradual improvement till 2004 since then which could be partly due to traffic decongestion from the construction of new flyovers in the neighbouring areas and commencement of metro rail services in the city. However in absolute terms pollution levels are very high and maximum in the city needing further drastic control measures.

(3) There is continuous and significant improvement of air quality at Shahzadabaug and Shahdara from 2002 onwards. Janakpuri, Sirifort and Nizamuddin showed significant improvement in 2003 in comparison to their 2002 levels that again showed deterioration in 2004. However, both ITO and Ashok Vihar showed continuous improvement in 2004 in comparison to their 2002 levels.

(4) In 1996, it was generally the winters that used to have the worst type of air quality (four out of seven sites) but in 2004, none of the site had winter as the worst season and it is mostly the summers (five out of seven sites) followed by post-monsoon that showed the worst type of air quality.

(5) Change of season for worst AQI from Winter to Summer in nearly 9 years of span may also be likely due to increased photochemical reactions playing major role with change in the nature of emissions imposed due to different control measures such as CNG in vehicles, more LPG usage in domestic sector etc. calling for a detailed study. There is also a consistent gradual increase in NO_2 levels from 2001 onwards which remains within the AQ standards except for one site ITO. This partially reflect changed emission patterns in the city and possibility of more photochemical reactions (Fig. 4). Improvement in Shahdara, Shahzadabaug, Ashok Vihar and ITO especially in 2004 may be contributed by the traffic decongestion by metro as these sampling stations are closer to metro in comparison to rest of the sites.

Table 11 Most severe season in terms of air quality each year at all seven sites in Delhi during 1996–2004

Year	The most severe season in terms of air quality						
	Nizzamuddin	Ashok Vihar	Shahzada Baug	Shahdara	Janakpuri	Sirifort	ITO
1996	W	S	W	S	S	P	–
1997	W	M	W	S	W	S	–
1998	P	P	P	P	P	P	P
1999	W	S	W	W	W	S	P
2000	S	P	S	S	P	P	P
2001	W	P	P	P	W	P	P
2002	S	P	P	S	S	S	P
2003	P	P	W	P	P	S	P
2004	S	S	S	S	S	P	P

W Winter, *S* summer, *M* monsoon, *P* post-monsoon

(6) There is no consistent trend (increase/decrease of AQI) from 2000 onwards at almost all the stations as there are mixed effects of various control measures for example construction of flyovers and metro throughout the city may add to traffic congestion and increased pollution whereas completed metro corridors and flyovers will result into less pollution.
(7) Overall, majority of sampling stations showed improvement in AQI from 1996 to 2004. This is the period when regulatory measures were implemented in a major way.

5.2.8 Possible reasons for the changing values of AQI of Delhi

There are many reasons those are responsible for the change in the air quality of Delhi. Following is the comprehensive list of the various actions taken resulting in the change in the air quality of Delhi [www.worldbank.org/sarurbanair].

1994–1995: Transport

Introduction of Catalytic Converters and Unleaded petrol

1996: Transport & Industry

- Fuel Quality: 0.5% Sulphur diesel introduced
- CNG vehicles and catalytic converters for government petrol vehicles, excluding public transport introduced
- Closure of 168 hazardous industries, including stone crushers completed
- Lower Sulphur content in coal (0.4% S) and oil for industrial use (1.8%) introduced

1997: Industry

- Relocation of 513 industries
- 337 hazardous category industries shifted (total of 1,160 industries closed or relocated including hot mix plants, arc induction furnaces, brick kilns)

Table 12 Best season in terms of air quality each year at all seven sites in Delhi during 1996–2004

Year	The best season in terms of air quality						
	Nizzamuddin	Ashok Vihar	Shahzada Baug	Shahdara	Janakpuri	Sirifort	ITO
1996	M	M	M	M	P	M	–
1997	P	P	P	M	M	P	–
1998	W	W	W	W	M	M	M
1999	P	M	M	M	M	W	M
2000	M	M	M	M	M	M	M
2001	M	M	M	M	M	M	M
2002	M	M	M	W	W	M	M
2003	M	M	M	M	W	M	M
2004	W	M	M	P	M	W	M

