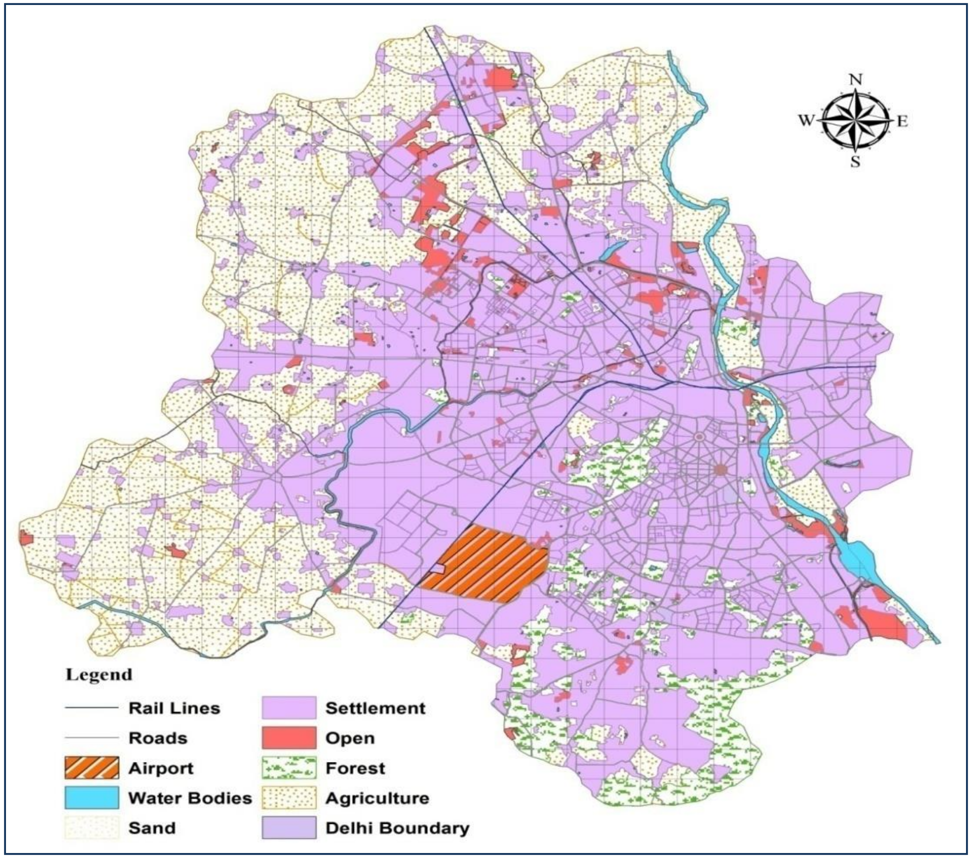
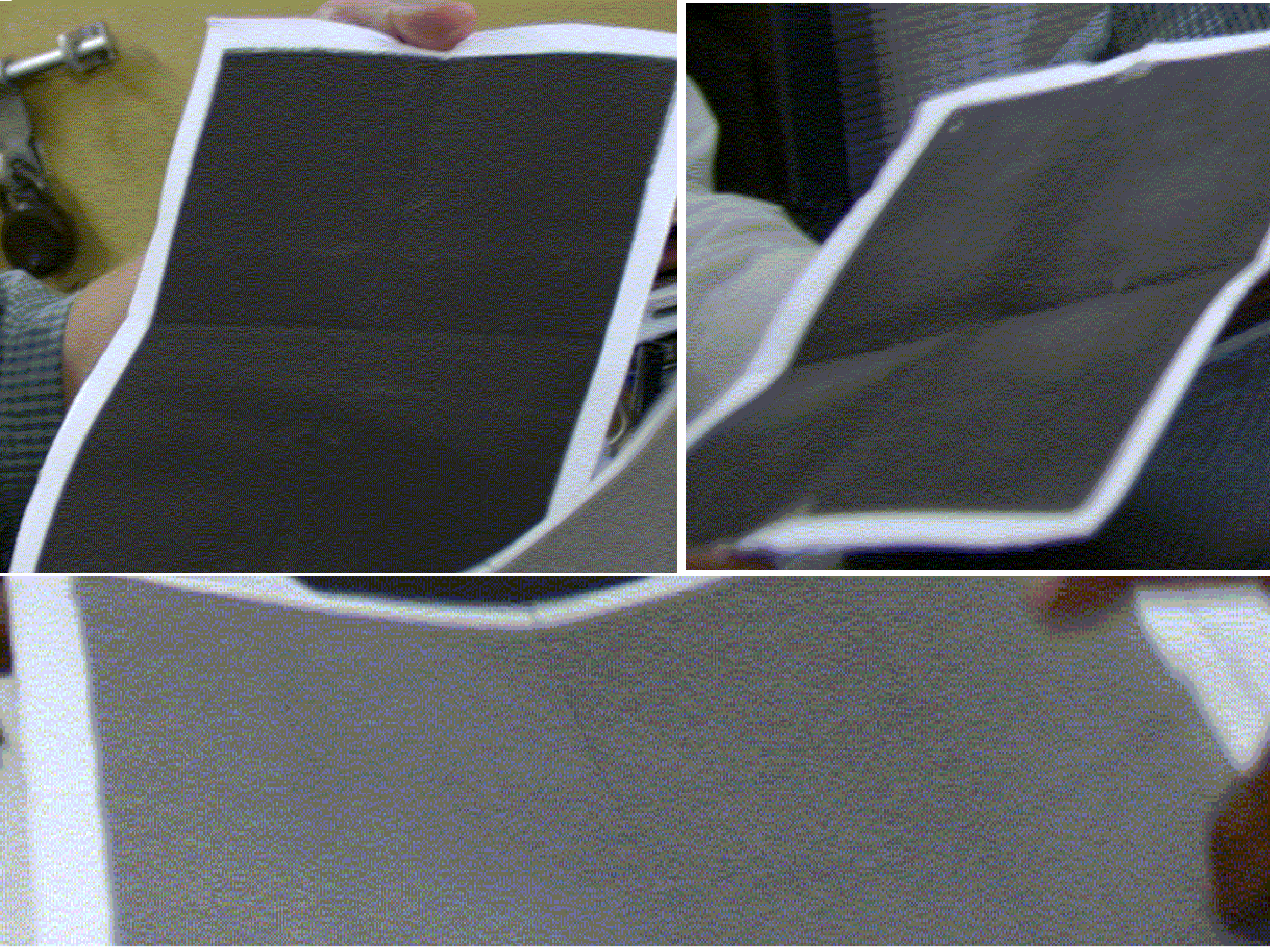
Breathing Clean Air

CII Meeting: November 17, 2016



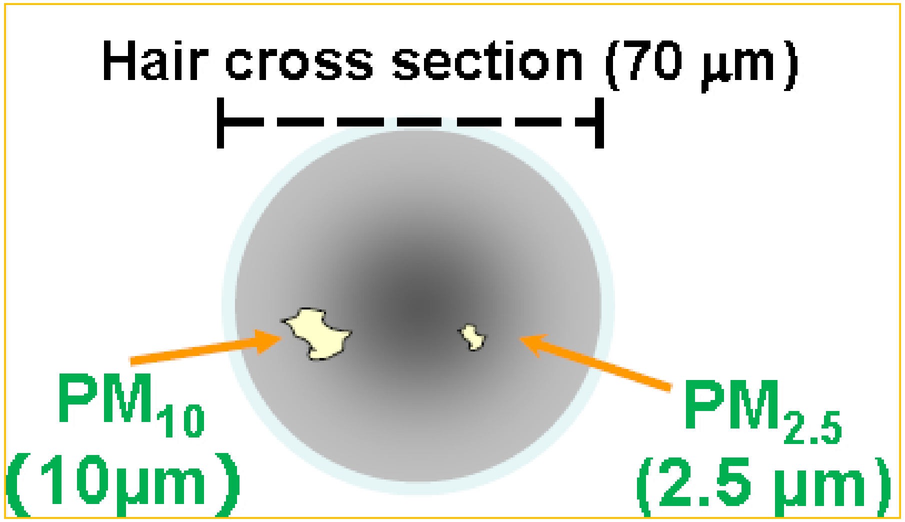
Mukesh Sharma; PhD, FNAE
Department of Civil Engineering
IIT Kanpur



Particulate Matter (PM)

PM_{10}

- Accumulates in lungs
- Contributes to:
  - Damaged lung tissue & decreased lung function
  - Aggravated asthma

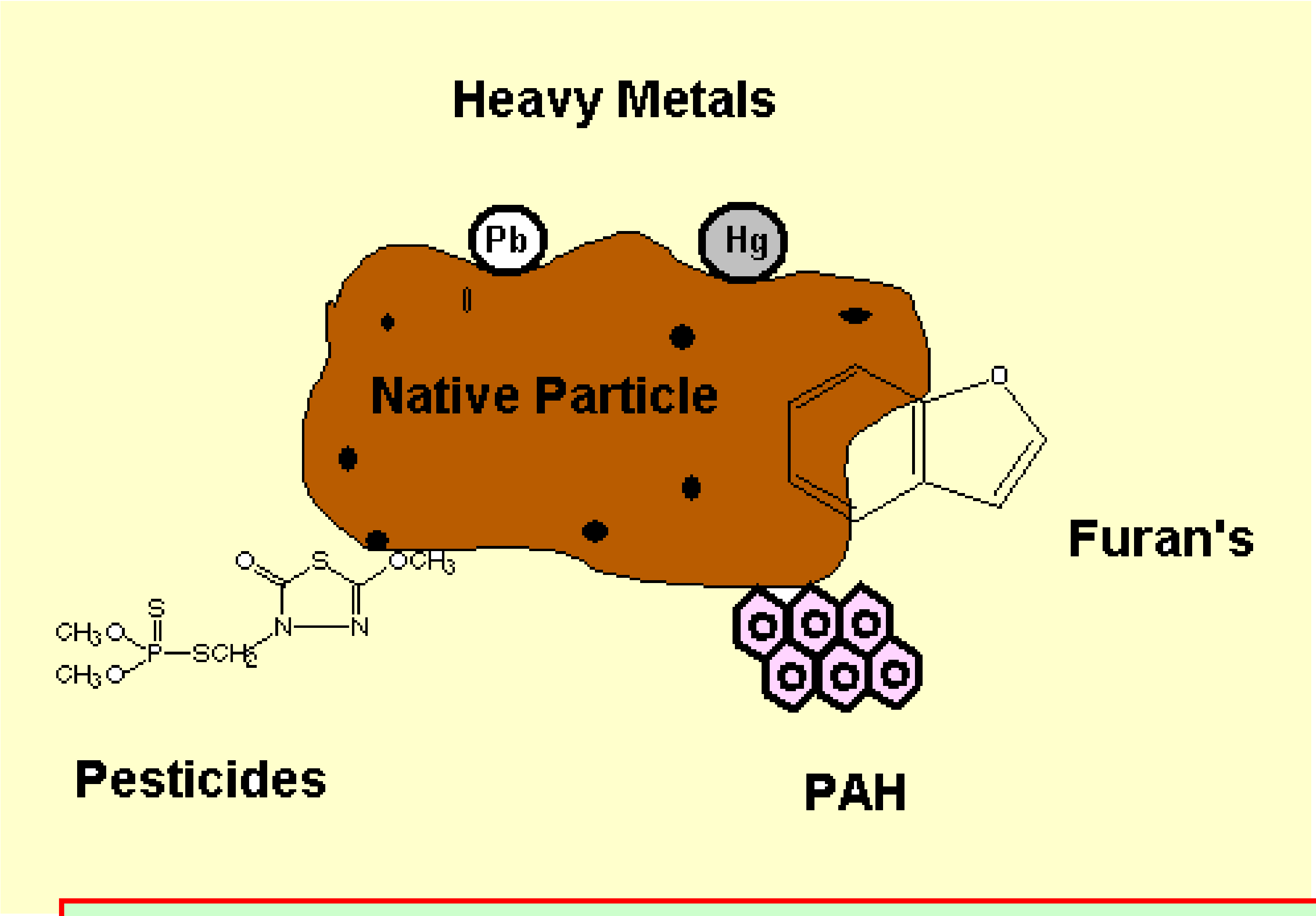


$PM_{2.5}$

- Penetrates deeply into lungs
- Contributes to:
  - Acute respiratory symptoms
  - Increased frequency in childhood illness such as chronic bronchitis
  - Cardiovascular illness
  - Mortality: premature death
  - Toxicity & carcinogen

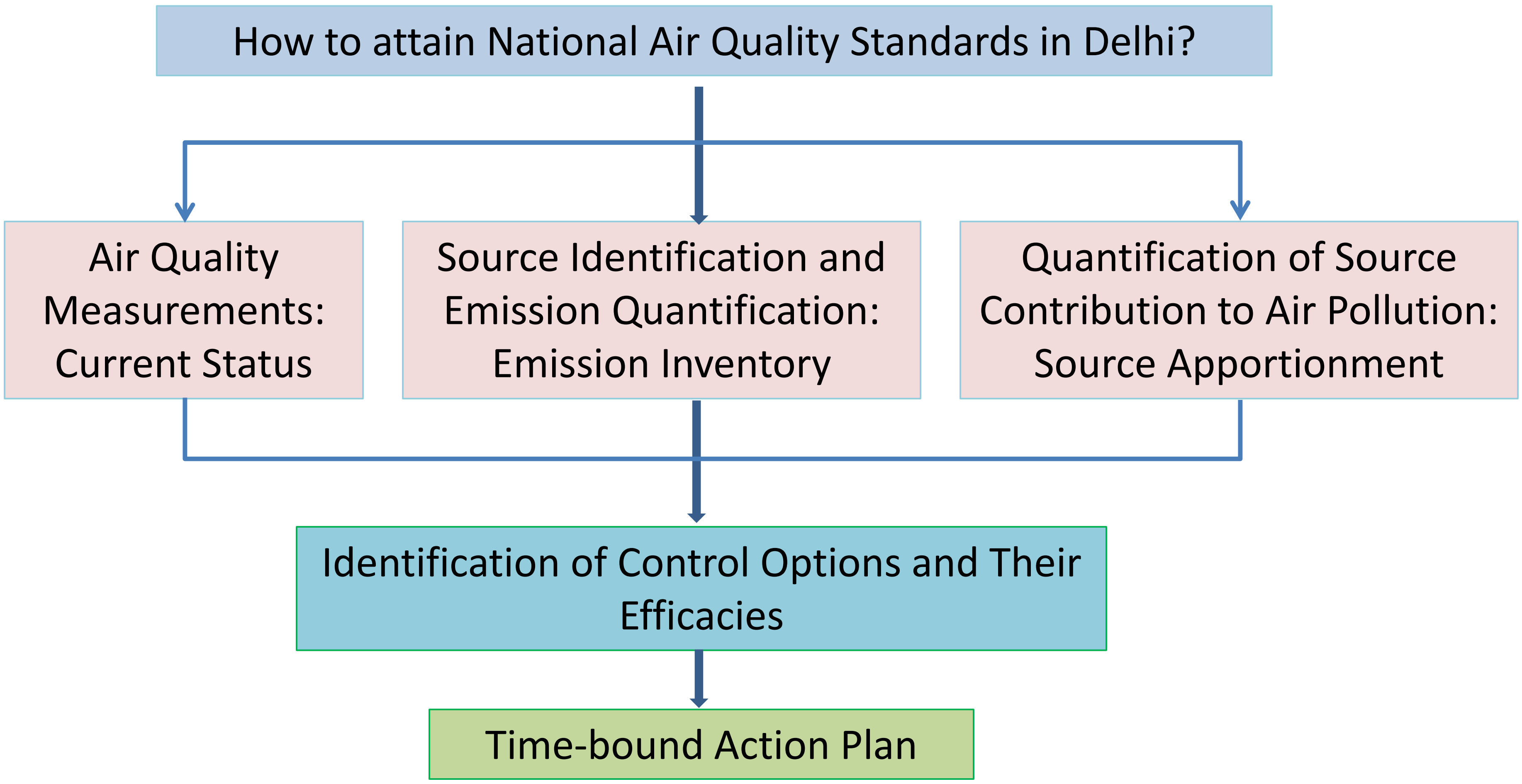
"Fine Particle ($PM_{2.5}$) is the most serious pollutant of concern for Public Health and Environment" *(EPA/OAR, 2002)*

