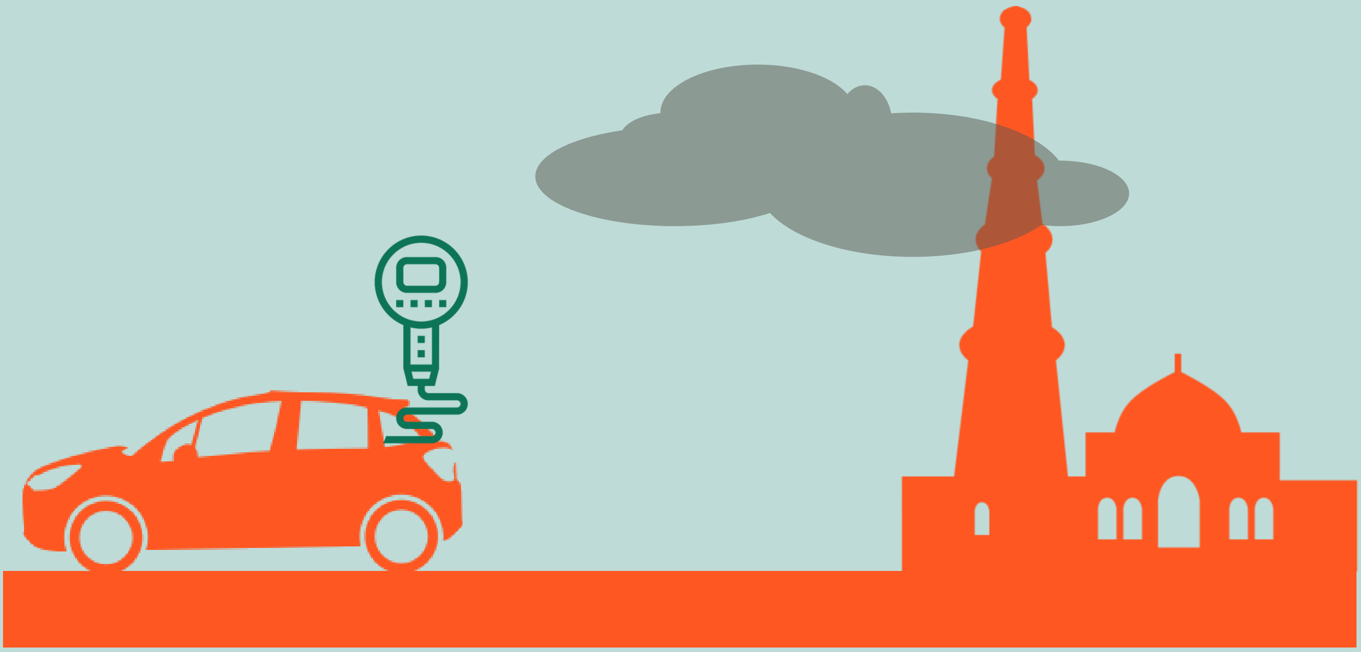
Monitoring & Mapping Urban Air Pollution

One Day Experiment in Delhi, India



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SIM-air working paper series # 29-2009

(UEinfo) was founded in 2007 with the vision to be a repository of information, research, and analysis related to air pollution. There is a need to scale-up research applications to the secondary and the tertiary cities which are following in the footsteps of the expanding mega-cities. Advances in information technology, open-data resources, and networking, offers a tremendous opportunity to establish such tools, to help city managers, regulators, academia, and citizen groups to develop a coordinated approach for integrated air quality management for a city.

UEinfo has four objectives: (1) sharing knowledge on air pollution (2) science-based air quality analysis (3) advocacy and awareness raising on air quality management and (4) building partnerships among local, national, and international airheads.

This report was conceptualized, drafted, and designed by the members of UEinfo.

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Monitoring & Mapping Urban Air Pollution: A One Day Experiment in Delhi, India

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Monitoring Air Pollution in Delhi, India

Like many cities in India (and in the developing world), Delhi lacks the necessary number of operational air quality monitors. **Figure 1** presents the location of the eight monitoring stations in Delhi, India. The red line indicates the inner ring road and the blue line indicates the outer ring road.

Among the eight stations,

- the ITO station is a major traffic junction[1]
- the Delhi University campus station is considered a background site
- the Siri Fort station is located in the premises of a sports stadium, but close to the major corridor
- the Nizamuddin station is a major traffic junction
- Shahdara, Pitampura, Janakpuri, and Ashok Vihar stations are semi-residential and semi-industrial.

Figure 1: Air pollution monitoring stations in Delhi, India

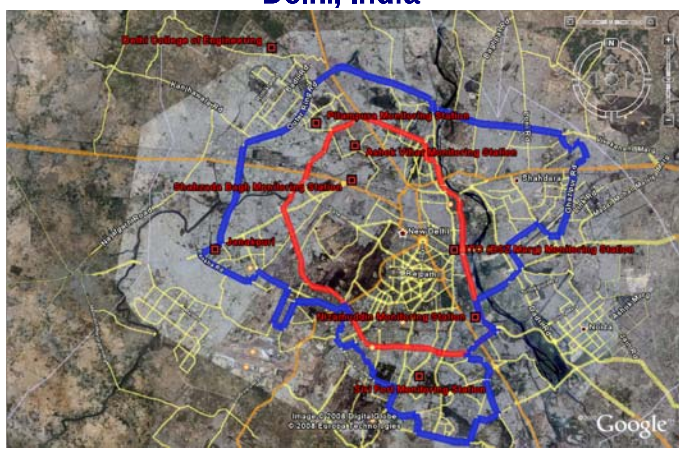

Figure 2 presents a summary of the PM and NO_x monitoring data from these stations.

While the urban area, including the satellite cities, is spread over 900 km^2, approximately 30 km is each direction, these 8 stations cannot sufficiently represent the mix of industrial and residential areas. There is a need for a large scale monitoring campaign to better represent and map the pollution levels based on monitoring.