W Winter, *S* summer, *M* monsoon, *P* post-monsoon

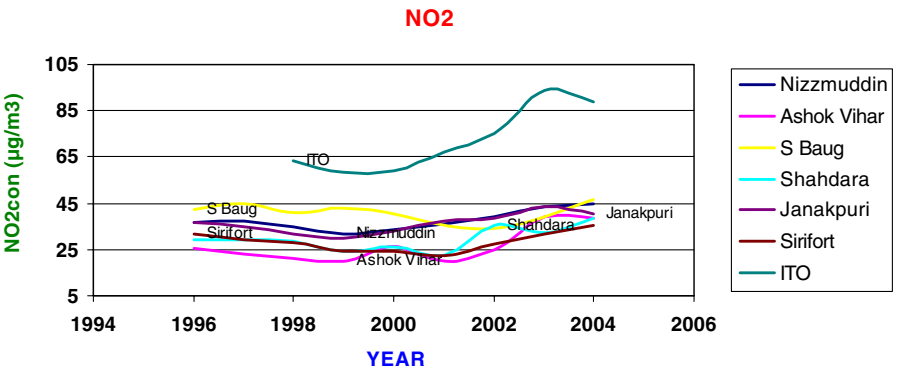

Fig. 4 Annual averages of Nitrogen-dioxide concentration at seven monitoring stations in Delhi

1998: Transport

- Supply of only premix petrol in all petrol filling stations to two stroke engine vehicles; ban on supply of loose 2T oils
- Phasing out/ban on old commercial/transport vehicles (>15 years)
- Start of major construction program: flyovers plus the Delhi metro

1999: Transport

- Registration of only EURO II three-wheelers and diesel taxis
- Restricting the plying of goods vehicles during the day
- Diesel sulphur reduced to 0.25%

2000: Transport, Industry & Urban

- Diesel and gasoline sulphur reduced to 0.05% in selected outlets
- Replacement of all pre-1990 three-wheelers and taxis with new vehicles on clean fuels
- All private four-wheeled vehicles to conform to Euro II
- Buses more than 8 years phased out or to ply on CNG
- The three coal based power plants to switch over to beneficiated coal
- Piped NG by March 2000 to 1,311 domestic, 9 small, and 3 large commercial establishments

2001: Transport, Industry & Urban

- Replacement of all post-1990 three-wheelers and taxis with new vehicles on clean fuels
- Sulphur content in diesel further reduced to 0.05% in select outlets
- Number of CNG vehicles as follows: 14,000 three-w; 2,200 taxis; 400 buses; 250 RTVs; 9,500 private (26,350 total)
- Piped NG by March to 2,821 domestic, 15 small, and 5 large commercial establishments
- Hazardous Industry closure continues: total of 3,538 closed

2002: Transport & Urban

- 94 CNG stations setup up to March
- All diesel buses phased-out/converted to CNG
- Number of CNG vehicles as follows: 35,678 three-w; 4,816 taxis; 4,231 buses; 2,165 RTVs; 10,350 private (57,240 total)
- Piped Natural Gas by March to 4,111 domestic, 37 small, and 5 large commercial establishments
- 16,340 non-destined good vehicles turned away from entering Delhi between July and November.

2003–2004: Transport

The state-of-the-art Mass Rapid Transit System Delhi Metro becomes operational. With the commencement of first corridor i.e. Shahadara-Rithala by Delhi Metro, public transport in Delhi has witnessed changing scenario as more than 1 lakh passenger trips are being covered by Metro. Delhi Metro will change public transport scenario to laudable extent. Till 2003, buses constituted about 1% of the total number of vehicles, but catered to 60% of the total traffic load, while personalized vehicles account for 93.64% of the total vehicles but cater to only 30% of the total traffic load.

During the Annual Plan 2002–2003 and 2003–2004, (Economic Survey of Delh 2003–04) 10

Flyovers were constructed by the concerned agencies (PWD, DDA, DTTDC and MCD) (During the 9th Five Year Plan, 11 flyovers/ROB/Grade-Separators were constructed in Delhi).

6 Conclusions

The study can be summarized as follows:

AQI percentages in different severity class from daily measurements can provide an in-depth analysis of seasonal and annual variations than the averaged values. This is performed for 9 years (1996–2004) on annual and seasonal basis being marked by drastic policy changes over Delhi. Shazadabaug and Shahdara are found to be least polluted with good AQI. Amongst remaining five sites, Ashok Vihar and Nizamuddin showed the best air quality in the year 2001 while Janakpuri and Sirifort showed best AQI in the year 2003 with ITO in 1999. After having worst AQI in 2002, AQI at ITO has improved in subsequent years. At both, Janakpuri and Sirifort, there is deterioration of AQI in the year 2004.

A shift in worst AQI season from winter to summer is noted and also an increased NO_2 concentration at all sites increased from 2000 onwards. There seems to be change in the nature of pollutants and more photochemical activity with changed regulations and emissions in the city. At certain traffic junctions and locations in the city improvement in air quality is noticed after the introduction of metro rail network.

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