Air Quality Index (AQI) for Delhi, India

Trend Analysis & Implications for the Commonwealth Games 2010 & Beyond

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Sarath Guttikunda

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Air Quality Index (AQI) for Delhi, India: Trend Analysis & Implications for the CWG 2010 and Beyond

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Delhi, the capital city of India, is gearing up to host the Commonwealth Games in October 2010 (CWG 2010). With the Games around the corner, the debate on air quality in Delhi and athletes health during the Games is slowly taking center stage, very similar to the debates on air quality in Beijing before and during the Olympics Games 2008. In case of Beijing, some stringent regulations and policy measures were implemented, months in advance, to ensure clean air days before and during the Olympic Games. However, this remains a challenge for the Delhi authorities.

A summary of the PM and Ozone pollution observed at one of the monitoring stations (located at ITO) in Delhi[1] is presented in **Figure 1**. On an average, the PM pollution is 2-3 times higher than the daily ambient standard and for Ozone the daily averages remains lower than the standard, except for the day time 8-hr maxima (plotted as thick blue line) which exceed the compliance levels.



A substantial portion of this pollution is due to Delhi's own local sources[2], though the overall impact on human health and ecosystem is increasingly being linked to the growing transport sector. A source apportionment study for Delhi[3] reveals a split in the sources of air pollution between the summer and the winter months, with the later dominated with biomass burning and frequent low inversions. Besides the vehicle exhaust from a mix of motor vehicles, power plants, and industries, a series of construction activities in and around the city (domestic, metro, flyovers, and the Games venues) and resuspension of dust along the roads are contributing significantly to the particulate, ozone and other pollutant pollution.

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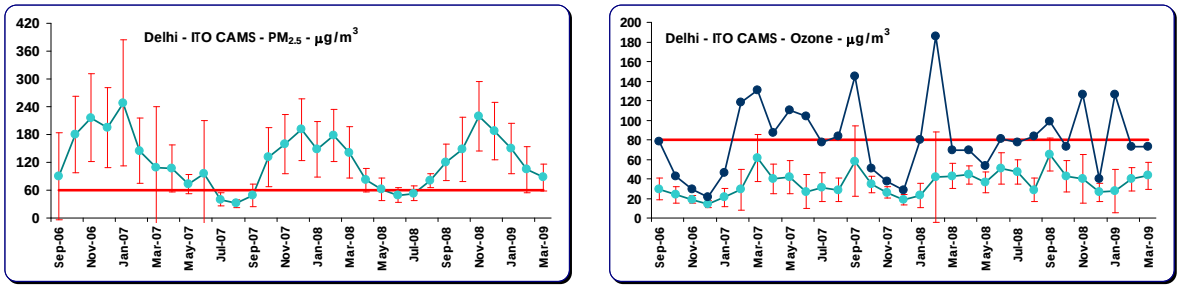
[1] Data is collected for the period of 2006-09 for the ITO station, operated by CPCB, India, covering a range of pollutants, including meteorology @ http://164.100.43.188/cpcbnew/movie.html

[2] See SIM-air working paper No. 22 – "AQM in Delhi – Then, Now, and Next" @ http://www.urbanemissions.info/

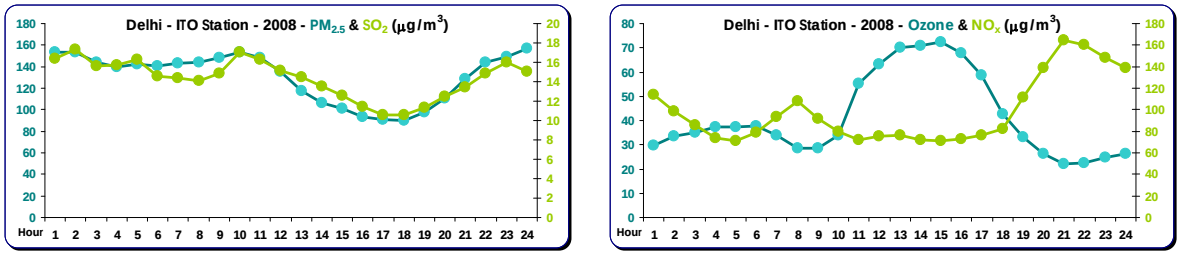
[3] Chowdhury, Z., et al., (2007) "A Speciation of ambient fine organic carbon particles and source apportionment of PM2.5 in Indian cities." Journal of Geophysical Research-Atmospheres @ http://www.agu.org/journals/ABS/2007/2007JD008386.shtml