Hazardous Air Pollutants in Particulate Matter



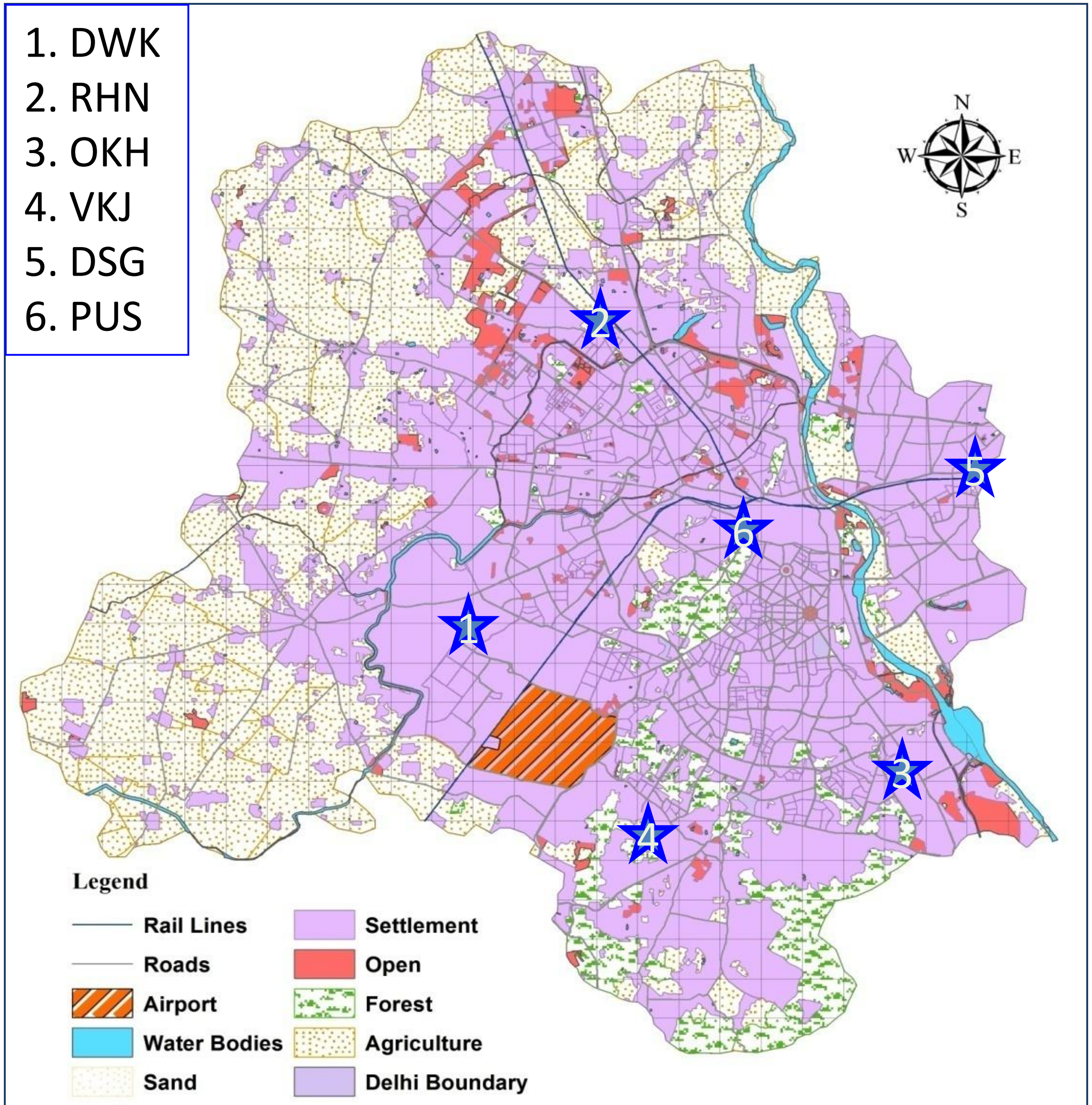
- Surface area (Smaller the Size more the HAPS)
- Elemental Carbon (more adsorption of HAPS)

Background



- A Comprehensive Scientific Study: quantified causal source-receptor impact analysis, control options and their effectiveness, action plan - focus: $PM_{2.5}$ and NO_x

Sampling Location and Land-use Pattern Map of Delhi



Winter

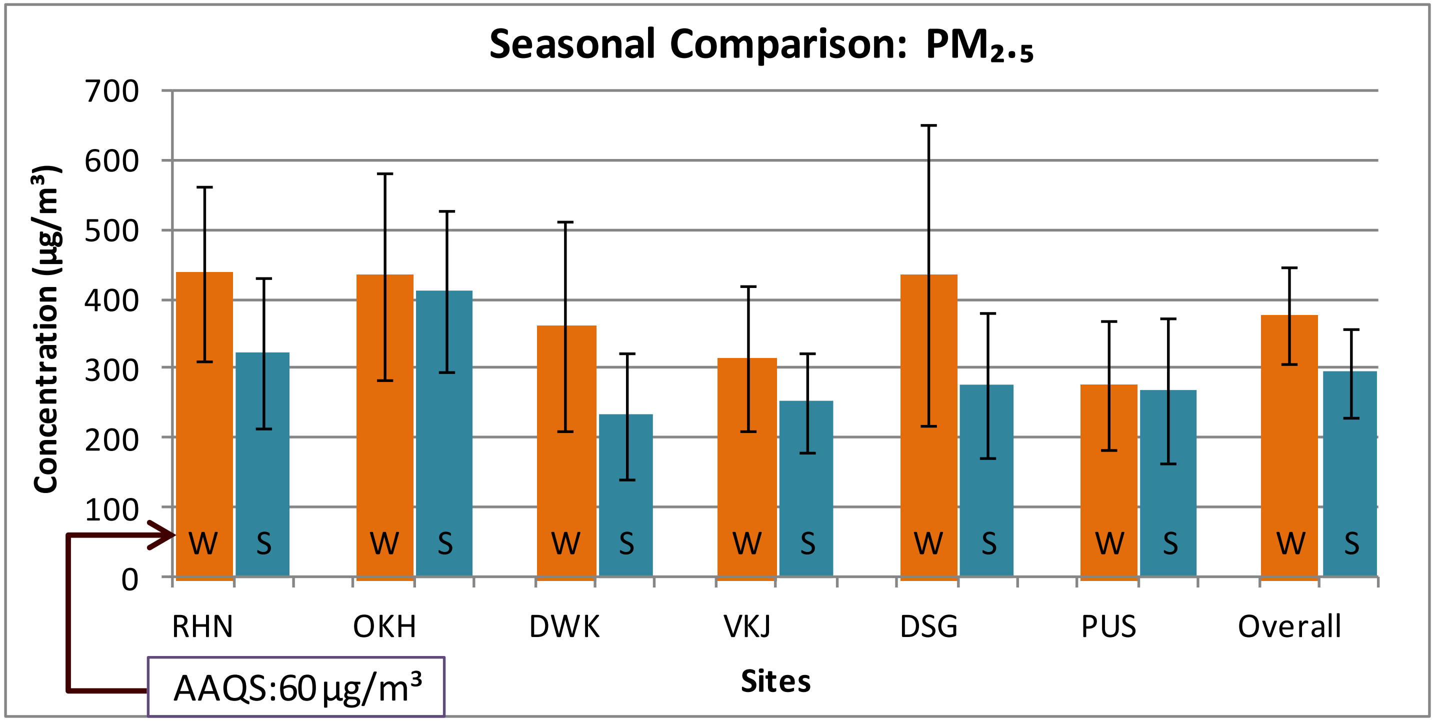
1. Nov 03 - 23, 2013
2. Nov 03 - 23, 2013
3. Dec 02 - 22, 2013
4. Dec 15, 2013 – Jan 04, 2014
5. Jan 24 - Feb 13, 2014
6. Jan 30 - Feb, 2014

Summer

1. Apr 04 - 23, 2014
2. Apr 04 - 24, 2014
3. May 01 - 24, 2014
4. Apr 29 – May 19, 2014
5. May 26 - Jun 14, 2014
6. May 25 – Jun 16, 2014

Air Quality Monitoring Results

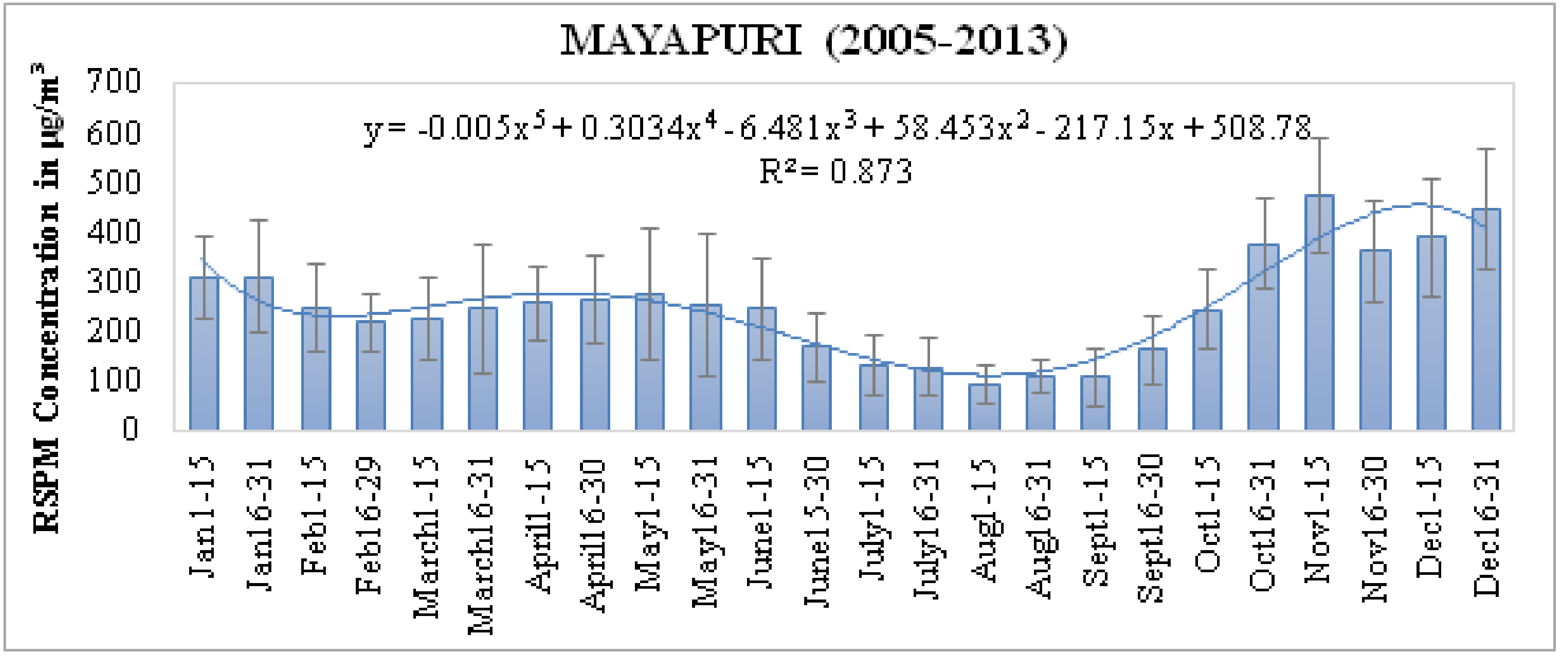
Variation in $PM_{2.5}$



- $PM_{2.5}$ levels are 4-7 times higher than the national air quality standards in summer and winter months.
- The overall average concentration of $PM_{2.5}$ in summer season is around 300 µg/m^3 against the acceptable level of 60 µg/m^3.
- The overall average concentration of $PM_{2.5}$ in winter is 375 µg/m^3 against the acceptable level of 60 µg/m^3.

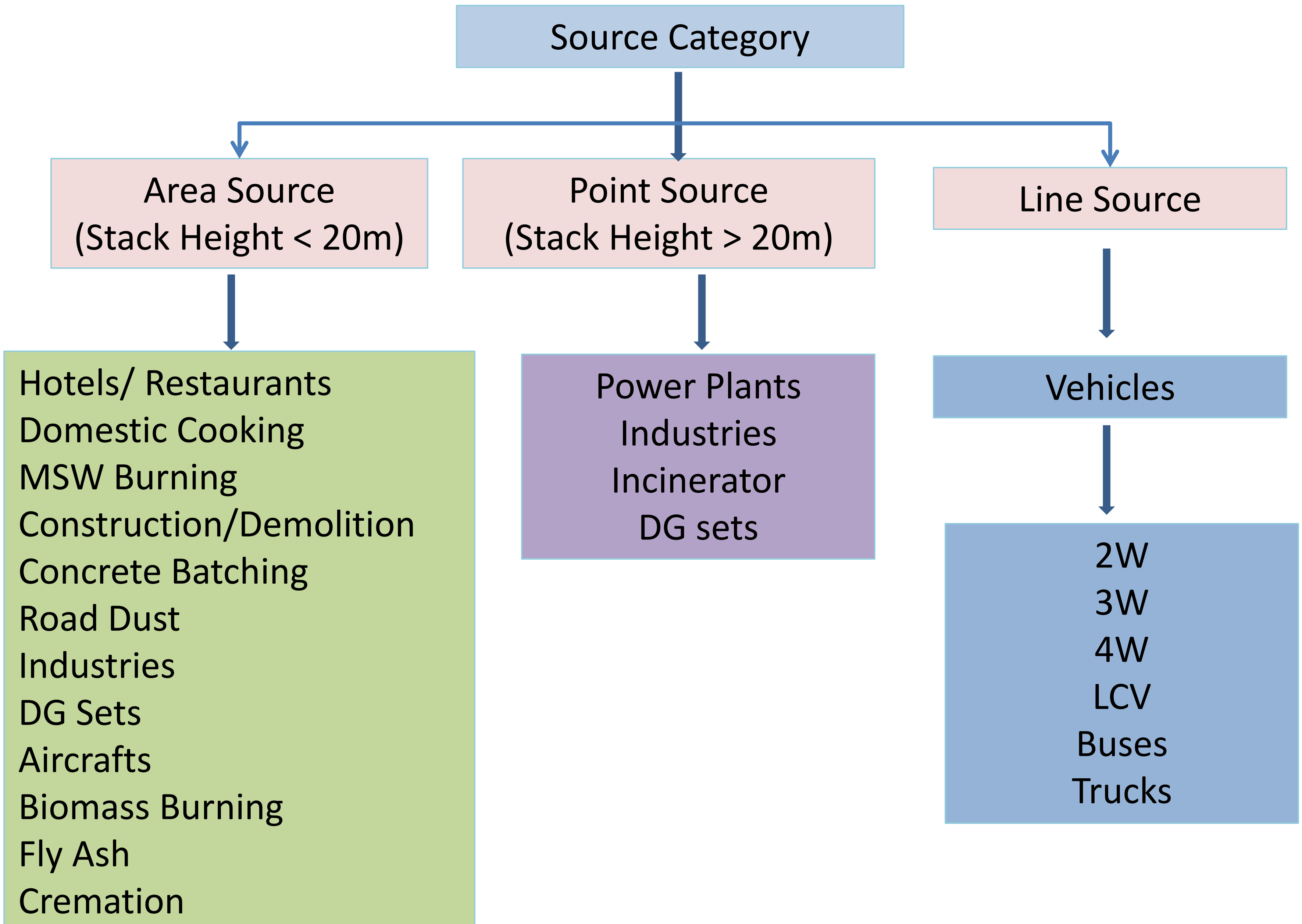
Ratio $PM_{2.5}/PM_{10}$: Winter - 0.63, Summer - 0.57