All the stations routinely exceed the ambient air quality standards[2].

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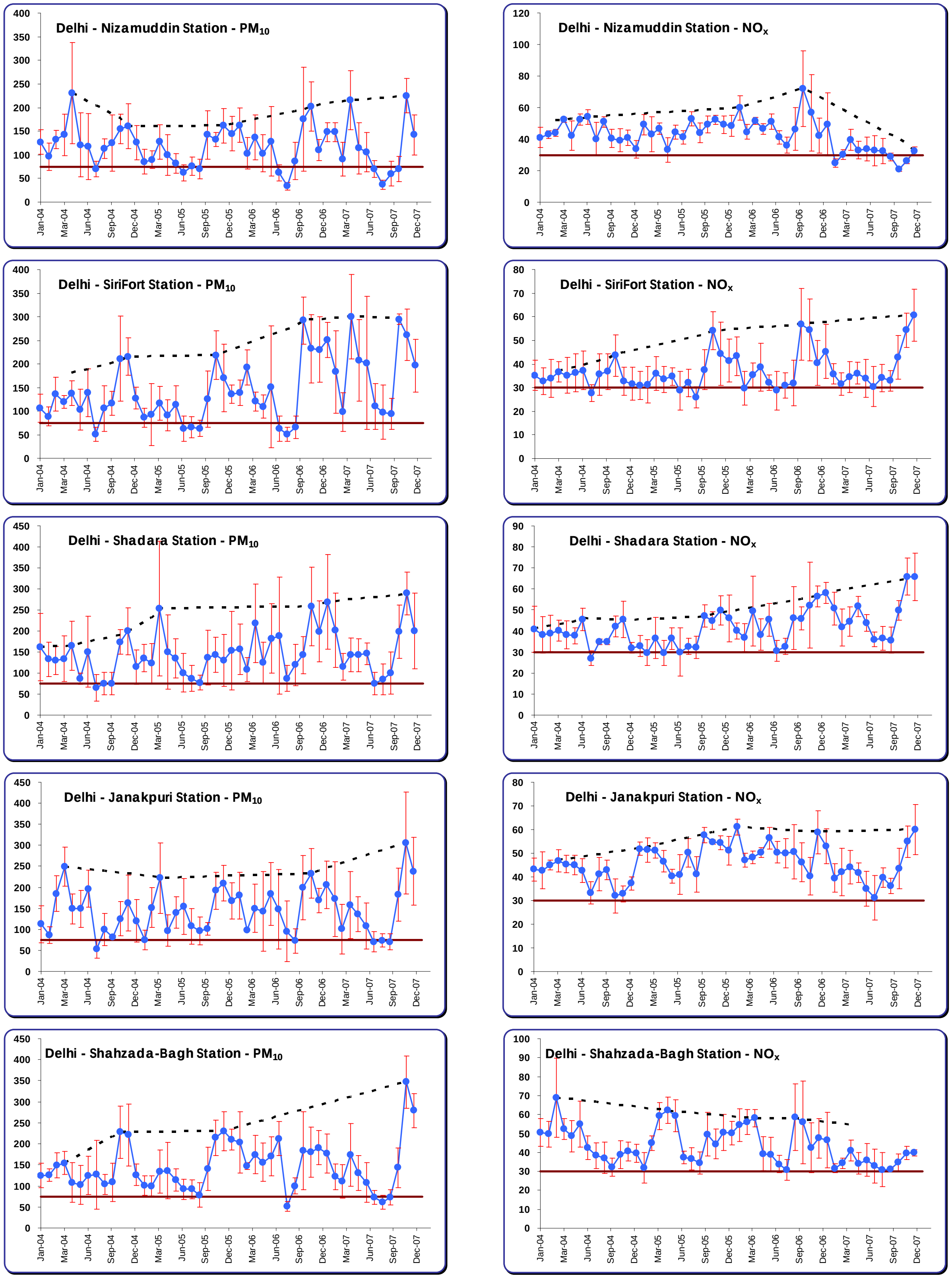
[1] For the detailed analysis of the data including diurnal cycles of pollutants and interpretation is presented in SIM-air working paper No. 23 "Photochemistry of Air Pollution in Delhi, India: A Monitoring Based Analysis" @ http://www.urbanemissions.info/simair/simseries.html

[2] National Ambient Air Quality Standards of India, revised by CPCB in November, 2009 @ http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php

Figure 2: Air pollution in Delhi – 24hr monthly averages with variance over each month



Monitoring Urban Pollution: A Proposal

For any city, "5 basic things for urban air quality management" include

- Monitoring
- Knowing the sources and geography
- Emissions database – baselines
- Modeling analysis – sources and alternatives
- Dissemination of information

Of the five, monitoring is the first. In general, the urban monitoring is restricted to a limited number of hot spots for technical and financial reasons. For urban air quality management and policy dialogue, a point measurement of 20 pollutants is not enough, but one pollutant (say PM, which is critical for exposure and health analysis) at 100 points across the city will provide larger support to argue and explain the science and physics of air pollution.

In today's day and age, with access to state of the art monitors (all sizes and all kinds), the accuracy and replicability of measurements is not an issue. At the end, it is a matter of purpose - mapping the critical pollutant that matters or monitoring many pollutants for compliance?

The proposal: "Measuring what we want to Manage" - 1 Monitor & 100 Points

1 Monitor: The Dust Trak monitors are economical, mobile, and work efficiently[3]. The new model allows the user to log the data with GPS synchronization and the blue tooth facility allows for online mapping (and more possible offline with a GIS interface).

Figure 3: A new model of Dust Trak

Traditionally, the city groups use the continuous monitoring systems which cost over $300,000 (also measure most of the pollutants) and monitors a tier lower which can cost $50,000 to $100,000 for one to three pollutants. This is still financially intense and limits the number of monitors that one can actually operate in the city. Most often, this does not include the operational and maintenance costs. Hence, the lack of required number of monitors in the cities.