Figure 1: Daily average monitoring data at the ITO station in Delhi, India



The diurnal and seasonal variation of the mixing layer height is very prominent in Delhi, which effects the night time and winter time concentrations. The winter time phenomenon is of utmost importance, because it starts forming in the month of October[4], the start of the CWG 2010. The diurnal cycles for passenger cars, buses, power plants and industries are commonly studied and represented in the day time measurements. However, the most important are the truck emissions, because, in Delhi the diesel operated trucks are allowed to pass through only at night and thus enhancing the night time ambient concentrations. Since the population exposed to these higher concentrations of PM (mostly diesel soot) and other pollutants is lower during the night, the exposure impacts of night emissions are generally less pronounced. However, the high concentrations observed during the night, tend to linger during the rush hours (mixed with the passenger travel) and beyond (through ~11 AM) and hence increasing the exposure times and related health concerns along the major corridors[5]. A summary of the diurnal cycles is presented in **Figure 2**. The strong correlation between the $PM_{2.5}$ and SO_2 concentrations during the night time is an indication that the sources might be the same – the diesel trucks contributing significantly to both $PM_{2.5}$ and SO_2 emissions.

Figure 2: Diurnal variation of pollution at the ITO station in Delhi, India, averaged over all days in 2008



Today, for the monitored or the modeled air quality in Delhi, there is no approved methodology for estimating the air quality index, a common denominator to compare the observed pollutant concentrations across a city as a measure of the health impacts.

[4] See SIM-air working paper No. 31 – "Role of Meteorology on Urban Air Pollution Dispersion: A 20yr Analysis for Delhi, India" @ http://www.urbanemissions.info/

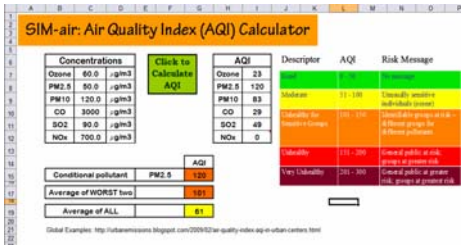
[5] An analysis of the diurnal cycle of pollution observed in Delhi and linkages to photochemistry are described in details based on monitoring data in SIM-air working paper No. 25 – "Photochemistry of Air Pollution in Delhi, India: A Monitoring Based Study" @ http://www.urbanemissions.info/

Following the methodology presented in SIM-air working paper No.34, a methodology was developed and applied to evaluate the air pollution in Delhi and this paper presents the observed trends.

Air Quality Index for Delhi

Applied Methodology

The methodology to calculate the air quality index (AQI) is presented below, along with the supporting data for various ranges.



$$AQI = \frac{AQI_{hi} - AQI_{lo}}{BP_{hi} - BP_{lo}} * (CONC - BP_{lo}) + AQI_{lo}$$

Where

CONC = concentration of the pollutant
AQI = air quality index for the pollutant
BP_{hi} = the breakpoint that is greater than or equal to CONC
BP_{lo} = the breakpoint that is less than or equal to CONC
AQI_{hi} = the AQI value corresponding to BP_{hi}
AQI_{lo} = the AQI value corresponding to BP_{lo}

Table 1: The applicable ranges for AQI methodology for Delhi, India

Range		Healthy		Moderate		Unhealthy (Senstitive Groups)		Unhealthy		Very Unhealthy		Hazardous	
Values	AQI-low	0		51		101		151		201		301	
	AQI-hi	50		100		150		200		300		500	
Concentrations		BP_{low}	BP_{hi}	BP_{low}	BP_{hi}	BP_{low}	BP_{hi}	BP_{low}	BP_{hi}	BP_{low}	BP_{hi}	BP_{low}	BP_{hi}
PM_{10} (µg/m^3)		0	30	30	60	60	100	100	200	200	300	300	
$PM_{2.5}$ (µg/m^3)		0	20	20	40	40	60	60	100	100	200	200	
SO_2 (µg/m^3)		0	20	20	40	40	80	80	160	160	400	400	
NO_2 (µg/m^3)		0	20	20	40	40	80	80	160	160	400	400	
O_3 (µg/m^3)		0	20	20	50	50	100	100	200	200	400	400	
CO (µg/m^3)		0	1000	1000	2000	2000	4000	4000	10000	10000	20000	20000	

The break point concentrations (high and low) are adjusted to the national ambient standards of India for each of the pollutant[6]. The AQI ranges are also adjusted with 150 as the threshold, corresponding to the ambient standard for that pollutant.

Note: *This is not an official AQI methodology for India, but an attempt to consolidate the available information and put together a reasonable methodology.*

An excel version of this methodology is available for the user to plug and play with the measured or modeled air pollution levels of each pollutant[7]. The tool provides the user to

[6] National ambient air quality standards @ http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php

input the concentrations of six pollutants – PM_{10}, $PM_{2.5}$, Ozone, SO_2, NO_2, and CO (all in micro-gm/m^3). It is not necessary that the concentrations of all six should be entered. If the data is available only for few, the tool will automatically ignore the cells without numbers and calculate the AQI with the concentrations available.

It is important to note that the AQI is not always calculated based on the monitoring data for these pollutants. The same methodology can be applied to modeled data over a city – gridded or grid averaged – to estimate AQI.