Annual Pattern of PM_{10}

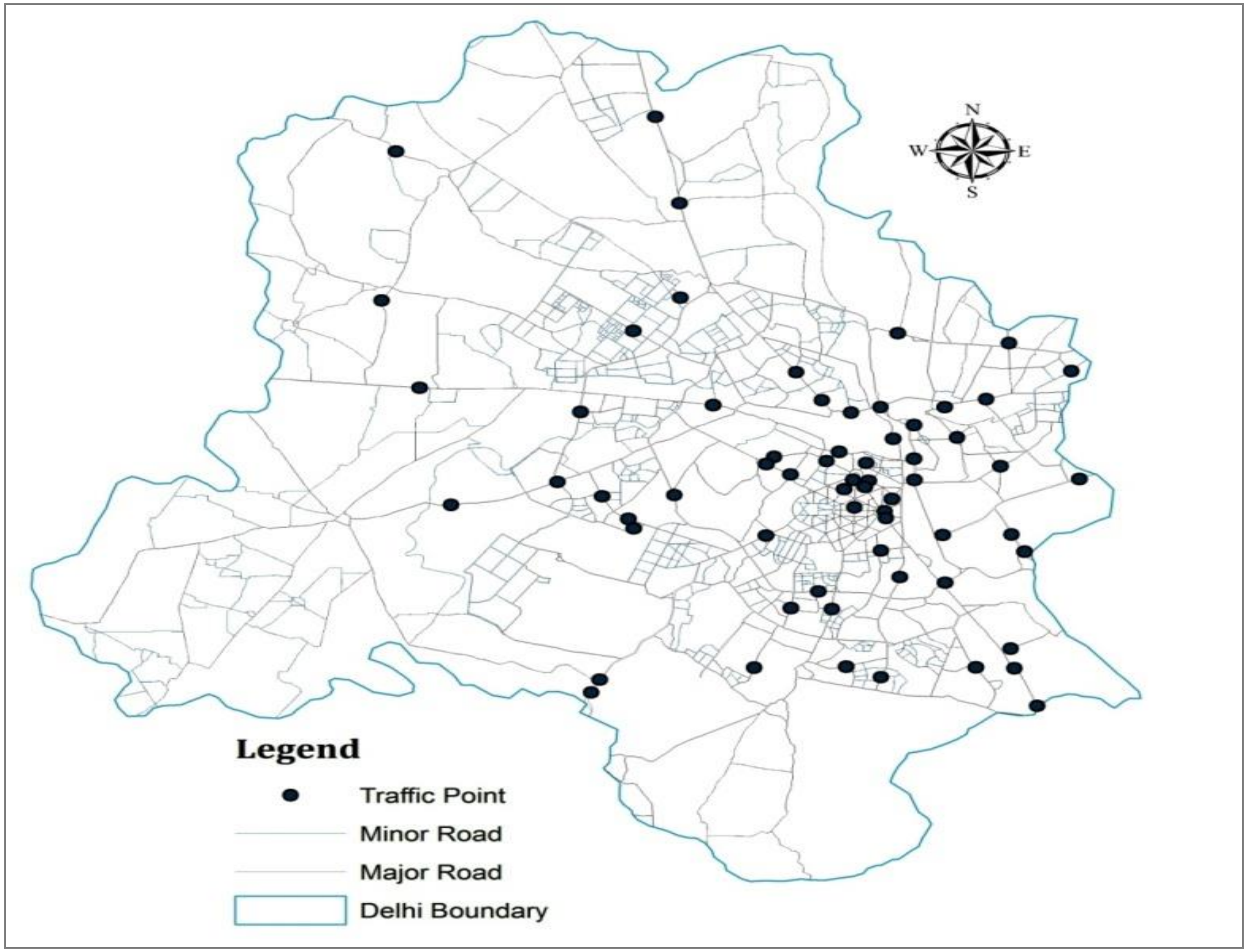


Emission Inventory

Source Categories

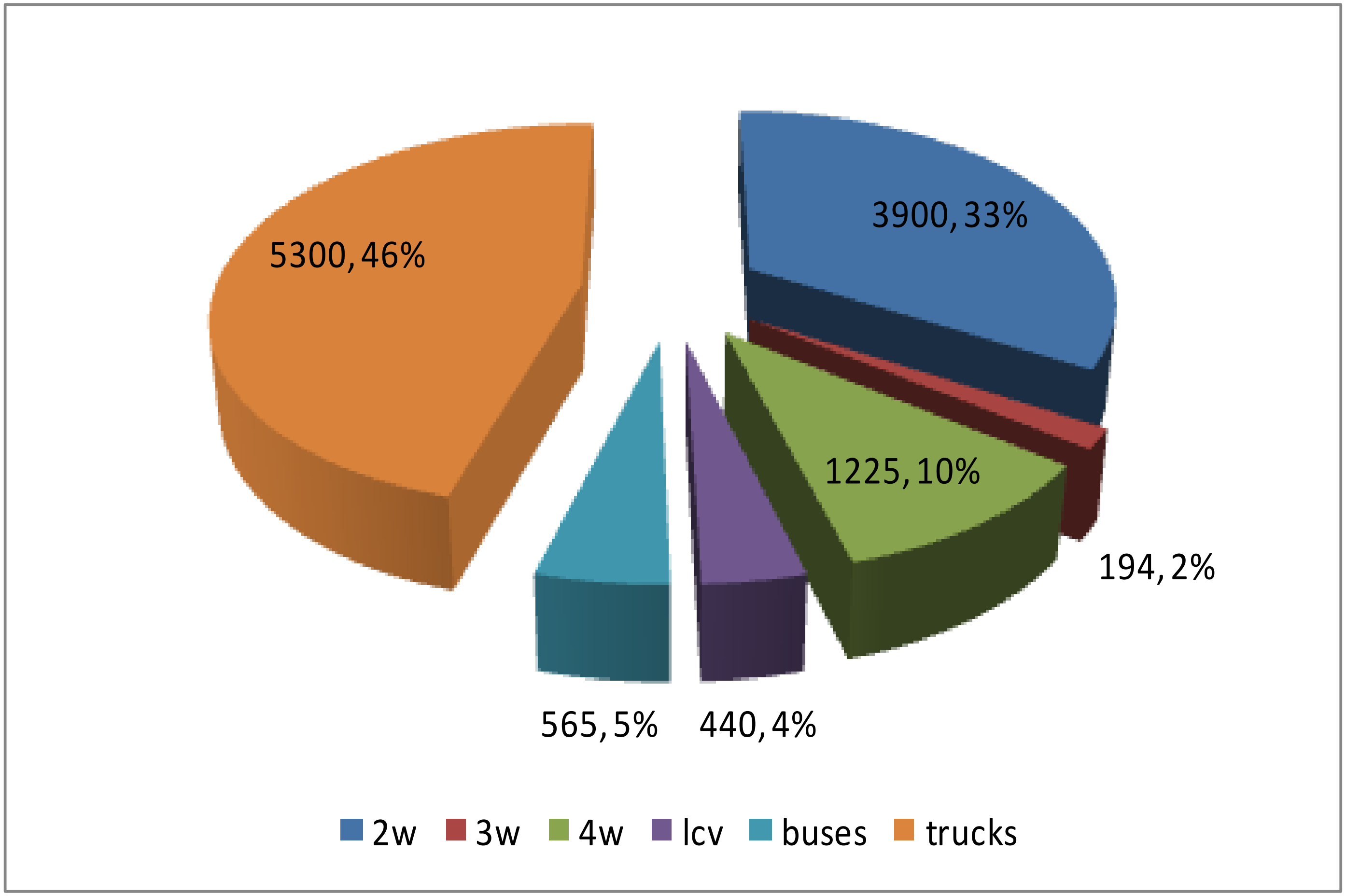


Vehicles - Line Source



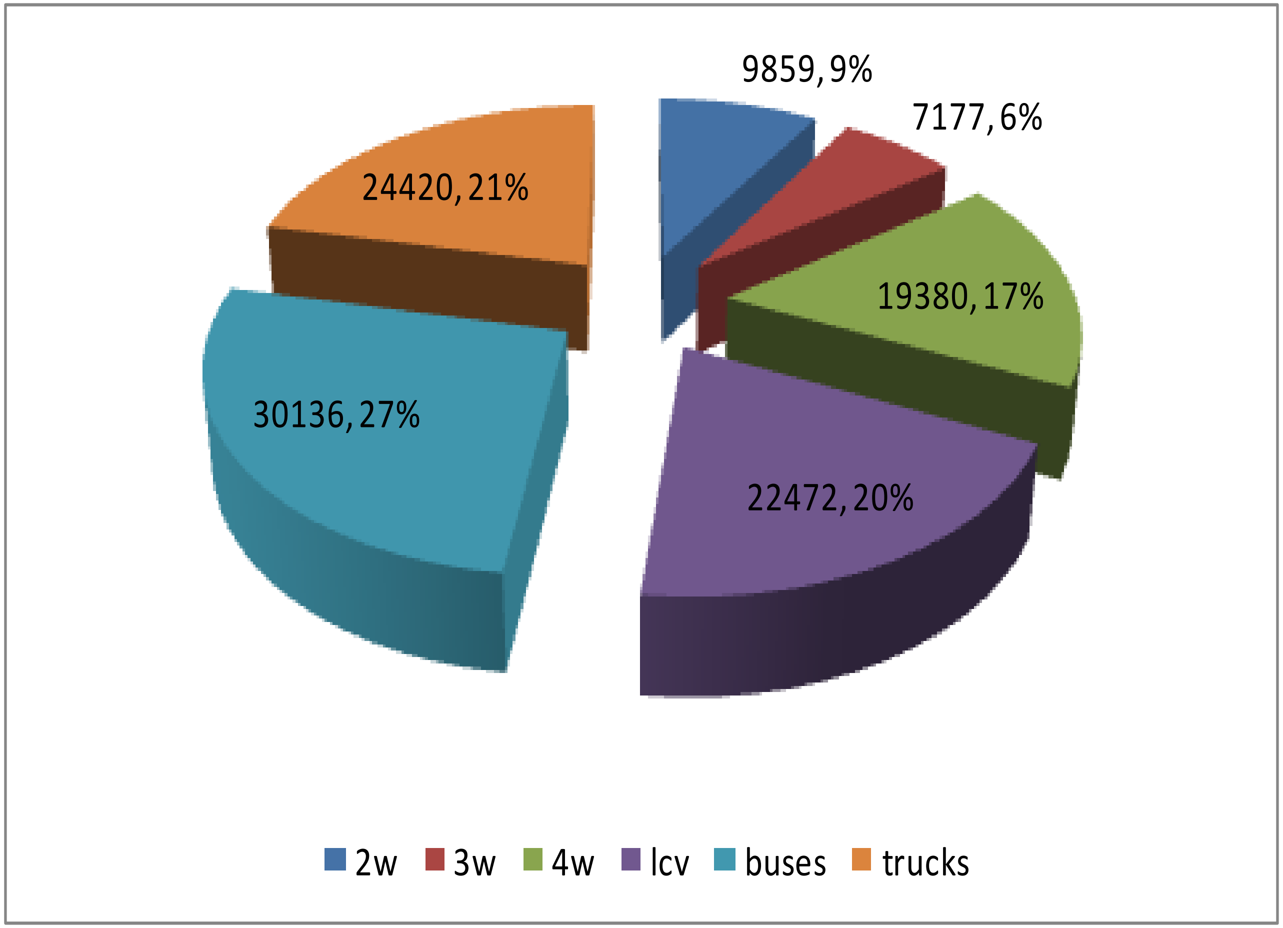
- Traffic Data location for vehicle emission

$PM_{2.5}$ Emission Load from Vehicles (kg/day, %)



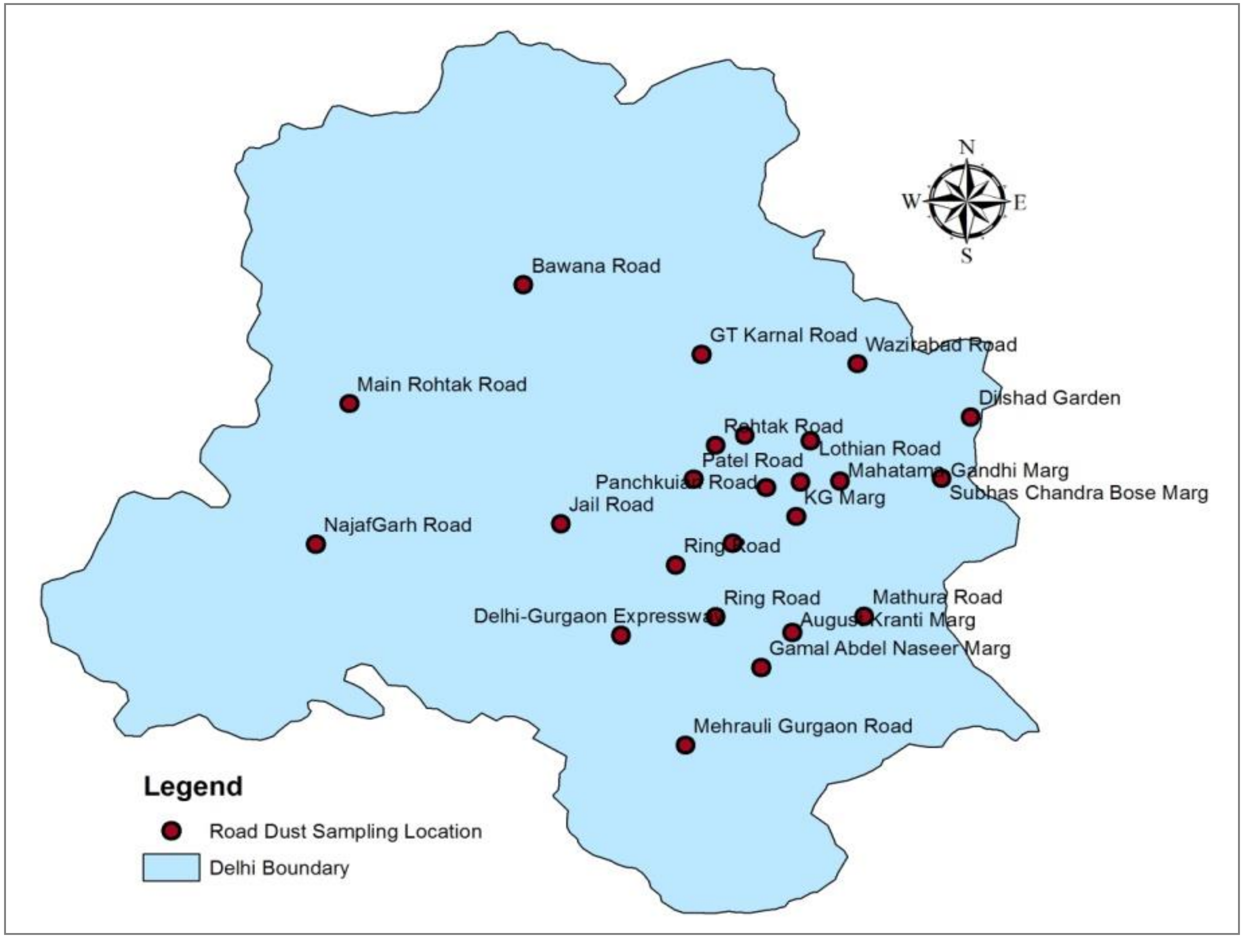
- **12000 kg/d**
- **Major Contributor : Trucks – 46% , 2W – 33%, 4W – 10%**