In which case, a simple optical monitor, like "dust trak", can help monitor the pollutant that matters the most cheaply. The "dust trak" is for measuring PM only. With calibration, this instrument is known to measure up to $PM_{1.0}$.

[3] For details on the models and specifications on Dust Trak, visit @ http://www.tsi.com/en-1033/products/14000/dusttrak%C3%A2%E2%80%9E%C2%A2_aerosol_monitors/3226/8530.aspx

100 points: For any city, being able to measure a single pollutant at 100 points on a regular basis is considered ideal - more the merrier.

A 100 point scan of the city and overlaid on a physical map with residential, road, and industrial backgrounds, with some interpolations, will provide an immense data set for hot spots and pollution analysis. For policy dialogue, a map like this will provide a better argument with the local authorities than from the modeling (which is also as important).

Methodology comes with its limitations on equipment and interpretations, but an exercise like this will provide a movie of the city air pollution in 3D, which is otherwise conducted via modeling - with perfect emissions inventory and full meteorology at the ground level. For example, **Figure 4** presents the results from a 3D modeling of PM pollution in London[4], highlighting the hot spots for exposure analysis and further monitoring.

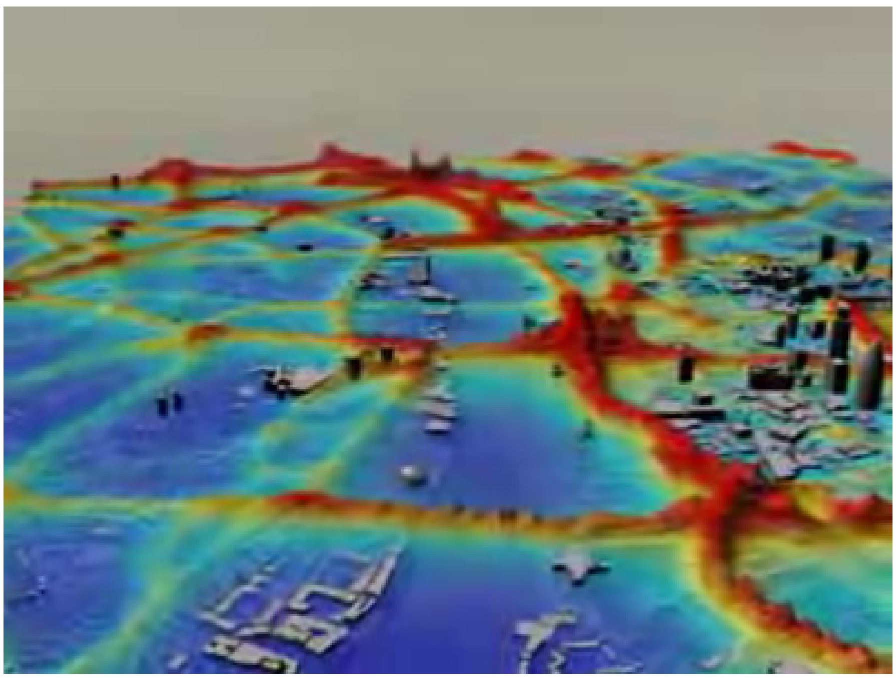


Figure 4: A 3D depiction of PM pollution in London

The goal is to monitor PM pollution at 100 points or more around the city and map it, like **Figure 4**, and gain additional understanding of the hot spots using the monitoring data. More importantly, to do it cheaply and efficiently, which is possible by using a "dust trak" and some planning.

[4] London pollution in 3D @ http://www.visualcomplexity.com/vc/project.cfm?id=513

A One Day Experiment in Delhi, India

This experiment was conducted on October 3rd, 2009 (Saturday) in Delhi, India. Summary of the experiment is presented in **Table 1** and a map of the route is presented in **Figure 5**.

The objective of the campaign was to

(a) test the instruments to measure the primary pollutants – PM coarse (with aerodynamic diameter less than 10 micron) and PM fine (with aerodynamic diameter less than 2.5micron)
(b) conduct a monitoring exercise, covering the residential and industrial areas (all the measurements were conducted roadside)
(c) verify the methodology to map the measured values over the city map

Figure 5: The route covered during the monitoring experiment

The experiment started at UrbanEmissions.Info office in Chittaranjan Park (red dot), west on the inner ring road, north to Azadpur, down to the central district @ Connaught Place, proceeded east towards Shahdara, south to Greater Noida, east on the outer ring road, north of Africa Avenue to India Gate and back to Chittaranjan Park. Follow the animated monitoring route @ http://www.urbanemissions.info/simair/delhimonitoring.html (times presented in the animation (from the GPS) and described in **Figures 7-10** (from hand watch) have a 10 minute discrepancy.

Experimental Setup

Two dust traks, one for measuring PM_{10} and one for $PM_{2.5}$, and one Athelometer for Black Carbon were used, in parallel for this experiment. The experimental setup[5] is presented in **Figure 6**. During the experiment, the BC concentrations were monitored in real time, is record any peaks or abnormalities linked to the surrounds, such as a passing truck or garbage burning. A Garmin GPS unit was used to trak latitude and longitude and a HOBO monitor was utilized to measure temperature and relative humidity along the route.

During the experiment, the BC filter was changed 5 times.