Air Quality Index Results

Using the methodology presented in the previous section, the AQI was calculated for the period of August, 2006 to June, 2010 for four stations spread across Delhi. For this analysis, AQI's are calculated in 6 bins as described below (see **Table 2**). The first three bins, at par with the national ambient air quality standards are considered "safe mode" or "clean air" days and the others "polluted" days.

Table 2: The AQI color codes and their definitions

0-50	"**HEALTHY**" – this range poses little or no risk to the general public. No cautionary actions are prescribed.	51-100	"**MODERATE**" - is acceptable for general public. However, unusually sensitive people should be cautious.
101-150	"**UNHEALTHY**" - is borderline unhealthy, particularly for members of sensitive groups.	151-200	"**UNHEALTHY**" - is considered unhealthy for most of the public where everyone may begin to experience some discomfort.
201-300	"**VERY UNHEALTHY**" - can trigger a health alert, meaning everyone may experience more serious health effects.	>300	"**HAZARDOUS**" – this range triggers health warnings under emergency conditions, affecting all age groups.

Of the six criteria pollutants – PM (coarse and fine), SO_2, NO_x, CO, and Ozone, the PM pollution is routinely above the daily average standards [8] and remains the dominant conditional pollutant for calculating the AQI for health impacts assessments – presenting the worst AQI[9].

For Delhi, the AQI is calculated for data from six stations (1) Income Tax Office (ITO) and (2) Delhi College of Engineering (DCE), (3) Central Pollution Control Board (CPCB), (4) Institute of Human Behaviour & Allied Sciences (IHBAS), (5) Siri Fort Sports Complex, and (6) Shadipur @ Delhi Milk Scheme.

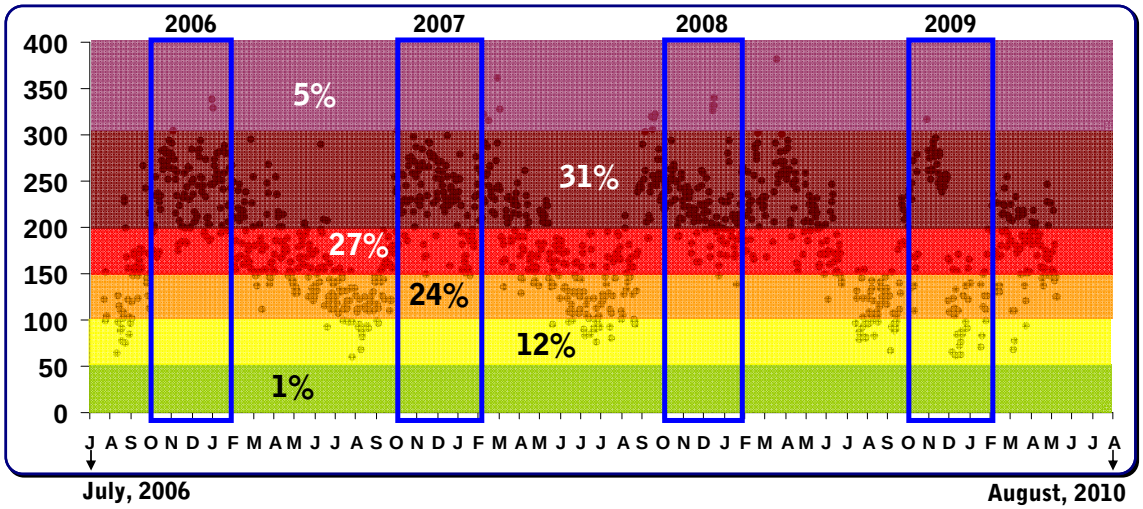
[7] The tool is available for free; applications of AQI and its use for public awareness is summarized in SIM-air working paper No.34 – "AQI: Methodology and Applications in the Cities"
@ http://www.urbanemissions.info/model-tools/aqi-calculator.html

[8] Daily average national ambient air quality standards for PM_{10} and $PM_{2.5}$ are 100 μg/m^3 and 60 μg/m^3, respectively. Comparatively, the national ambient standards for $PM_{2.5}$ in United States and Europe are 35 μg/m^3 and 25 μg/m^3, respectively.

[9] The AQI was also calculated for all six pollutants, but not presented in this report. Only the average of the worst two pollutants is presented. A value of 150 is considered as threshold for health impacts, depending on the national ambient air quality standards.

The **Figure 3** presents estimated AQI (in the form of average of worst two pollutants). The concentrations of the six pollutants were first averaged (for all six stations), then daily AQI was calculated for each pollutant. The worst two pollutants were picked from the six AQI for each day, averaged and presented in **Figure 3**.