NO_X Emission Load from Vehicles (kg/day, %)



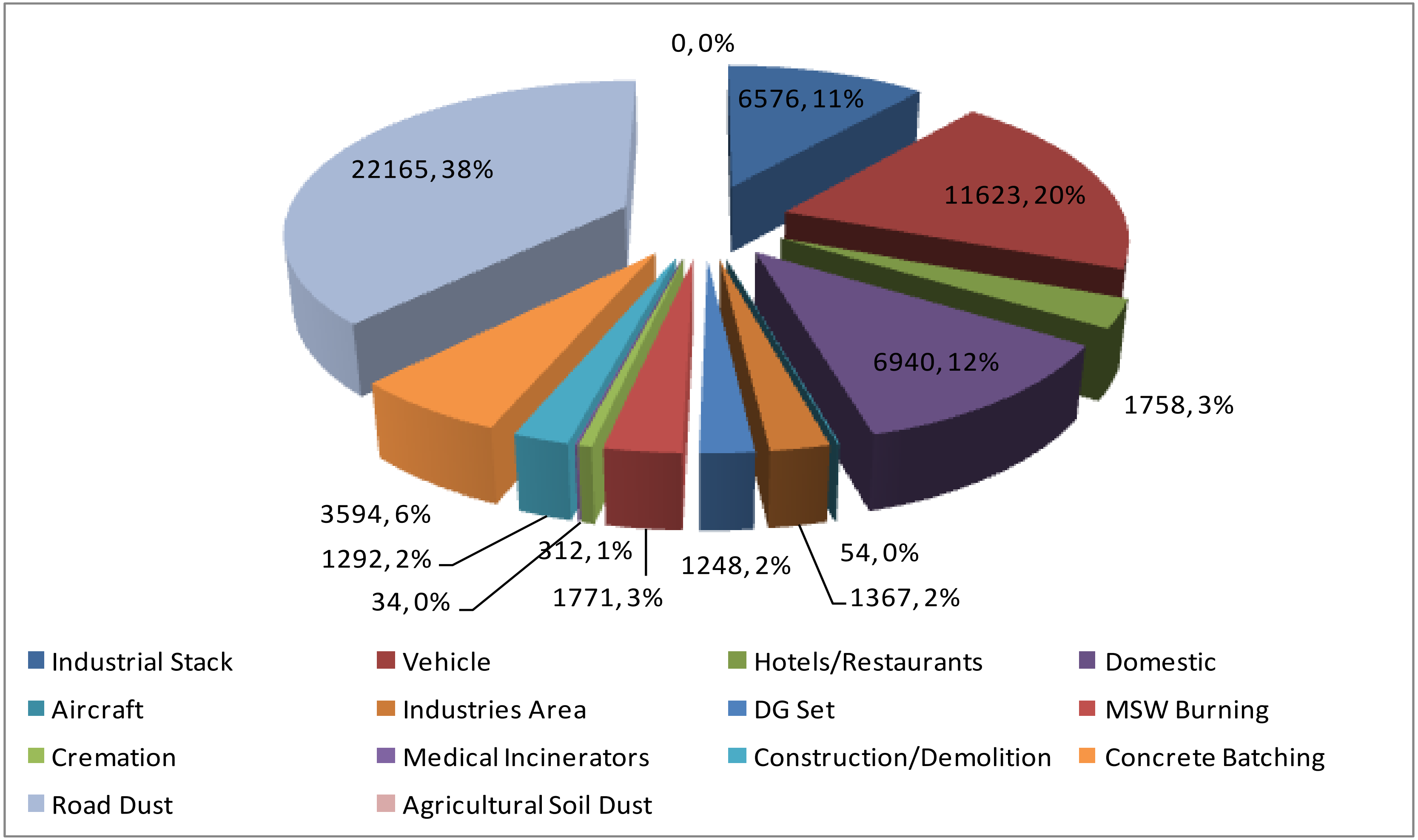
- **Major Contributor : Buses- 27%, Trucks – 21%, LCV – 20%, 4W – 17%**

Road Dust Sampling Locations



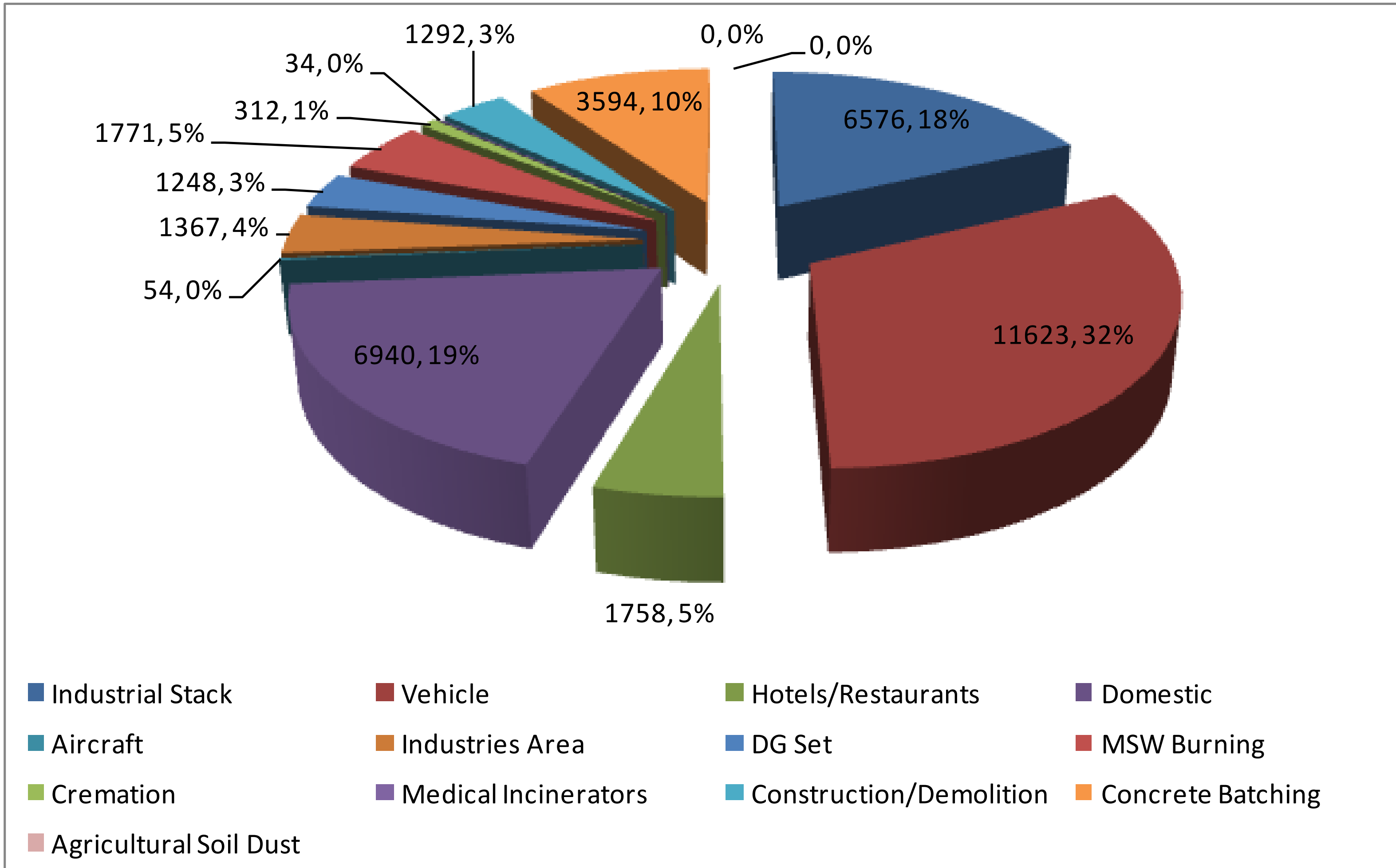
- PM_{10} emission from road dust: 79626 kg/day
- $PM_{2.5}$ emission from road dust: 22165 kg/day

$PM_{2.5}$ Emission Load of Different Sources



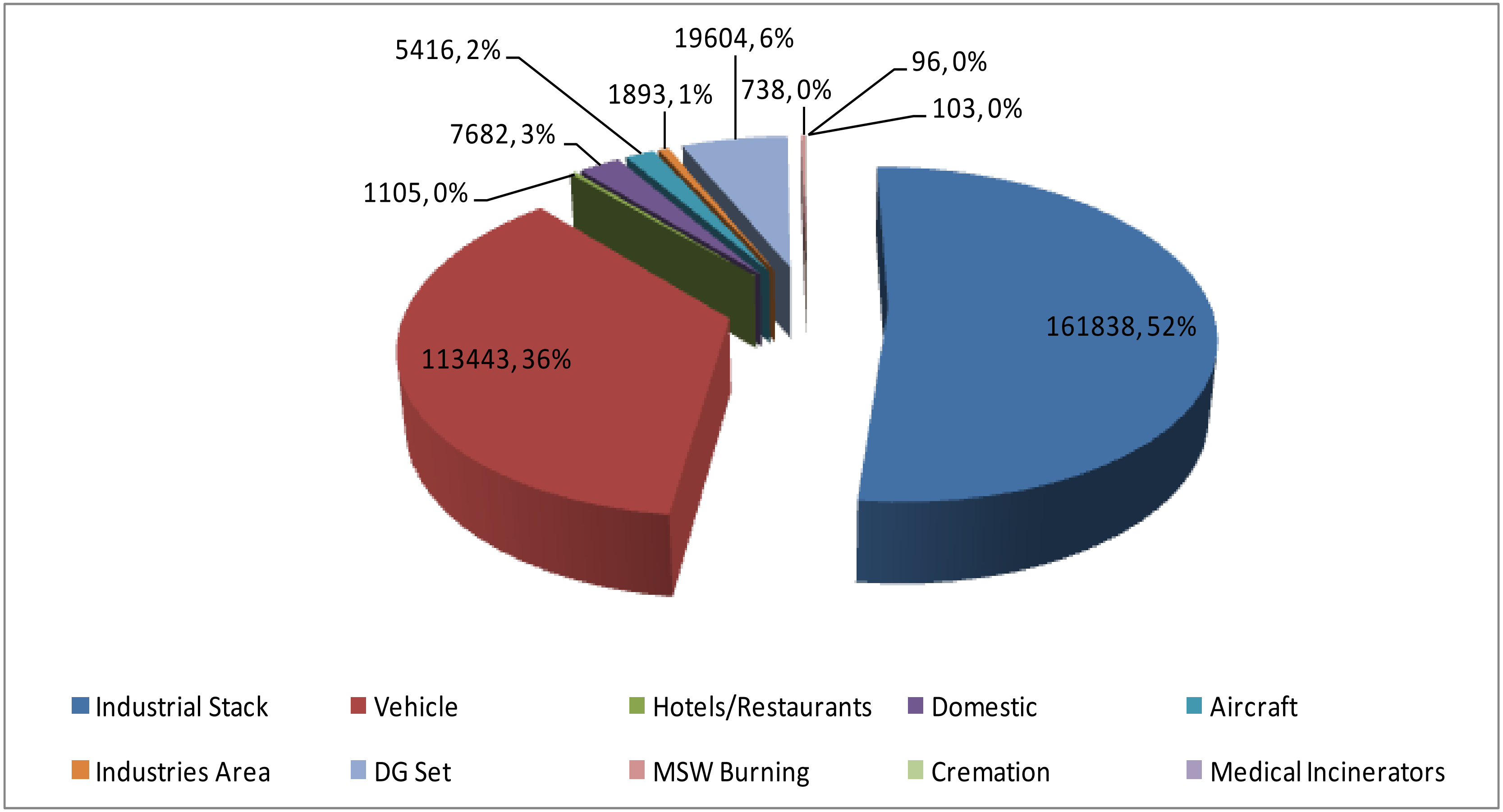
- $PM_{2.5}$ emission load: 59 t/d.
- Road dust (38 %), vehicles (20 %), domestic (12 %) and industrial point sources (11%).
- PM_{10} emission load: 143 t/d.
- Road dust (56%), concrete batching (10%), industrial point sources (10%) and vehicles (9%).