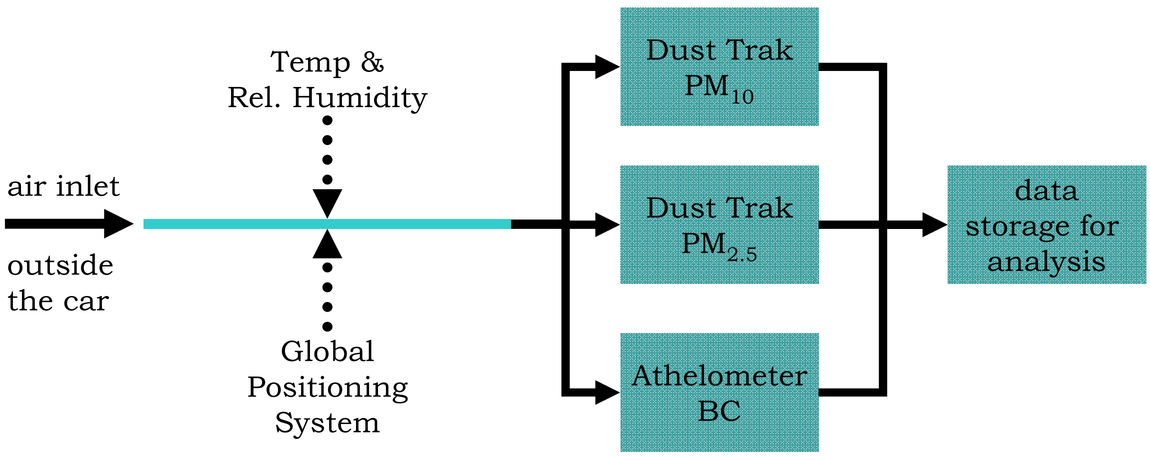


Figure 6(a): Experimental set-up and air flow from inlet to storage

Figure 6(b): Pictorial experimental setup

[5] Authors thank Mr. Conor Reynolds and Dr. Andy Grieshop from the University of British Columbia, Canada, for helping us set up the instruments.

Summary of the Experiment (Table 1)

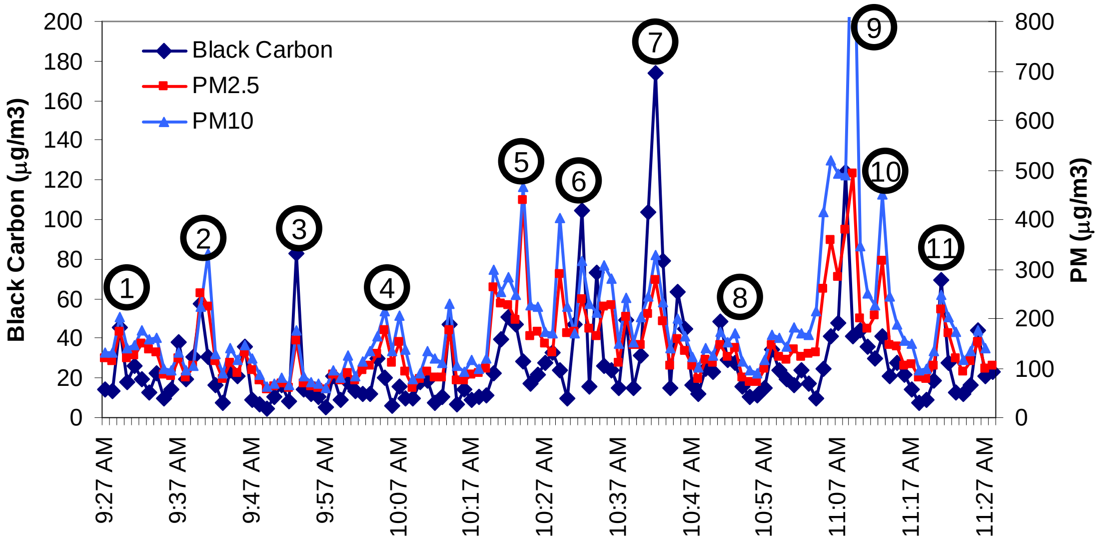
Date	October 3rd, 2009
City, Country	Delhi, India
Day	Saturday – working day for some offices and schools
Time	9:00 AM to 7:00 PM
Pollutants	PM_{10}, $PM_{2.5}$, Black Carbon
Instruments - PM	Dust Trak
Instruments - BC	Athelometer
Distance covered	160 km
Avg. speed while measuring	16 km/hr
PM_{10}	μg/m^3
Range	58 – 2303 (one minute average)
Mean	206
Standard Deviation	210
$PM_{2.5}$	μg/m^3
Range	44 – 2000 (one minute average)
Mean	163
Standard Deviation	153
BC	μg/m^3
Range	4 – 994 (one minute average)
Mean	36
Standard Deviation	57
Temperature	°C
Range	31.1 – 41.5 (one minute average)
Mean	35.5
Standard Deviation	2.4
Relative Humidity	%
Range	29.4 – 60.6 (one minute average)
Mean	45.3
Standard Deviation	6.9

Total number of data points collected at 1 sec interval = 30,812 per pollutant

Figure 7-10 presents a summary of the observations. Values are averaged over each minute.

Observations & Notes

Figure 7: Measurement Period: 9:00 AM to 11:30 AM



9:00 AM – Start from the UrbanEmissions.Info office in Chittaranjan Park. Instruments were setup and monitoring started in 15 minutes.

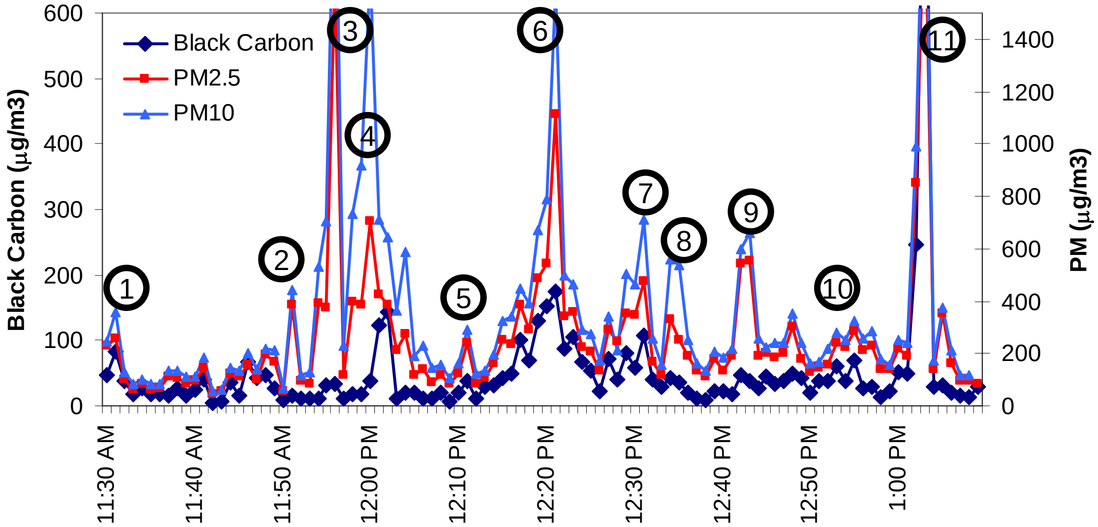
A brief explanation of the observed peaks and surrounds along the way