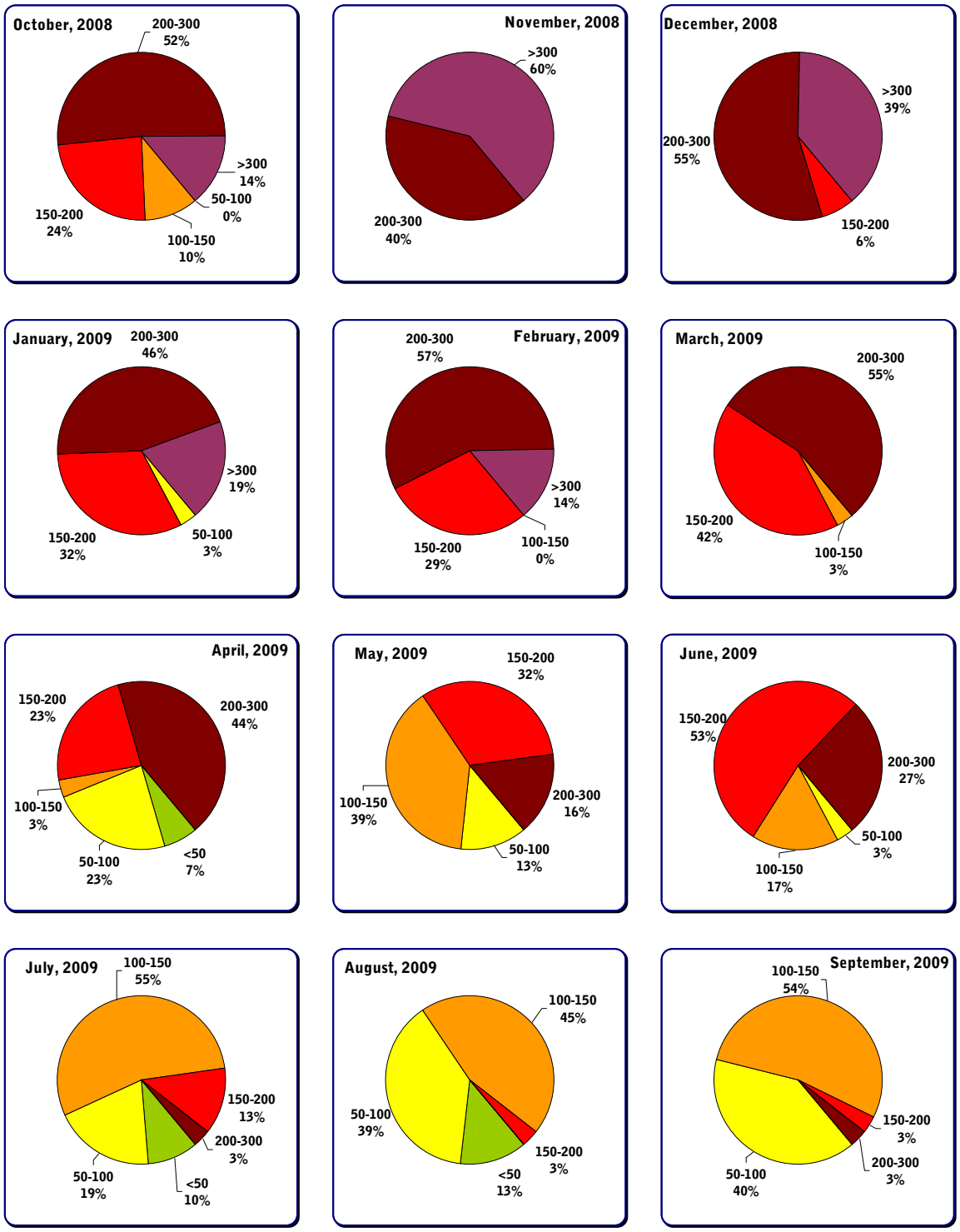
Figure 3: Delhi average AQI (average of worst two pollutants)