$PM_{2.5}$ Emission Load excluding Road dust



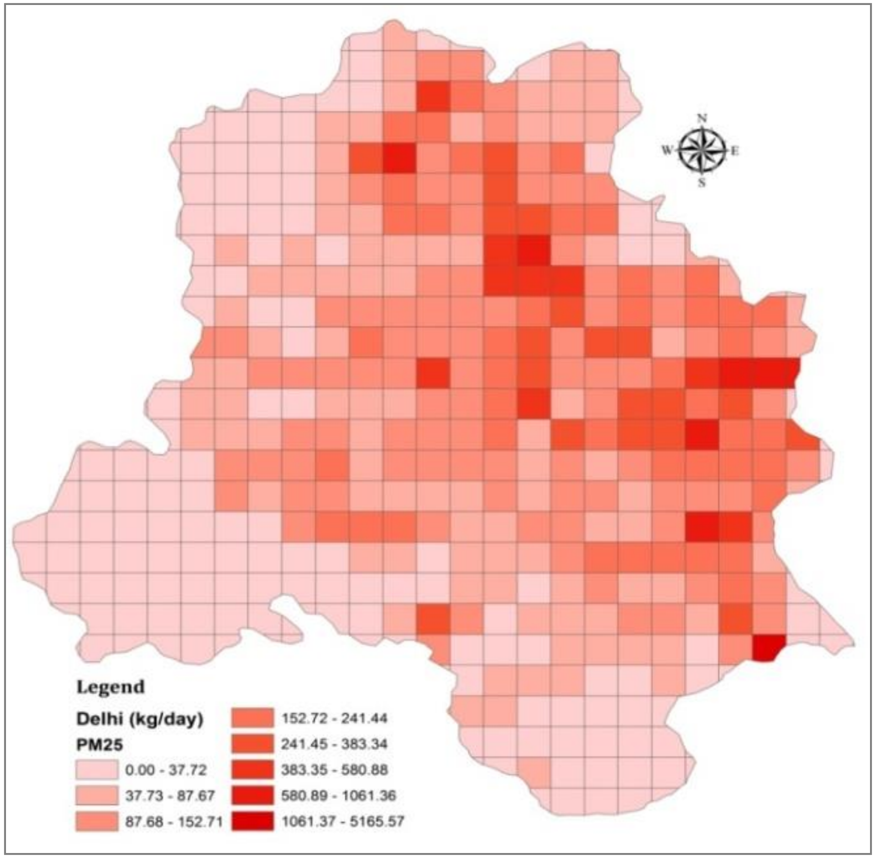
- Major Contributors: vehicles (32 %), domestic fuel burning (19 %) and industrial point sources (18%), concrete batching (10%)

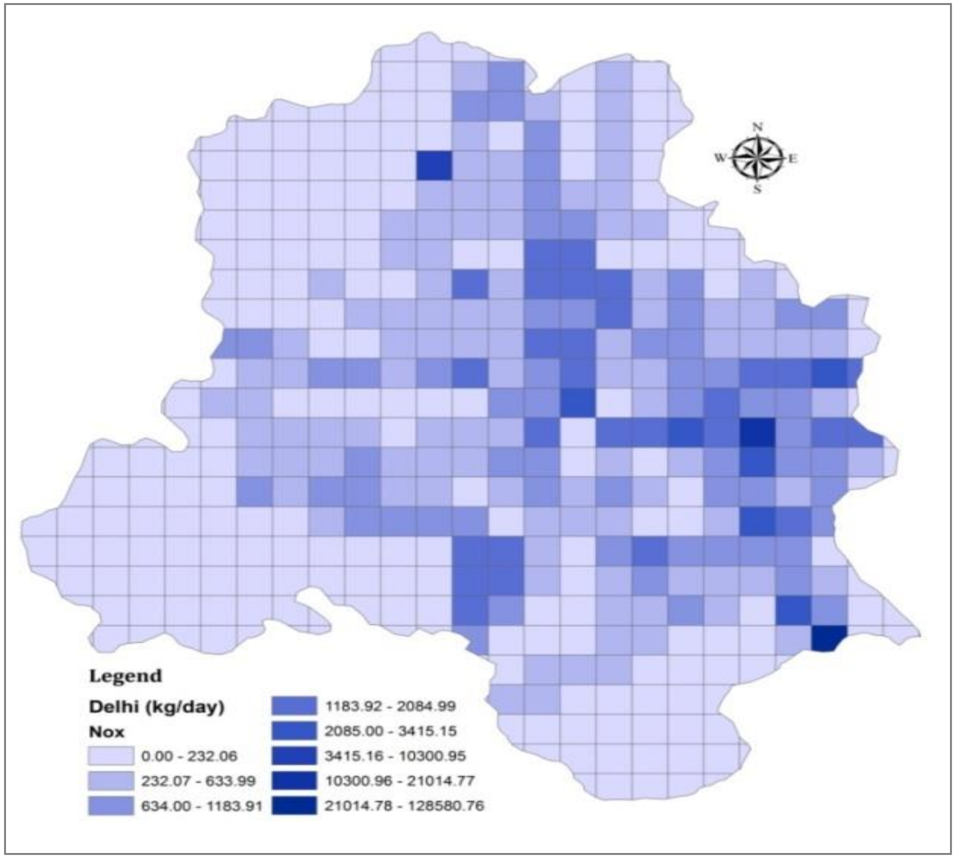
NO_X Emission Load of Different Sources



- NOx emission load: 312 t/d.
- Nearly 52 % emissions from industrial point source (largely from power plants).
- Major Contributors: Industrial (52 %), vehicles (36%), DG set (6%), Domestic (3%)

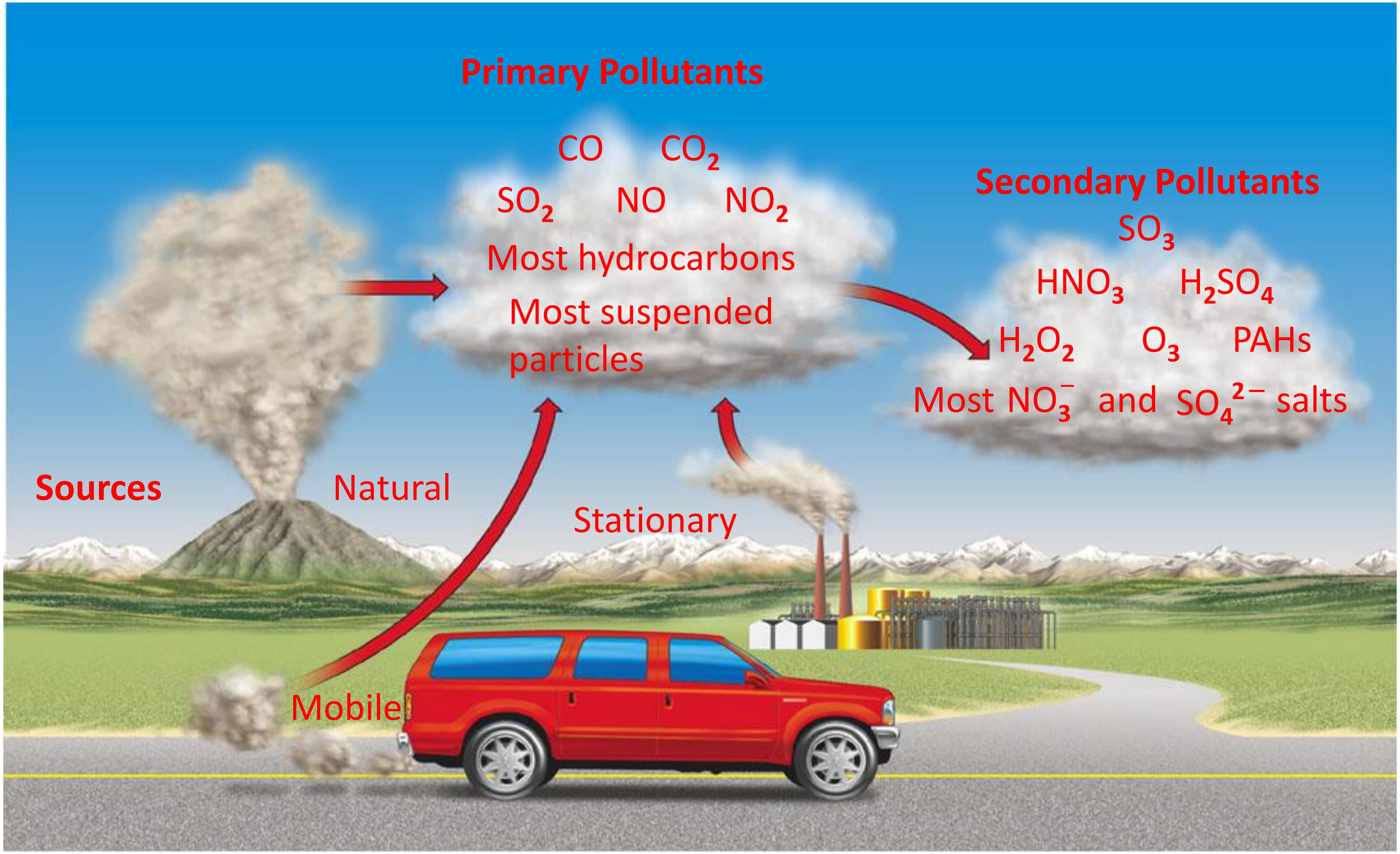
Spatial Distribution of $PM_{2.5}$ and NO_X





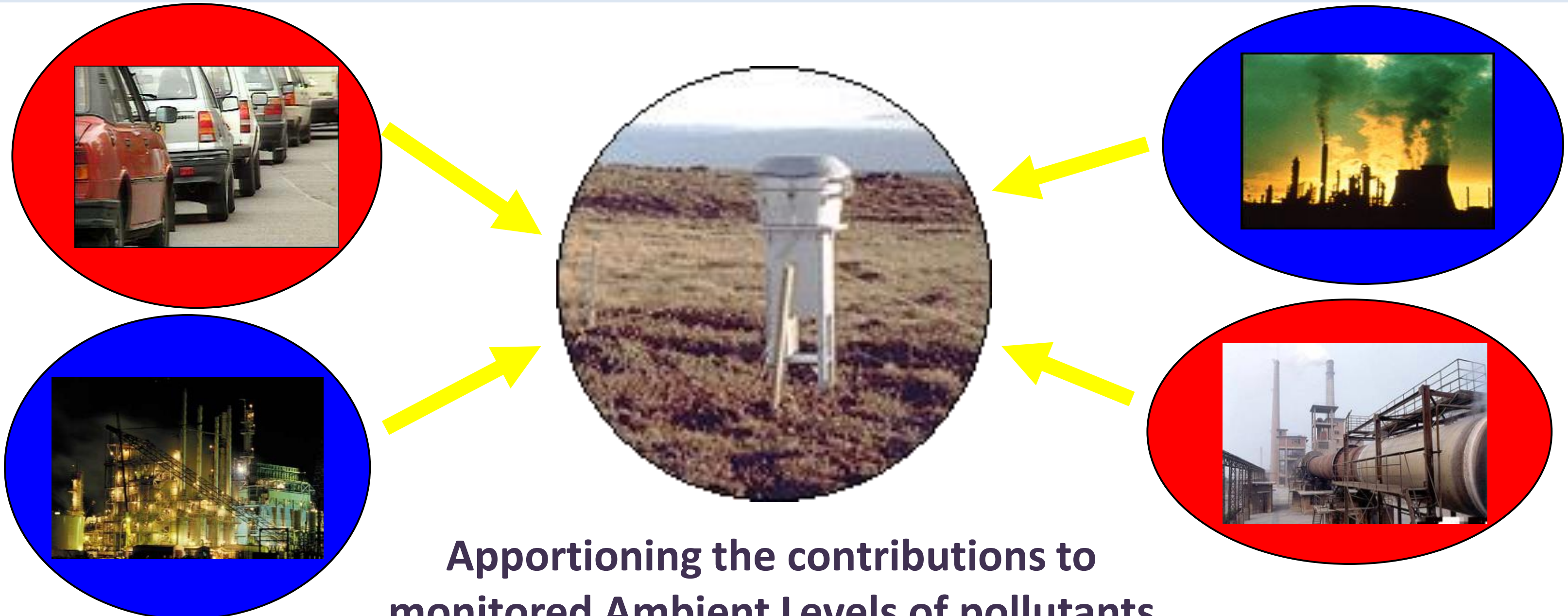
Observe the pictures

Emissions of Pollutants: Primary and Secondary



Source Apportionment: PM Composition and Receptor Modeling

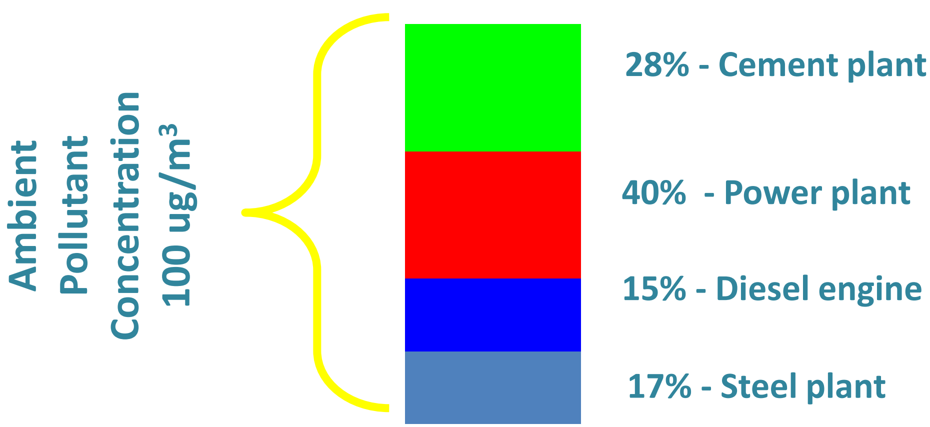
Receptor Modeling: Chemical mass balance (CMB)



Apportioning the contributions to monitored Ambient Levels of pollutants among various sources

Capabilities

Identification of pollutant contribution due to several sources (for example)



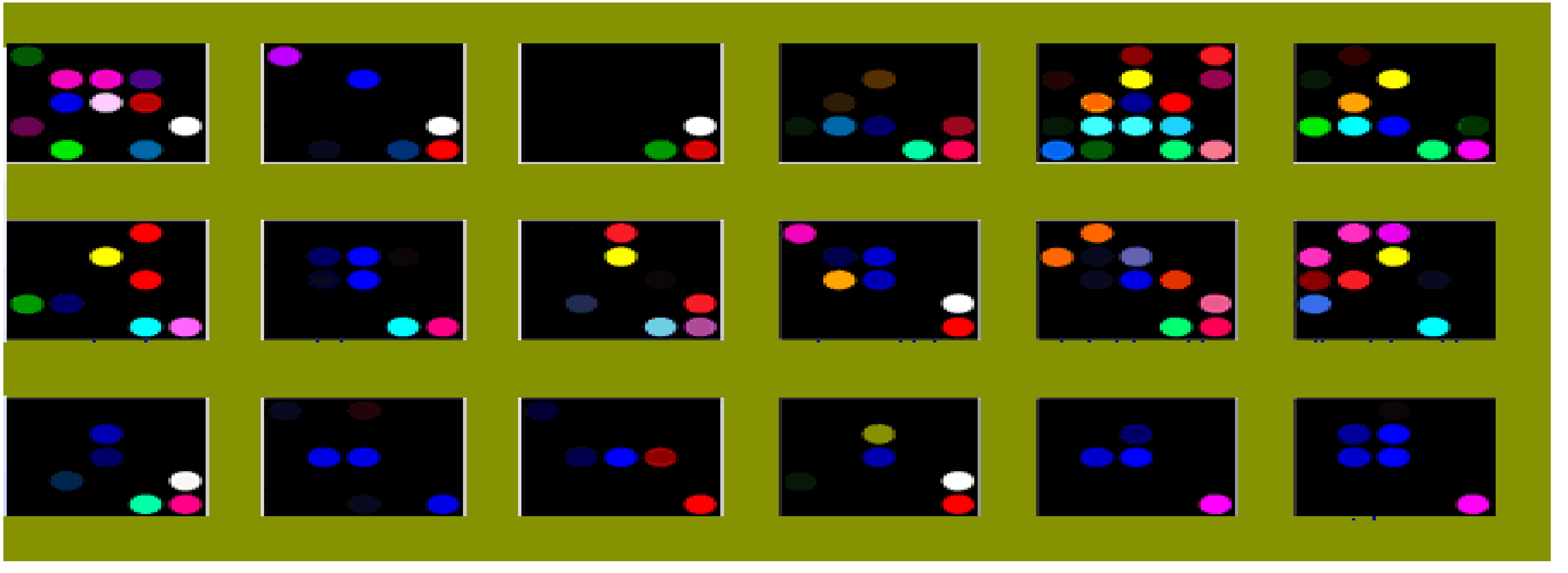
Back calculate impacts due to specific sources