1) 09:30 AM @ South Extension on the inner ring road
2) 09:40 AM @ Moti Bagh (South)
3) 09:52 AM @ Mayapuri Junction, idling in slow moving traffic
4) 10:05 AM @ Sagarpuri Market, idling in slow moving traffic
5) 10:22 AM @ intersection of Najafgarh Road
6) 10:31 AM @ Subhash Nagar metro station
7) 10:40 AM @ Rajouri Gardens metro station
8) 10:50 AM @ Rothak Road crossing (flyover)
9) 11:09 AM @ GT Road; in the middle of construction sites on unpaved roads
10) 11:15 AM @ Jahangir puri metro station
11) 11:20 AM @ Pitampura, idling in slow moving traffic

At the metro stations, peaks were observed, possibly due to the tunnel effect and funneling of vehicles into narrower roads. On average, idling in slow moving traffic drove the measurements high.

During this period:
Average: PM_{10} = 185 µg/m^3; $PM_{2.5}$ = 143 µg/m^3; BC = 27 µg/m^3
Range: PM_{10} = 60-1141 µg/m^3; $PM_{2.5}$ = 55-491 µg/m^3; BC = 4-174 µg/m^3

Figure 8: Measurement Period: 11:30 AM to 1:30 PM



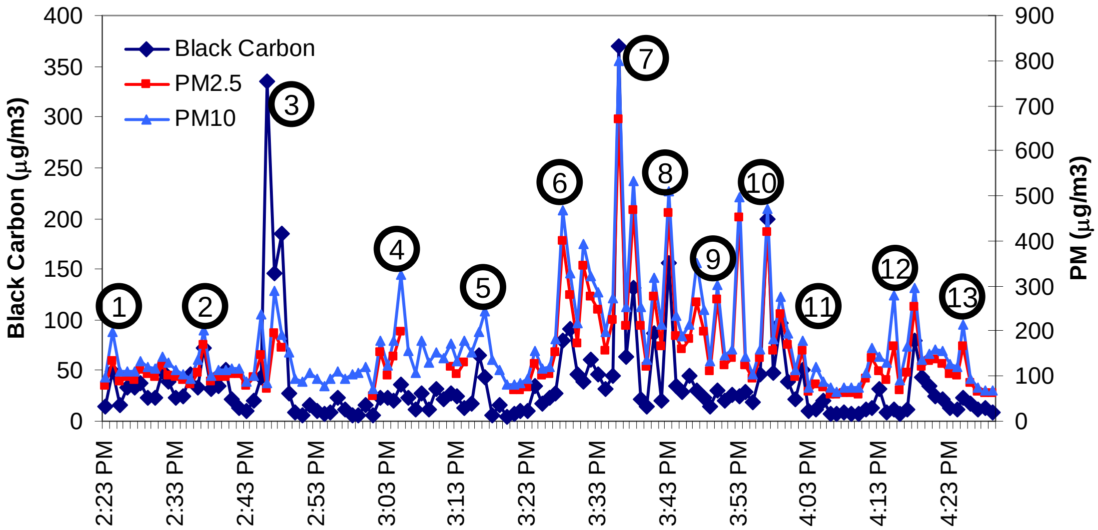
The second section observed higher numbers, partly due to an increase in the traffic. A brief explanation of the observed peaks and surrounds along the way

1) 11:32 AM @ nearing Pitampura metro station, idling in traffic
2) 11:50 AM @ Lawrence Road, slow moving traffic
3) 11:58 AM – car trouble, likely self emissions
4) 12:05 PM – car trouble, likely self emissions
5) 12:10 PM @ entrance of Rothak road, junction
6) 12:20 PM @ Rothak road; long jam, construction site
7) 12:30 PM @ Rothak road; still in jam; slowing moving traffic
8) 12:35 PM @ construction along the road
9) 12:42 PM @ Anand Prabhat
10) 12:55 PM @ Panchkuan towards Connaught Place (CP)
11) 01:03 PM @ Idling around CP

At 12:00, the rental car accidentally entered a ditch on the road and generated extra emissions. Overall, this section observed slower speeds and more idling.

During this period:
Average: PM_{10} = 362 µg/m^3; $PM_{2.5}$ = 261 µg/m^3; BC = 51 µg/m^3
Range: PM_{10} = 58-2303 µg/m^3; $PM_{2.5}$ = 44-2000 µg/m^3; BC = 4-994 µg/m^3