Observations on AQI

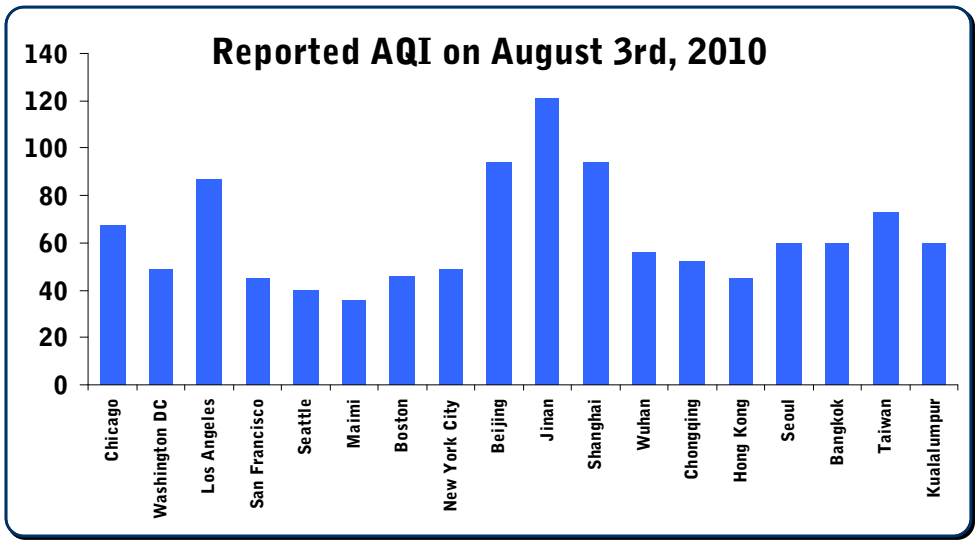
- The **Figure 3** also presents the percentage of each color code estimated, based on the average AQI. At the monitoring sites, AQI is often worse than the health standard of 150. On an average only 37% of the days between July 2006 and August 2010 was calculated with AQI less than 150.
- In **Figure 3**, the winter months are highlighted with a blue box for each year. The winter months experience the worst pollution starting in October and leading into February, the following year.
- The AQI's greater than 300 are most often associated with the winter season.
- For one continuous year between October, 2008 and September, 2009, **Figure 4** presents the frequency of AQI occurrences by month. The pollution levels are particularly enhanced in the winter months due to inversion and higher amounts of biomass usage for heating purposes (a low lying source, which tends to disperse less under low inversion conditions).
- The worst is observed in the winter months and the best during the monsoon months of July and August.

Figure 4: Monthly variation in the frequency of AQI ranges between Oct'08 to Sep'09 as city average AQI (average of worst two pollutants)



Compare this (**Figure 5**) with the data available for cities like Hong Kong, where the motorization is as high as Delhi, plus an active port, Delhi rates among the worst air quality cities in the world. In Hong Kong, between January 2010 and March 2010, AQI was higher than 100 for 2% of the hours in the residential areas and 12% of the hours along the transport corridors[10].

Figure 5

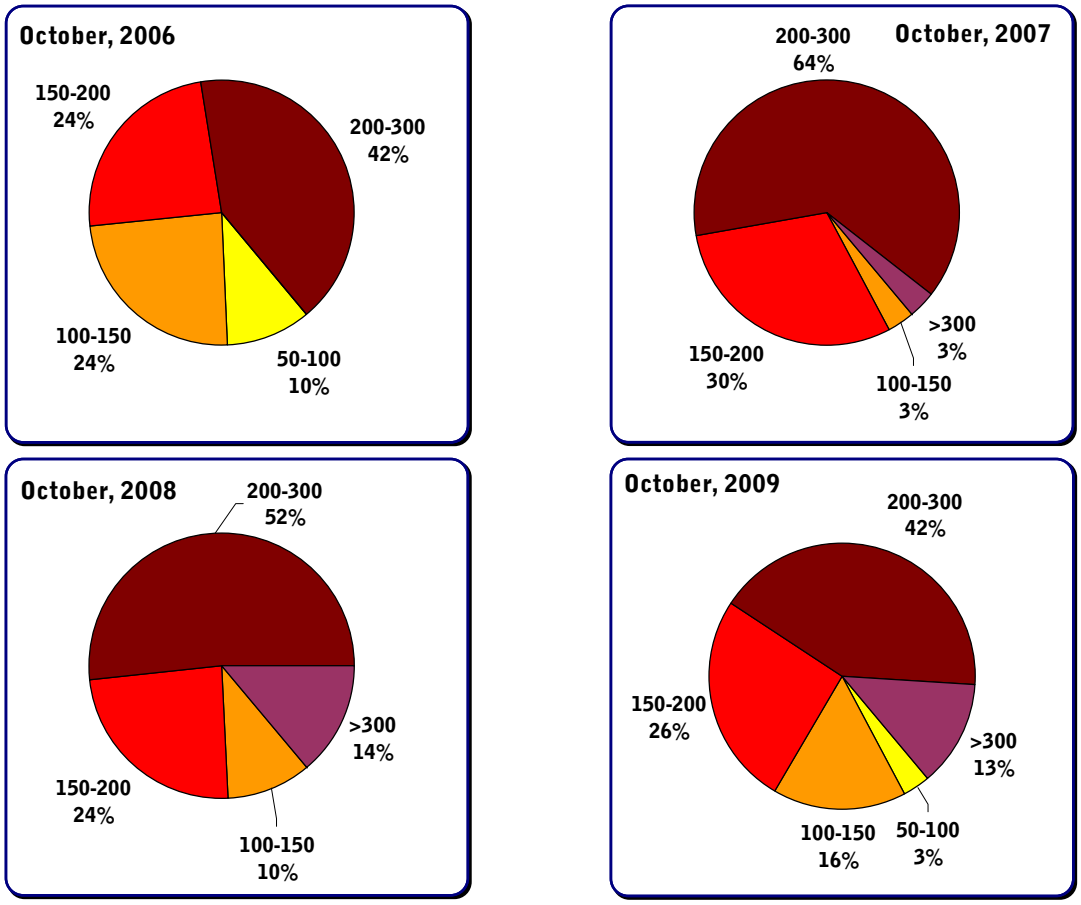


[10] For details on AQI in Hong Kong, see @ http://www.epd-asg.gov.hk/english/apisum/apisum.php and for other cities @ http://urbanemissions.blogspot.com/2009/02/air-quality-index-aqi-in-urban-centers.html