Source Composition

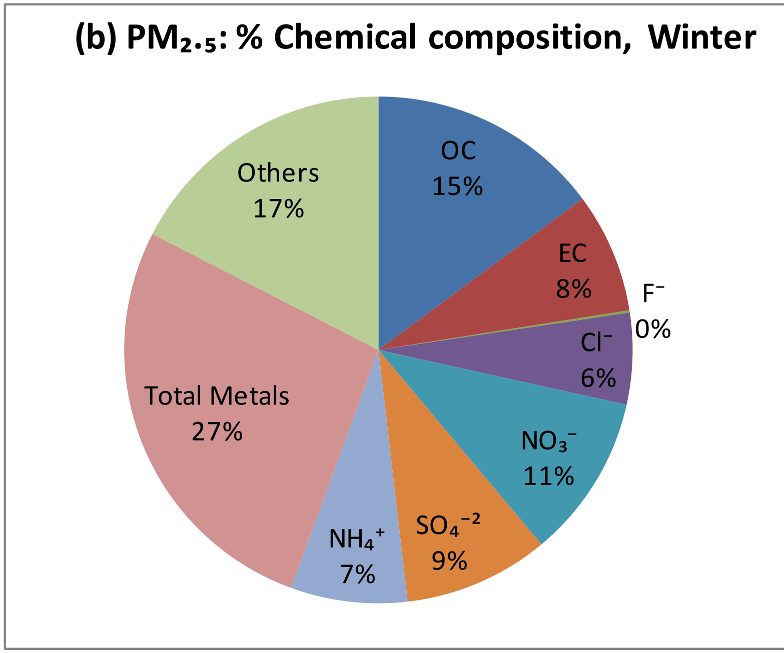
Each source may possess unique

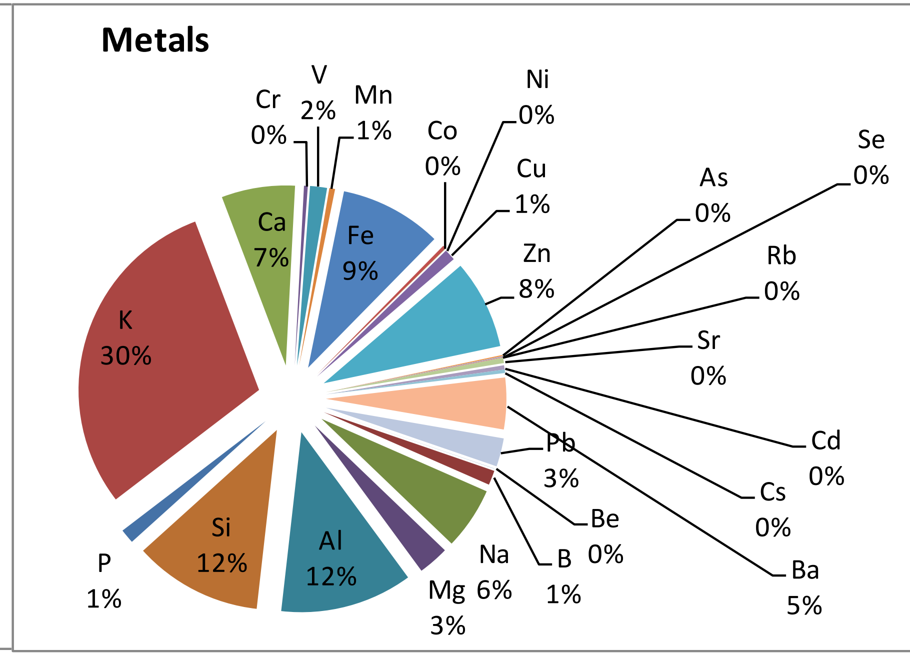
- **Chemical composition or**
- **Size distributed species**
- **Unique tracer compound**