Figure 9: Measurement Period: 2:30 PM to 4:30 PM



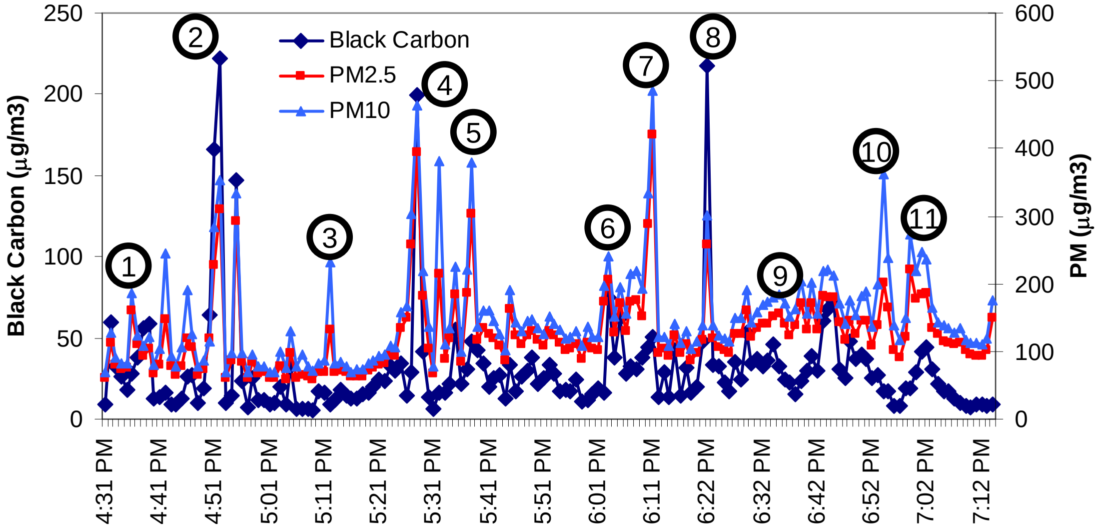
Post-lunch starting at 2:23 PM, this section observed moderate pollution levels (comparatively), as the route passed through semi-residential areas in the East. A brief explanation of the observed peaks and surrounds along the way

1) 02:25 PM @ CP, circling the outer ring
2) 02:40 PM @ Police headquarters near ITO
3) 02:45 PM – car punctured; tire change; passing truck
4) 03:05 PM @ entrance of Laxmi Nagar market
5) 03:15 PM @ entrance of Swami Dayanand Marg;
6) 03:20 PM to 03:25 @ and around CPCB
7) 03:35 PM @ Welcome metro station; slow moving traffic
8) 03:41 PM – saw roadside burning
9) 03:52 PM – saw roadside burning
10) 03:59 PM @ the power plant
11) 04:03 PM – filling petrol; idling cars
12) 04:15 PM @ towards entrance of DND
13) 04:25 PM @ DND; passing truck

Between 3:20 and 4:00, the pollution was observed from a mix of sources, which was not the case in the earlier sections. Overall, the traffic the major roads with metro are observed to be slower than the others.

During this period:
Average: PM_{10} = 172 µg/m^3; $PM_{2.5}$ = 153 µg/m^3; BC = 37 µg/m^3
Range: PM_{10} = 66-799 µg/m^3; $PM_{2.5}$ = 56-668 µg/m^3; BC = 5-370 µg/m^3

Figure 10: Measurement Period: 2:30 PM to 4:30 PM



The fourth section is synonymous to background concentrations, driving through the Greater NOIDA highway and back into the city limits @ 6:00 PM. A brief explanation of the observed peaks and surrounds along the way

1) 04:37 PM @ the Atta market
2) 04:51 PM @ the highway to Greater NOIDA
3) 05:05 PM @ Sultanpur residential area
4) 05:26 PM @ Kalendi Kunj; crossing Yamuna
5) 05:40 PM @ entrance of Outer Ring road
6) 06:02 PM @ IIT gate; entering Africa Avenue
7) 06:11 PM @ crossing of Inner ring road
8) 06:22 PM @ the India Gate
9) 06:35 PM @ crossing of National Zoo
10) 06:56 PM @ GK-1 entrance
11) 07:02 PM @ Nehru place

In all, the monitoring drive covered 160 km in 10 hours.

During this period:
Average: PM_{10} = 152 µg/m^3; $PM_{2.5}$ = 125 µg/m^3; BC = 31 µg/m^3
Range: PM_{10} = 68-484 µg/m^3; $PM_{2.5}$ = 59-420 µg/m^3; BC = 5-222 µg/m^3

It is important to note that the data points are spread across the city and the instruments are sensitive to the temperature and relative humidity around the measurement points. The **Figure 11** presents the measured temperature and relative humidity along the route and the diurnal cycle. The variation in the temperature is attributed to the traffic conditions, peaks were observed while in the slow moving traffic.