Air Quality Implications during the Commonwealth Games (CWG) 2010

In Hindustan Times, June 14th, 2009, an article "From Beijing, a lesson for Delhi" highlighted the traffic problems that Delhi could face if the lessons from Beijing (with six ring roads) are not taken into consideration before the Commonwealth Games 2010[11]. Delhi averaging ~1,000 new vehicles a day and Beijing registering ~1,500 a day are on similar boats and adding to the already congested traffic problems in the city and the PM pollution along the roads is at the worst levels and at increasing health risk[12]. Come October (2010) the onset of the winter inversion is only expected to worsen the air quality. A summary of the frequency of good vs. bad air days is presented in **Figure 6**, as city average AQI for 2006-09.

Figure 6: Frequency of AQI in October of each year as city average AQI (average of worst two pollutants)



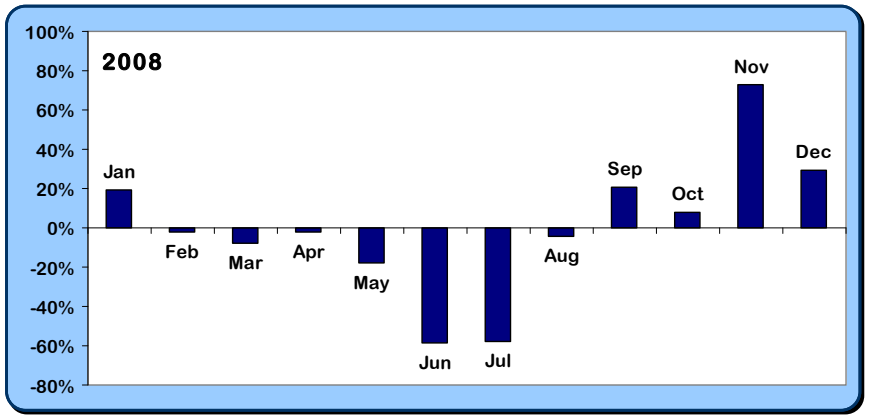
[11] The official website for the Games @ http://www.cwgdelhi2010.org/

[12] A monitoring experiment along the major corridors of the city was conducted in October 2009, covering ~170 km over 10 hours, measuring PM_{10} and $PM_{2.5}$. The average concentrations during the day averaged ~206 $\mu g/m^3$ for PM_{10} and ~163 $\mu g/m^3$ for $PM_{2.5}$. Details of the experiment and data is available as part of the SIM-air working paper No.29 @ http://www.urbanemissions.info/

The data is evidence that the air quality just about starts to deteriorate in October and continuing in the following months. Between 2006 and 2009, the air quality also worsened for the month of October; primarily due to increase in the emissions from the vehicular exhaust and heightened construction activities across the city, in preparation to the 2010 CWG.

A study conducted to evaluate the role of meteorology on the air pollution in Delhi presents an interesting scenario. The results summarized in **Figure 7**, include the monthly variation in average concentrations for tracer (dummy) emissions over the Delhi area, assuming constant emissions from each grid and varying only the meteorology every 6hr for the entire year[13]. A clear conclusion is that irrespective of the constant emissions over each month, the observed concentrations are invariably 20% to 80% higher in the winter months (September to January) and 10% to 60% lower in the summer months (May, June, and July) when compared to the annual average tracer concentrations for the emissions domain. The pattern is consistent over the years and the shift is primarily due to the variability in the mixing layer heights and wind speeds between the seasons (and years)[14].

Figure 7: Variation of monthly average tracer concentrations compared to the annual average concentration for the Delhi area



In 2009, the Central Pollution Control Board (CPCB) announced that Delhi is now the "Asthma Capital" of India[15]. Starting in late September and early October, 2010, depending on the meteorological conditions, **assuming that the air pollutant emission trends remain the same across Delhi, very little can be expected to change in the current air quality trend**.