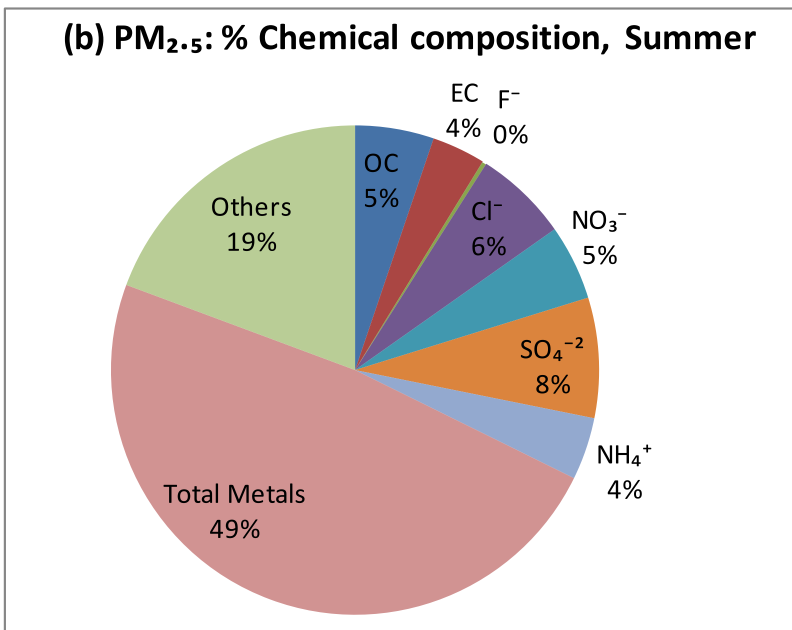
Fingerprints

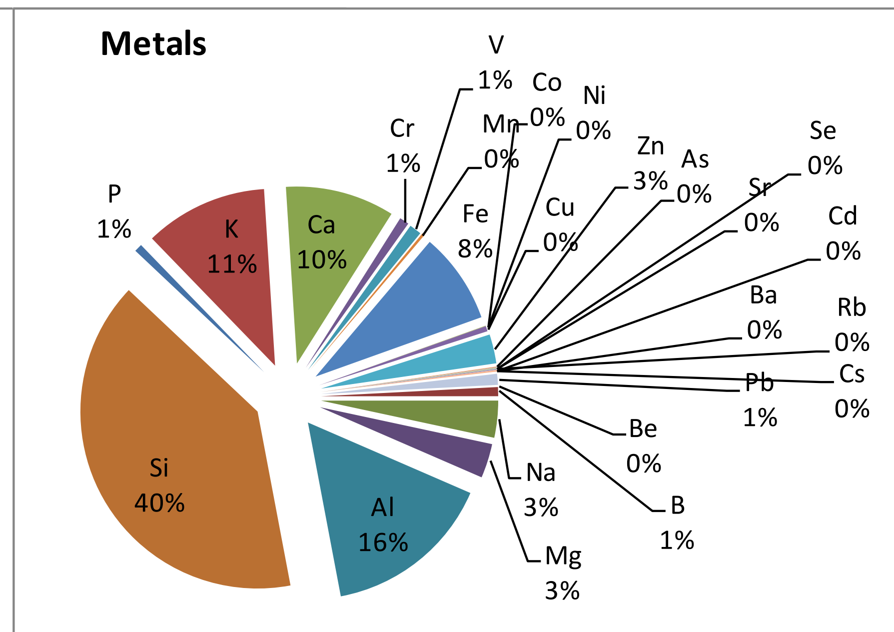


Overall Distribution of Species in $PM_{2.5}$

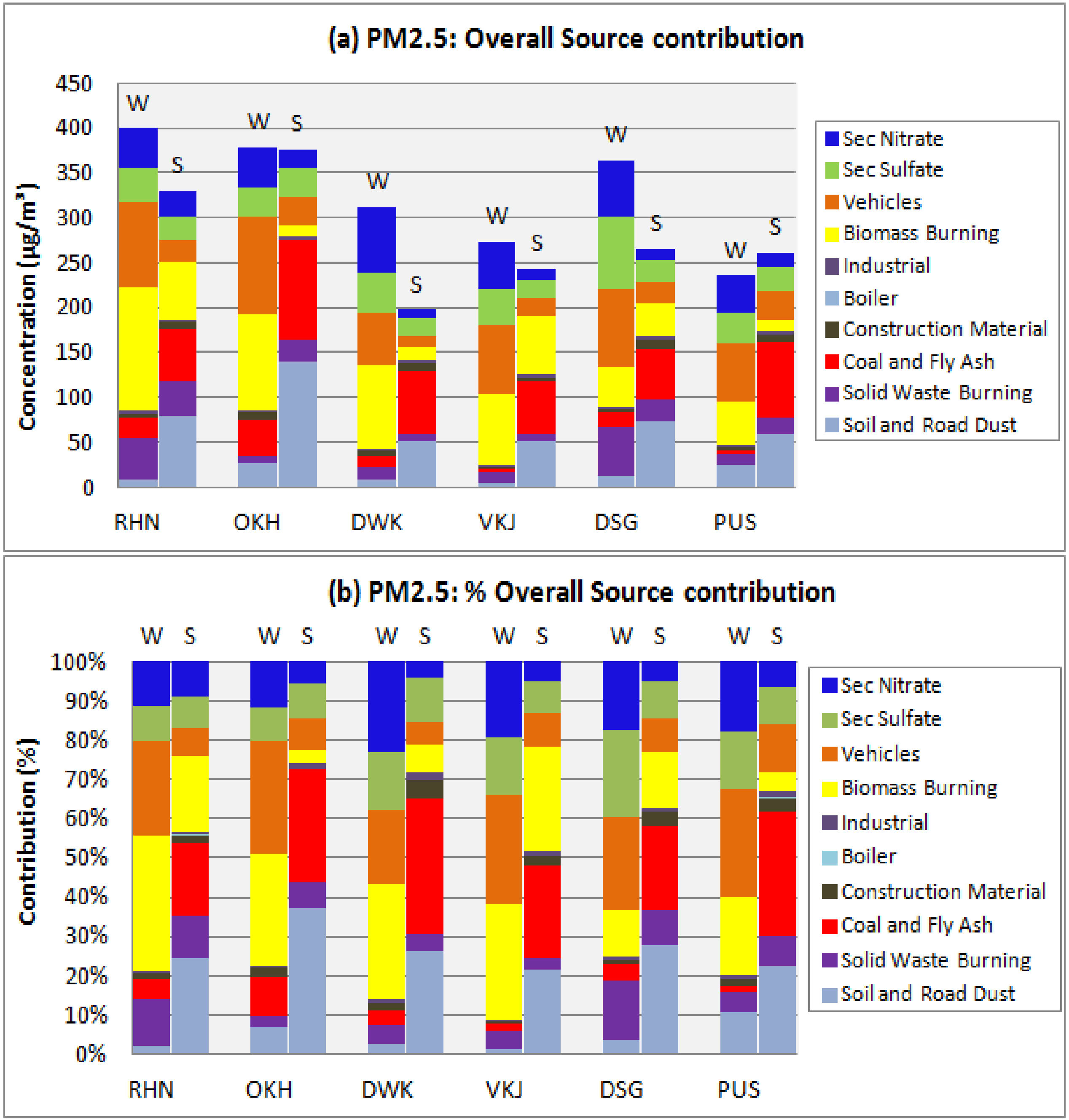




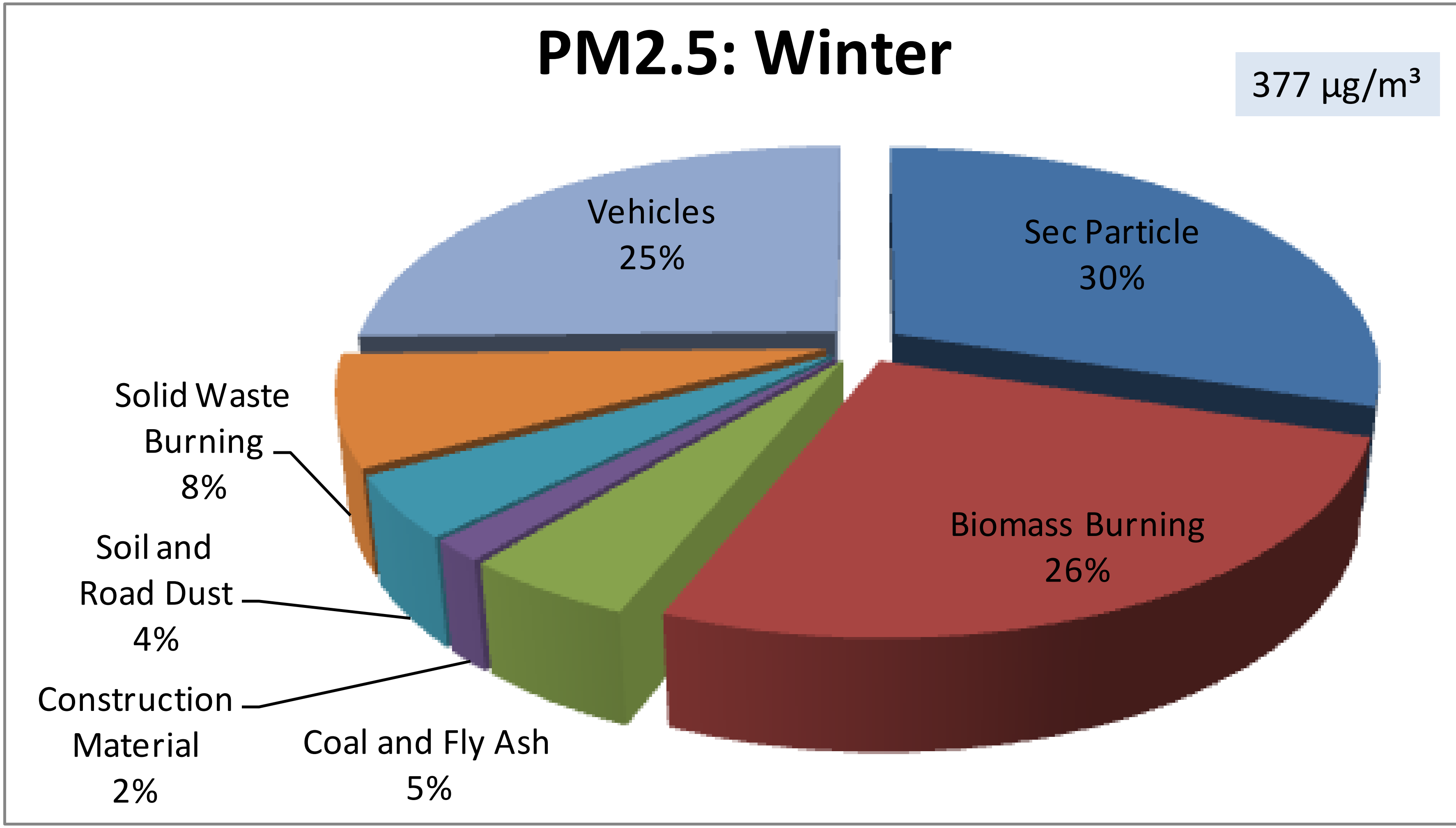




Overall CMB Modeling Results for $PM_{2.5}$



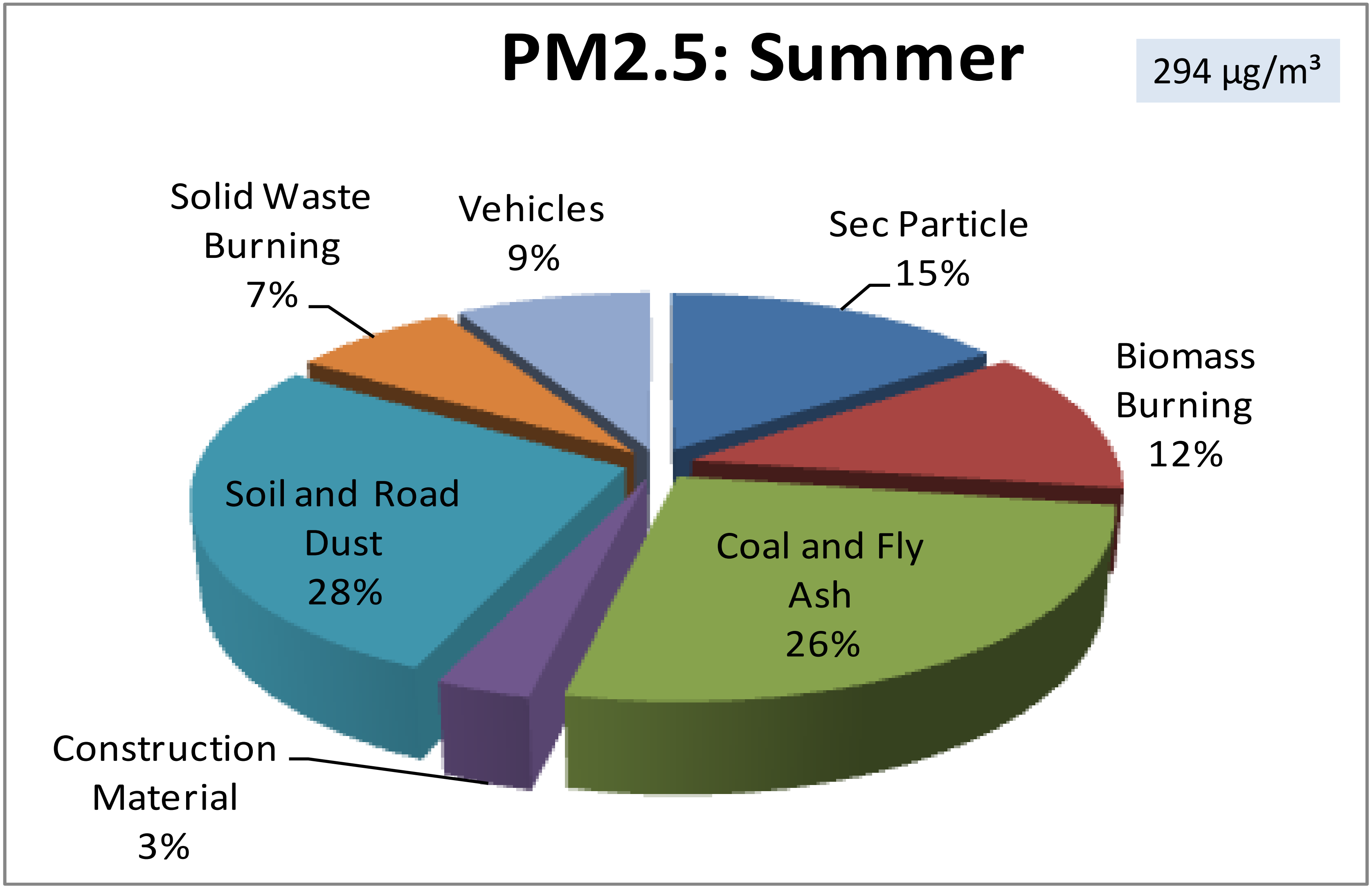
CMB: Overall Summary of Source contribution in Delhi



- **Winter sources % contribution**: **Secondary particles** (30%), **vehicles** (25%), **biomass burning** (26%), **MSW burning** (8%)

- **Secondary nitrate particles of vehicles origin contribute to 3% of total $PM_{2.5}$**
- **Total Average vehicle contribution to $PM_{2.5}$ at about 28%**

CMB: Overall Summary of Source contribution in Delhi



- **Summer sources % contribution**: **coal and flyash** (26%), **soil and road dust** (27%), **secondary particles** (15%), **biomass burning** (12%), vehicles (9%) and **MSW burning** (7%).

Agriculture Crop Residues (Biomass) Burning

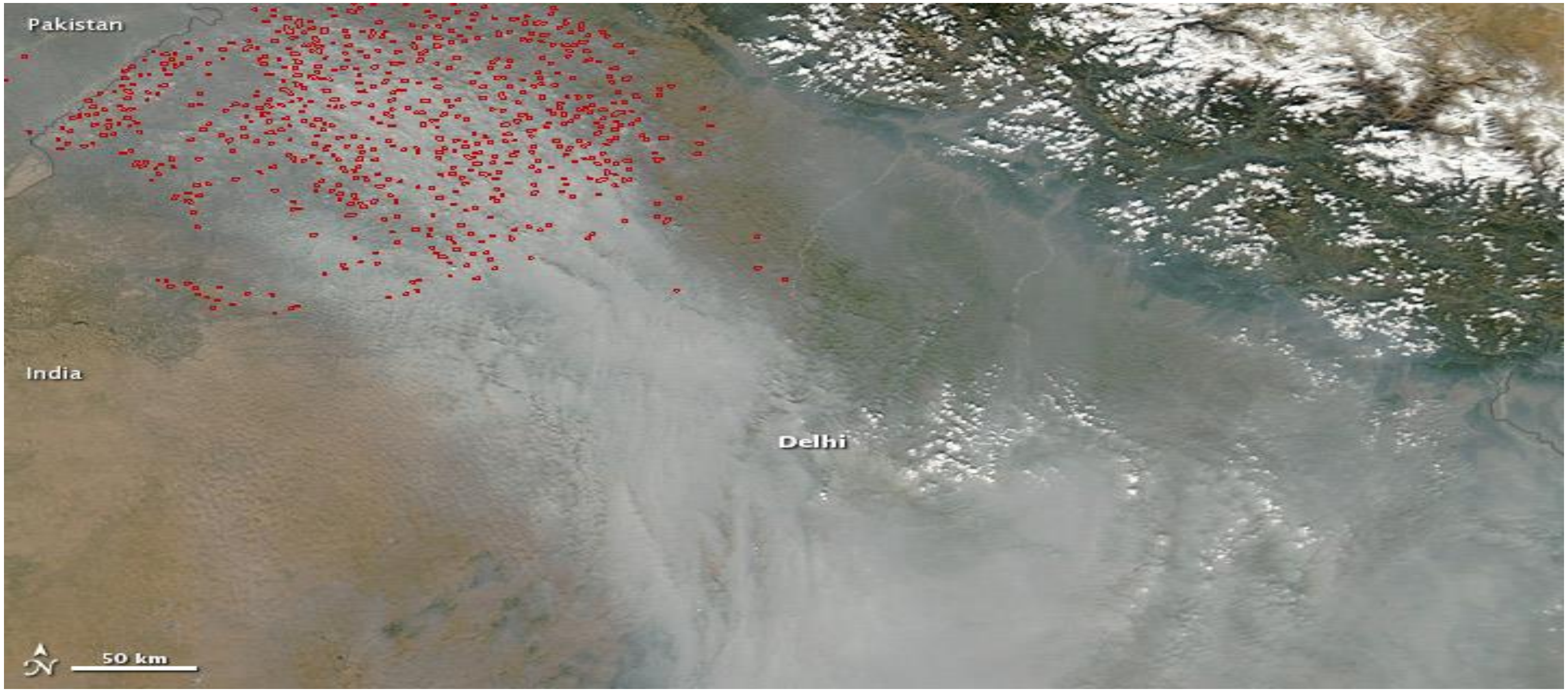
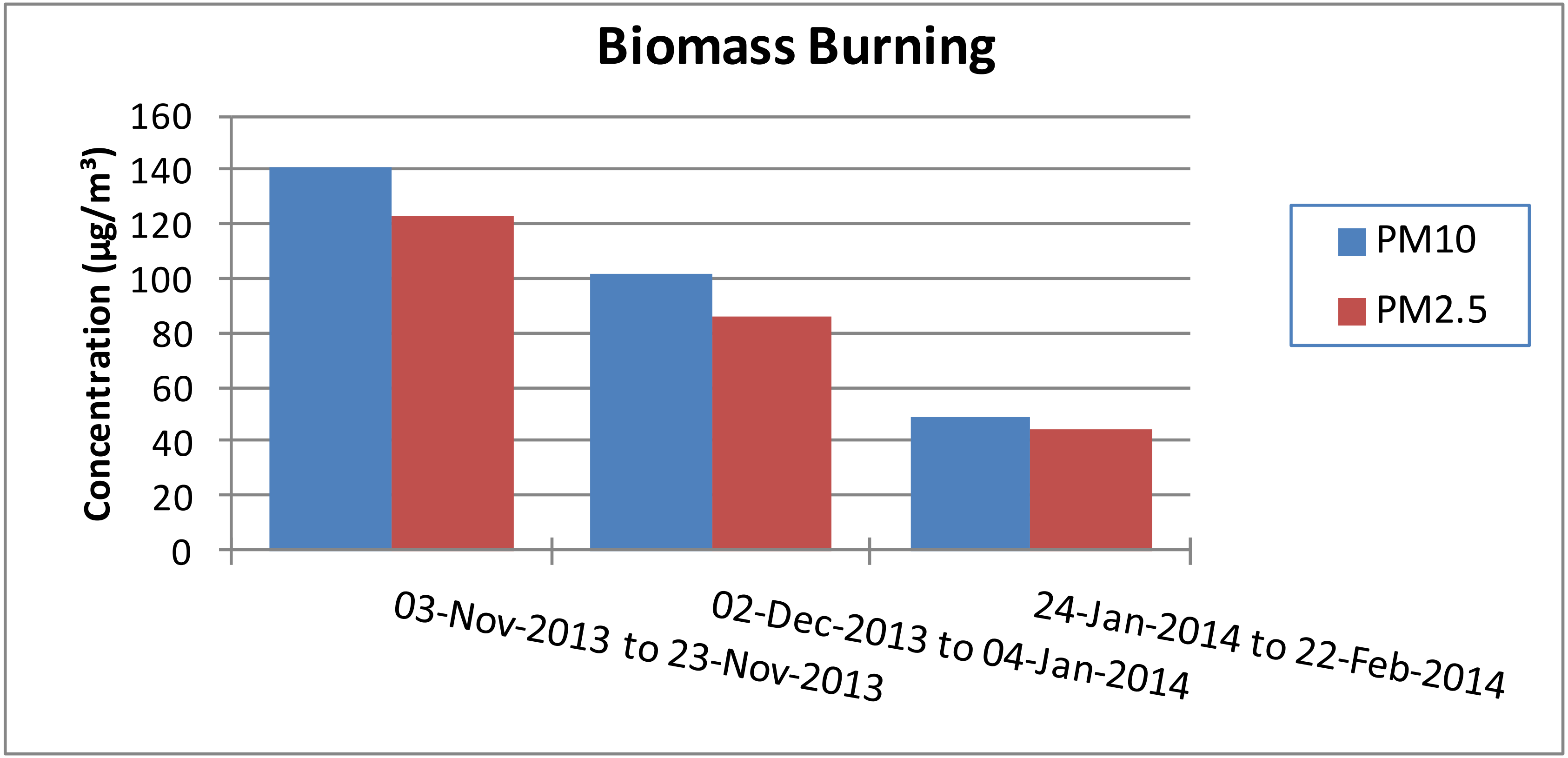


Image of biomass burning induced smoke captured by **Moderate Resolution Imaging Spectroradiometer** (MODIS) on NASA's **Aqua satellite**, November 5, 2012

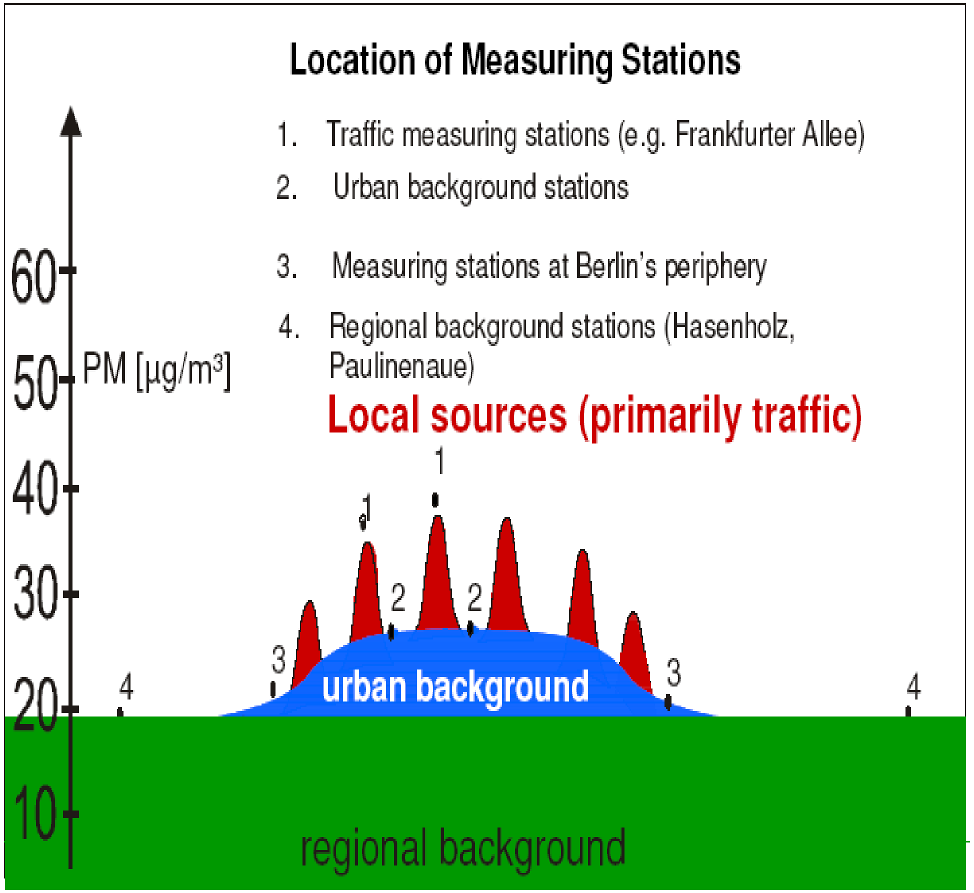
- The fire active (agricultural-waste burning) area: IGP including Punjab, Haryana and western part of Uttar Pradesh) ~ 48,400 sq. km (Justice et al., 2002)
- CRB is active for four months in a year: rice-residue burning during October–November and wheat-residue burning during April–May.