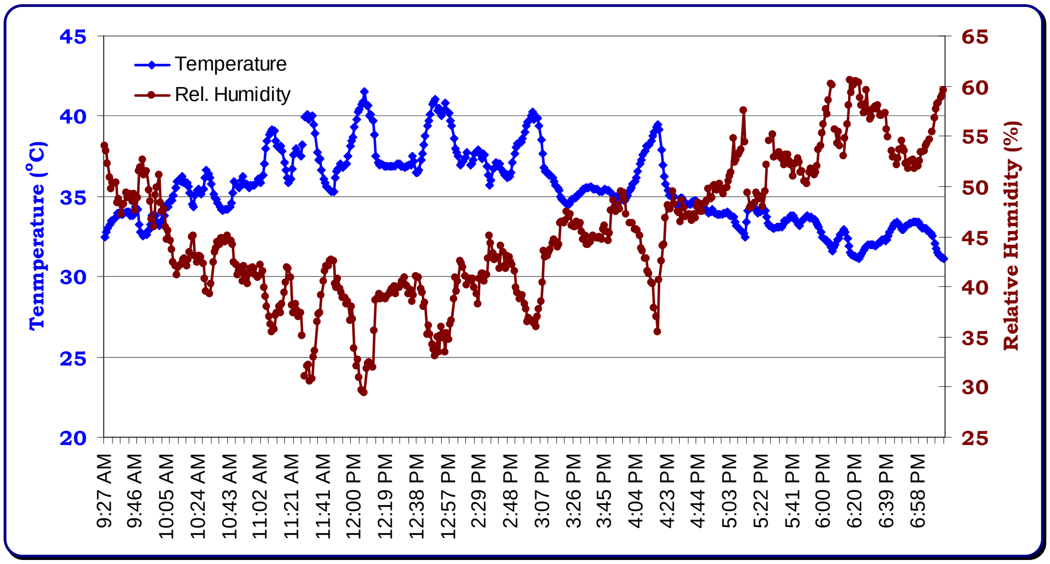


Figure 11: Temperature and relative humidity along the monitoring route

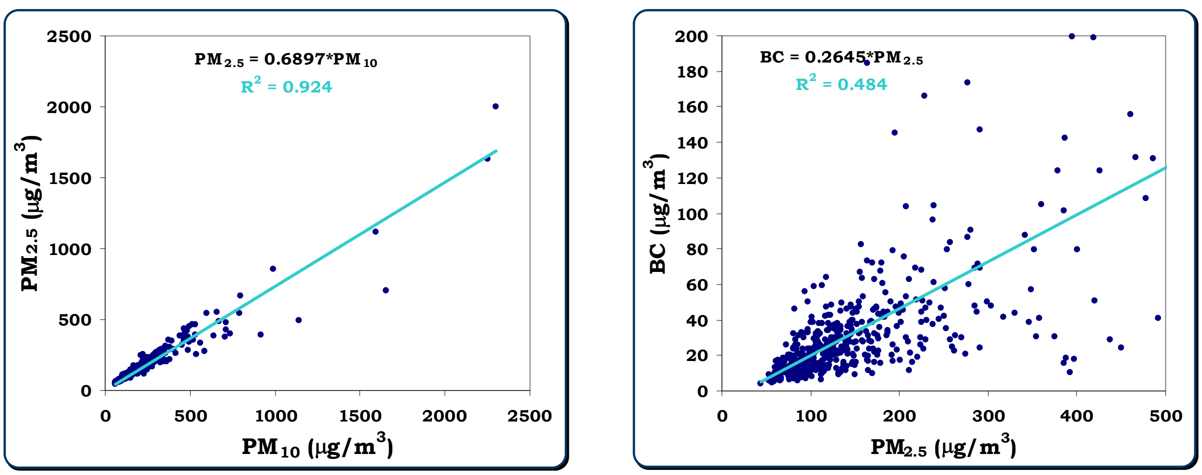


Figure 12: Comparison of measured PM_{10} vs. $PM_{2.5}$ and $PM_{2.5}$ and BC

The availability of two Dust Trak instruments allowed us to study the size fractions in the measured samples. **Figure 12** presents ratios between $PM_{2.5}$ and PM_{10}, which averaged at 0.69, emphasizing the need to monitor the $PM_{2.5}$, more harmful to human health of the two size fractions. The ratio between BC and $PM_{2.5}$ fluctuated, emphasizing a mix of pollution sources besides diesel based along the roads.

Mapping Urban Air Pollution in Delhi, India

While monitoring the air pollution in the city at multiple points was conducted in this experiment along the major roads covering the industrial and the residential areas, the next step of mapping the urban air pollution demonstrates the need for further such studies on a routine basis. **Figure 13** presents an interpolation of the **measured PM_{10} data** over the Delhi map, using the GrADS software.

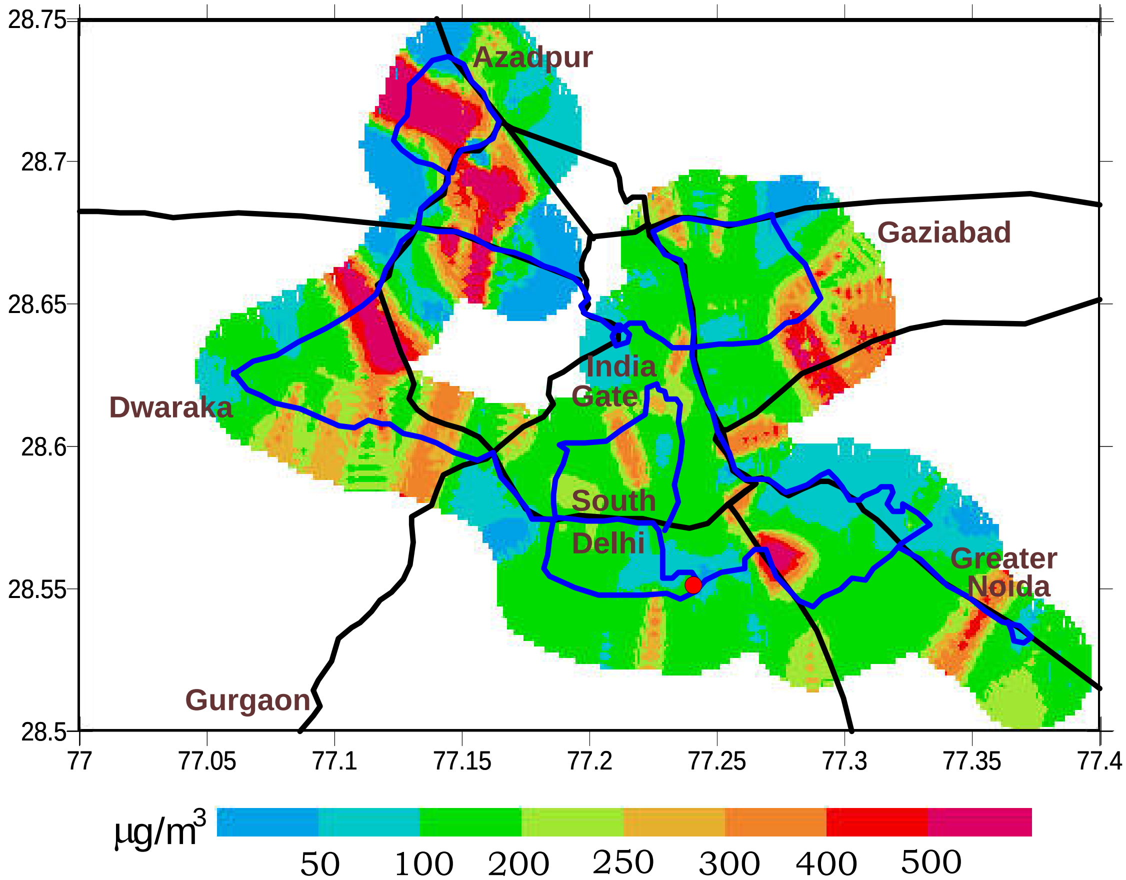


Figure 13: An interpolation of one-minute averaged PM_{10} measurements on Oct 3rd, 2009 blue line indicates the monitoring route; black lines indicate the major roads in and out of Delhi; red dot indicates the starting/ending point

The interpolation of the data presents a bias along the roads and where the measurements were conducted in dense (like the Northern sector). This also shows that if the density of measurements can be increased by many folds, a clear picture of the hot spots and possible exposure levels in the city can be estimated more accurately.