[13] The meteorology utilized in this analysis is from NCEP Reanalysis data, including 3D fields of wind speed, wind direction, mixing layer height (calculated using 9 other meteorological parameters), and precipitation. NCEP Reanalysis data for a number of meteorological parameters is available for free from 1/1/1948 @ http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

[14] Full report for this study is available as SIM-air working paper No. 31 – "Role of Meteorology on Urban Air Pollution Dispersion: A 20 Year Analysis for Delhi, India" @ http://www.urbanemissions.info/

[15] Mail Today, March 2009, "Delhi is India's Asthma Capital" @ http://www.intoday.in/index.php?id=24240&option=com_content&task=view&sectionid=5

Air Quality Management

The air quality in Delhi improved in the early 2000's due to a number of interventions, including the large scale conversion of the bus fleet and the 3 wheeler fleet from the conventional gasoline and diesel to compressed natural gas (The benefits of CNG conversion in Delhi on global climate and local pollution are summarized *Reynolds, et al., 2008*) [16]. However, the large increase in the demand for personal transport and construction activities reversed these trends in the last 3 years. An illustration for the passenger cars is presented in **Figure 11**, depicting the doubling of cars since 2000 and how this affects the total emissions. Though the air pollution improved immediately after the bus and 3-wheeler conversions, a constant growth in the car sector, especially the diesel vehicles, nullified all the benefits in case of the PM pollution.

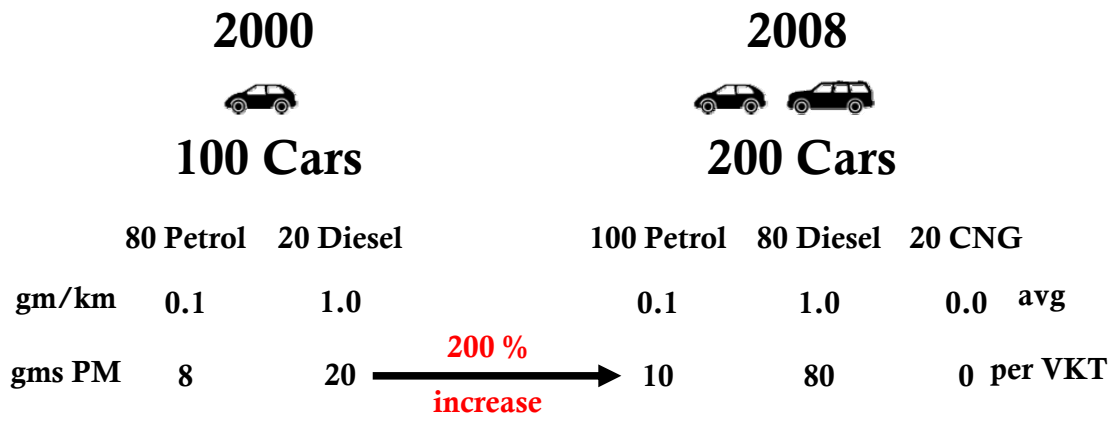


Figure 11: An illustration of how benefits of CNG bus conversion are lost to diesel cars

A major intervention that Delhi is banking on is the extension of the metro rail system, to shift the motorized transport trends to the metro rail system. The expected level of shift is uncertain, which depends on a number of factors. A "what-if" analysis revealed a reduction of ~7 percent in the criteria pollutant emissions due to the existing metro lines in the northern sector and the benefits could range from 20-45 percent when the full 165 km of the metro rail system is functional by the end of 2010. This is also very consistent with other cities like Mumbai, Shanghai, Beijing, Bangkok, and Hong Kong, which experienced significant changes in the air quality after the expansion of the public transport systems with a metro system. Certainly, the challenge will be public awareness, promotions, and incentive schemes for the public to use these systems more frequently than their personal mode of transport.

[16] A recent report on the benefits of CNG conversion are summarized in "Climate Impacts of Air Quality Policy: Switching to a Natural Gas-Fueled Public Transportation System in New Delhi", *Environmental Science and Technology*, 2008. @ http://pubs.acs.org/doi/abs/10.1021/es702863p

Table 3: Measures introduced by the Delhi/National Government during the Commonwealth Games[17]

Increase in road supply	Government has invested Rs. 56,460 million on 26 flyovers, ROBs and road under-bridges.
Extension of public transport system	3,775 sleek low-floor buses are added to the fleet, - to ferry spectators to and from different Games' venues. Delhi Transport Corporation will be providing a special bus fleet consisting of more than 600 CNG-fuelled buses. New metro lines - is being added with the allocation of Rs. 12,600 crores and increasing the metro coverage to 190 km. Smart card-based ticketing service for integrating public transport during the Games between Metro and Bus. Free travel in public transport for those carrying tickets.
Extension of taxi services	Increase in taxi supply with more sedans added to the fleet and more drivers trained for the mega event. Reports suggest that ~15,000 radio cabs will be operational before the Games. At least 1,000 solar rickshaws will deployed to ferry over 7,000 athletes and their delegates during the Games.
Strengthening Vehicle Emission Standards and improving fuel quality	It's as per the National Plan – Euro IV fuel was introduced in the city in April, 2010. Not specific to Commonwealth games
Increase in park and ride facilities/Parking supply	Increase in parking supply with an investment of Rs. 4,730 million.
Vehicle restrictions in specific areas	Vehicle banning on certain roads around major stadiums and games village. Two proposals in discussion are (1) to ban vehicles not registered in Delhi to enter the restricted zone (2) congestion fees in the restricted zones during the games.
Improvement in Intelligent Transport Systems (ITS)	GPS buses, CCTV's, e-payment of traffic violations, Google transit facility for Metro. Customized travel footprint calculator will be installed at kiosks where people can come and calculate the carbon emission during their travel from their home to the Village or venues. Reports suggest that ITS operation plan with smart signals would be delayed and would not be ready before the games.
Promoting Car Pools	Pan City Mega Carpool Scheme. The cars of all the members would be fitted with a device comprising of a card reader, global positioning system (GPS) etc. The device can read the smart card based photo identity card of a member, sense the location of the car and transmit this data digitally to a central agency. A member of the carpool scheme may give a ride to any of the enrolled members who have a common or along-the-way travel destination. By giving rides, the member would earn mileage points which would be redeemed as cash or family