During the experiment, the average
PM_{10} pollution over the 8 hour period = 206 $\mu g/m^3$
$PM_{2.5}$ pollution over the 8 hour period = 163 $\mu g/m^3$
BC pollution over the 8 hour period = 36 $\mu g/m^3$

In the Northwest and West sections, traffic movement was slow, especially along the major corridors, along with construction activities, which contributed to higher ambient pollution levels. The Northwest and East sections also home for industrial areas. The South Delhi, which is more residential, tends to experience on average 100 to 200 $\mu g/m^3$, which is well above the national and WHO health guidelines.

For the current observations, utilizing the average concentrations over Delhi, assuming at least 30% of the population (~5,000,000) is constantly exposed to these levels, and a dose-response function from premature mortality[6] (0.000014 cases/$\mu g/m^3$/percapita), a back-of-the-envelope calculations yields an **annual mortality rate of ~10,900**.

This at willingness-to-pay rate of ~US$50,000.00 (~25,00,000.00 Indian Rupees) translates to **US$545 millions** in health damages due to premature mortality annually.

Recap & Future Plans

The impacts of air pollution on human health are well studied and documented from across the world. However, the depth of the damage is unknown, especially in the developing country cities due to the lack of on-the-ground understanding of where the pollution is and how much. One, we do need to know where the pollution is coming from, which translates to the energy consumption statistics and emissions inventories, but more importantly, we need to know what we are breathing.

If managing the pollution for better health is our primary goal, then we have to measure what we want to manage.

This one-day experiment was put together to demonstrate the new and available technology for monitoring the particulate pollution in the cities, cheaply and effectively. Total cost incurred (excluding the man-power) during this experiment included the following.

1. Instruments – borrowed, thanks to Prof. Julian Marshall at Univ. of Minnesota (otherwise cost ~$10,000 per instrument)
2. Rental car for one day – US$30
3. Food – US$10
4. Software - The data is analyzed and mapped using free or commonly available programs (MS Excel)

[6] For details on the methodology and dose response functions for estimating health impacts of urban air pollution refer to the SIM-air working paper No.6 @ http://www.urbanemissions.info/simair/simseries.html

This is a one-day experiment. This should be repeated 2-3 times a week, for the entire year, to create an animation of the urban air pollution.

A more appropriate and effective methodology will include covering in-between the major corridors, some point measurements across the city (for example, as shown in **Figure 14**) which can be interpolated to a physical map better than what is presented in **Figure 13**.

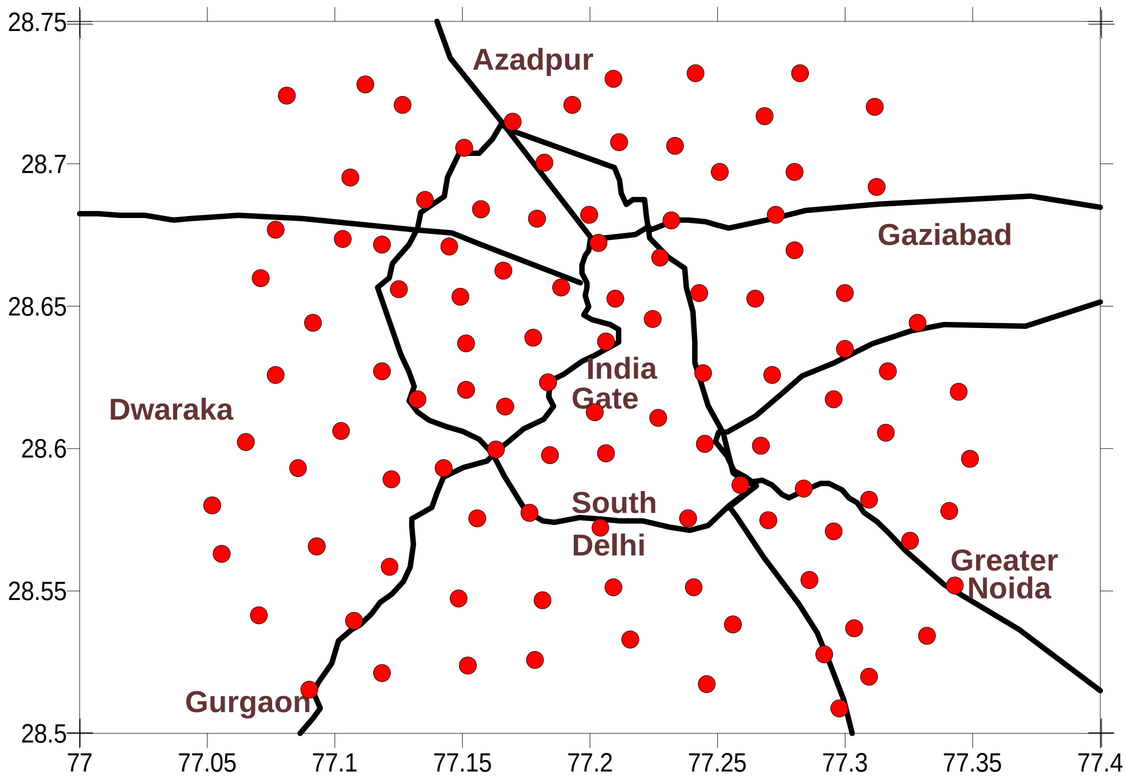


Figure 14: A monitoring and mapping proposal for future

In the coming months, the monitoring route will be repeated, preferably on a working day.

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