[17] Source: The material on measures is compiled by
Mr. Sudhir Gota @ Clean Air Initiatives for Asian Cities, Manila, Philippines

	members can avail of them by using the car pools.
School holidays	As a step towards easing traffic during the Games, the Delhi government has decided to give schools – both government and private – a 17 day autumn break this year.
Power plants and industries	The power plants inside the Delhi area will be either closed or work under reduced loads. A proposal is put forward for closing some industries beyond the outer ring road.
Air quality information	The Indian Institute of Tropical Meteorology (IITM), Pune, has developed a System of Air Pollution Forecasting and Research (SAFAR) In technical collaboration with CPCB, Aria Technologies SA (France) developed another forecasting system, which will remain operational under CPCB's guidance after the Games.

In the transport sector, the emphasis is on the public transport. The JNNURM funds for buses and urban transport strategy of India are promoting the need for infrastructure for new buses (via two of the largest manufacturing firms - Tata and Ashok Leyland). A good public transport system, including substantial support for non-motorized transport (NMT), is expected to help reduce the congestion levels, energy demand, and thus emissions from the transport sector. However, the initial phase via the introduction of the Bus Rapid Transport for ~5km lane and promoting NMT along the path dealt with severe teething problems in Delhi.

In the Short Term

With the Commonwealth Games around the corner, a lesson from Beijing to Delhi is very obvious. The involved institutions need immediate focus on the local air quality in order to bring the pollution to a manageable level, fast and efficiently. Some suggestions to public bodies include

- Improve the number of air quality monitors operated in the city. There are more monitoring stations than the stations that can actually deliver monitoring data. Even if we consider the most important pollutant, such as PM and not worry about the other pollutants (in order to keep the costs low), the stations that measure this are limited.
- More than operations, the data should be made public as frequently and consistently as possible, so general public are also aware of the consequences of their actions.
- Better understand the sources, the contributions of in-city and outside-city pollution sources. Currently, a lot of emphasis is put on the transport sector. However, the contributions from the industrial, power, and residential sources are very significant and in October (and in the winter months), with low inversions, these low lying residential sources (via biomass burning) will hinder the "clean air" goal.
- The hot spots of industrial and residential areas (many of them outside the Delhi area, but included in the National Capital Region) should be monitored to manage the emissions in real time.
- In case of Beijing, stringent regulations and policy measures were implemented, months in advance, to ensure clean air days before and during the 2008 Olympic Games. However, this remains a challenge for the Delhi authorities. Given that the

Delhi Government can neither shut down industries nor stop half their in-use vehicle fleet during the CWG 2010, a series of innovative interventions could be introduced for fast and effective air quality management. Such as

- Shut down part of the industries, depending on the meteorological and air quality forecasts (either daily and weekly)
- Strict restrictions on garbage burning during the winter months, especially the open burning for heating purposes in the residential areas
- One way transport along the major corridors for better flow of the traffic. Some corridors are already dedicated for the movement of the athletes, but similar provisions should be made for passenger travel
- Aggressive procurement of buses and incentives to promote the use of bus and metro rail systems
- Promote telecommuting where possible, especially along the satellite cities like NOIDA and Gurgaon, which experiences the largest rush hour traffic during the week days
- Promote wet sweeping of the all the major roads, at least once in two days to reduce the amount of dust loading and thus reduce the resuspension due to increasing vehicular movement

In the Long Run

- The air quality monitoring network needs serious improvement in all respects – the number of operational monitors, placement of the monitors across the city, dissemination of the monitoring data to the public and the media, access to the archives of monitoring data, and provisions for further analysis.
- In general, there is greater understanding of the pollution sources in the city, now than before. There is also a greater awareness among the public on the harmful impacts of growing air pollution. Systematic programs should be introduced in all sectors, starting with tackling low lying sources, such as road dust and residential open waste burning to reduce the daily pollution levels.
- In the power plants, the coal usage is slowly being substituted with the natural gas, at least in the smaller power plants; in order to reduce pollution during the 2010 Commonwealth Games. This intervention should be part of the long term strategy.
- In the transport sector, the public transport (via buses) and the NMT should be promoted equally, along with better traffic management for the passenger cars.

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