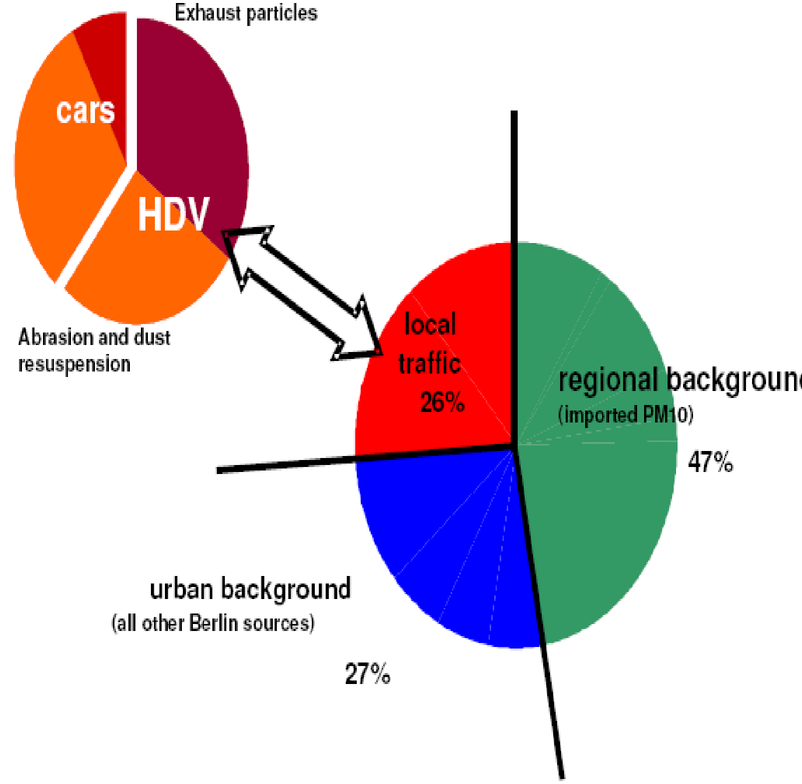
Trend in biomass burning in winter



- Significantly reduced after crop residue burning period

Case study of Berlin





Clean Air and Action Plan for Berlin 2005-2010

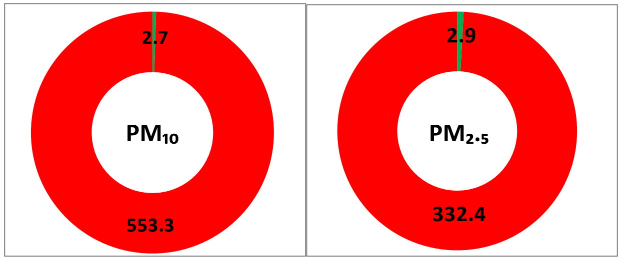
Control Options and Action Plan

1. Hotels and Restaurants

- Stop use of Coal

Parameter	Existing (kg/day)	Controlled (kg/day)	Mean Modeled Concentration (µg/m^3)		
			Existing	Controlled	% Reduction in AP Level
PM_{10}	3493	1350	4	1.3	67.5
$PM_{2.5}$	1758	675	3.6	0.7	80.56

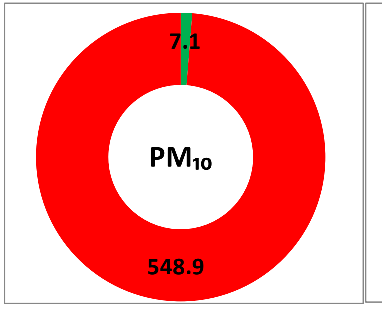
- 9000 Hotels/Restaurants uses coal (mostly in tandoors)
- Restaurants of sitting capacity more than 10 should not use coal and shift to electric or gas-based appliances

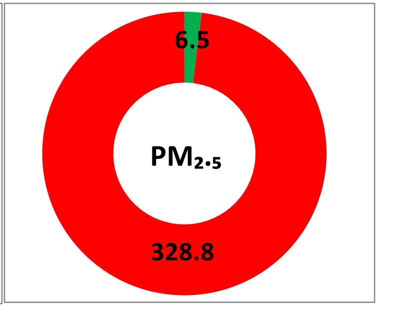


2. Domestic Sector

- LPG should be made available to remaining 10% households to make the city 100% LPG-fueled.

Parameter	Existing (kg/day)	Controlled (kg/day)	Mean Modeled Concentration (µg/m^3)		
			Existing	Controlled	% Reduction in AP Level
PM_{10}	7381	4111	8.0	3.6	55.0
$PM_{2.5}$	6940	4111	7.2	3.6	50.0



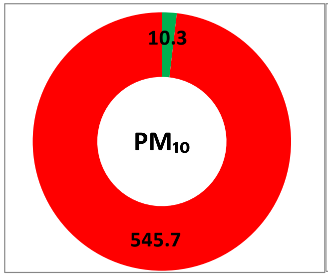


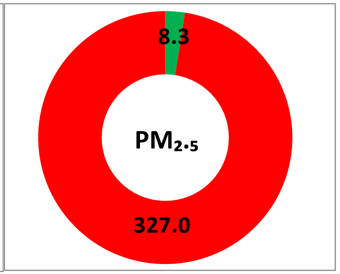
3. Municipal Solid Waste (MSW) Burning

- Stop MSW burning

Parameter	Existing (kg/day)	Controlled (kg/day)	Mean Modeled Concentration (µg/m^3)		
			Existing	Controlled	% Reduction in AP Level
PM_{10}	1968	0	3.2	0.0	100.0
$PM_{2.5}$	1771	0	1.8	0.0	100.0

MSW burning of 190-246 tons/day (~2–3% of MSW generated; 8390 tons/day) (Nagpure et al., 2015)

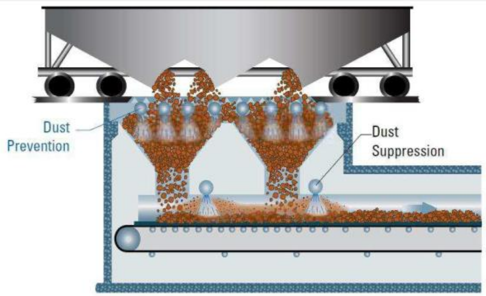




4. Construction and Demolition

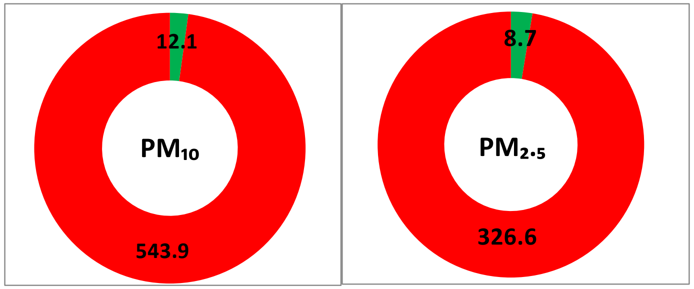
- Wet suppression
- wind speed reduction
- Actual construction area is covered by fine screen
- Proper handling and storage of raw material
- No storage (no matter how small) of construction material near road side (up to 10 m from the edge of road)
- Regulations must be brought in for construction/demolition

Parameter	Existing (kg/day)	Controlled (kg/day)	Mean Modeled Concentration (µg/m^3)		
			Existing	Controlled	% Reduction in AP Level
PM_{10}	5167	2584	3.4	1.6	52.0
$PM_{2.5}$	1292	646	0.8	0.4	50.0



Suppression System

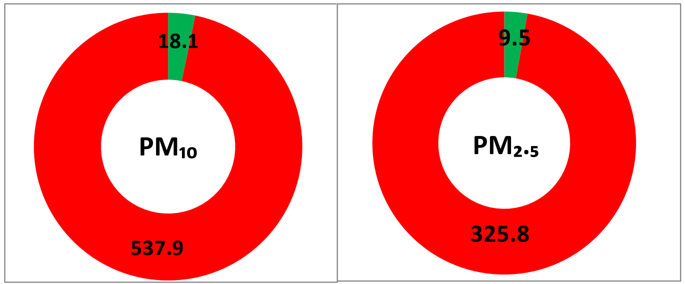

Windscreen for dust control



5. Ready Mix Concrete Batching

- Wet suppression
- wind speed reduction
- The transfer of cement and pozzalan material to silos is one of the major emission sources in the plant, and installation of fabric filter should be compulsory
- Proper handling and storage of raw material
- No storage (no matter how small) of construction material near road side (up to 10m from the edge of road)
- Regulations must be brought in for concrete batching

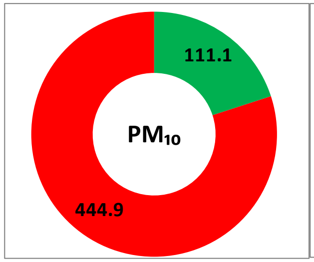
Parameter	Existing (kg/day)	Controlled (kg/day)	Mean Modeled Concentration (µg/m³)		
			Existing	Controlled	% Reduction in AP Level
PM_{10}	14370	516	8.0	2.0	75.0
$PM_{2.5}$	1292	646	0.8	0.4	40.0

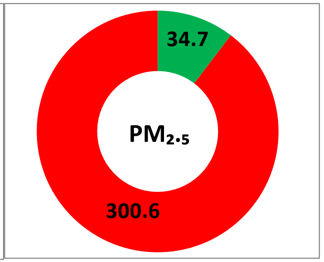


6. Road Dust

- **Vacuum Sweeping of major roads (Four Times a Month)**
- Roads are maintained properly
- Watering of roads
- paved wall to wall
- open fields should be kept slightly wet and small shrubs are planted to prevent drift of dust in summer
- No storage and disposal of material (construction, ash, etc) near road side (up to 10 m from the edge of road).

Parameter	Existing (kg/day)	Controlled (kg/day)	Mean Modeled Concentration (µg/m^3)		
			Existing	Controlled	% Reduction in AP Level
PM_{10}	79626	23887	131.0	38.0	71.0
$PM_{2.5}$	22165	6649	36.0	10.8	70.0

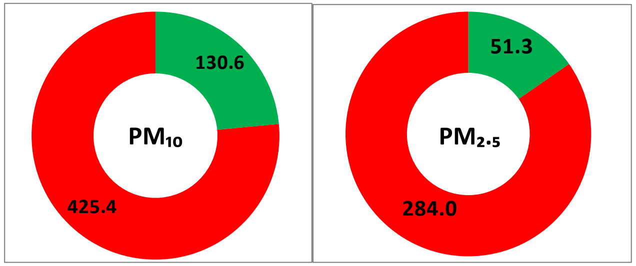




7. Vehicles

- Electric/Hybrid Vehicles: 2% of 2-Ws, 10% of 3-Ws And 2% 4Ws wef January 2017
- Retro Fitment of Diesel Particulate Filter: wef July 2016
- Implementation of BS – VI : wef January 2019*
- Inspection/ Maintenance of Vehicles
- Ultra Low Sulphur Fuel (<10 PPM): wef January 2018

Parameter	Existing (kg/day)	Controlled (kg/day)	Mean Modeled Concentration ($\mu g/m^3$)		
			Existing	Controlled	% Reduction in AP Level
PM_{10}	12914	6453	38.0	18.5	51.3
$PM_{2.5}$	11623	5807	33.2	16.6	50.0

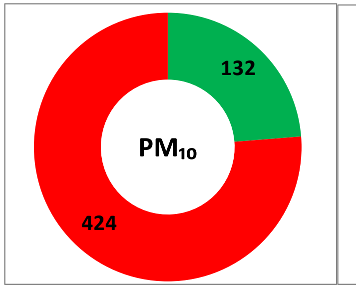


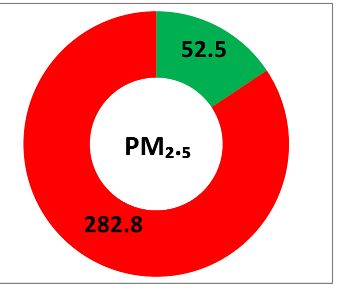
8. Industries and Diesel Generator Sets

- Reduce sulphur content in Industrial Fuel (LDO, HSD) to less than 500 PPM

Parameter	Existing (kg/day)	Controlled (kg/day)	Mean Modeled Concentration (µg/m^3)		
			Existing	Controlled	% Reduction in AP Level
PM_{10}	1937	1355	4.7	3.3	30
$PM_{2.5}$	1743	1220	3.9	2.8	30

- Sulphur Content (Present Day)
  - LDO = 18000 ppm ; HSD = 10000 ppm
- Expected PM control would be about 15 to 30 %.
- DG sets of size 2 KVA or less should not be allowed to operate

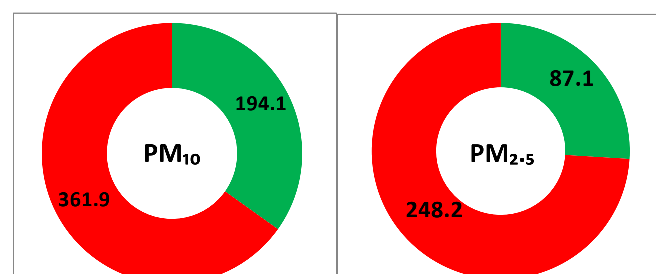




9. Secondary Particles: Control of SO_2 and NO_x from Large sources

- De-SOx-ing at Power Plants Within 300 Km of Delhi
- De-NOx-ing at Power Plants Within 300 Km of Delhi

Parameter	Controlled (kg/day)	Mean Modeled Concentration ($\mu g/m^3$)		
		Existing	Controlled	% Reduction in AP Level
PM_{10}	132437 (SO2 emissions)	69.0	6.9	90
$PM_{2.5}$		38.5	3.9	90
PM_{10}	153349 (NOx emissions)	41.0	4.1	90
$PM_{2.5}$		25.2	2.5	90



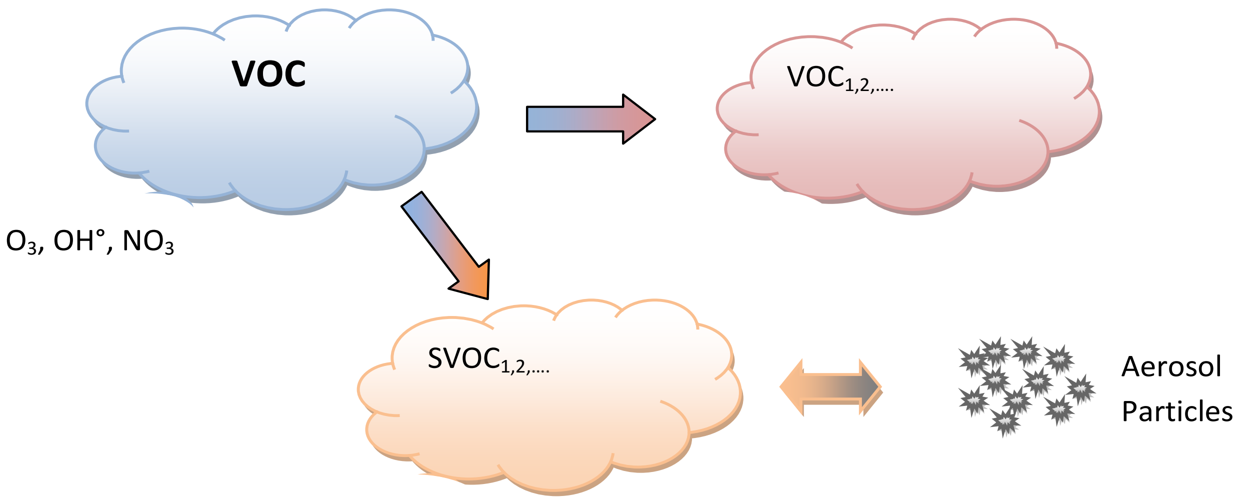
Secondary Organic Aerosols

Chemical Transformation

- SOA involves two crucial steps [Turpin et al., 2000; Pun et al., 2000] –

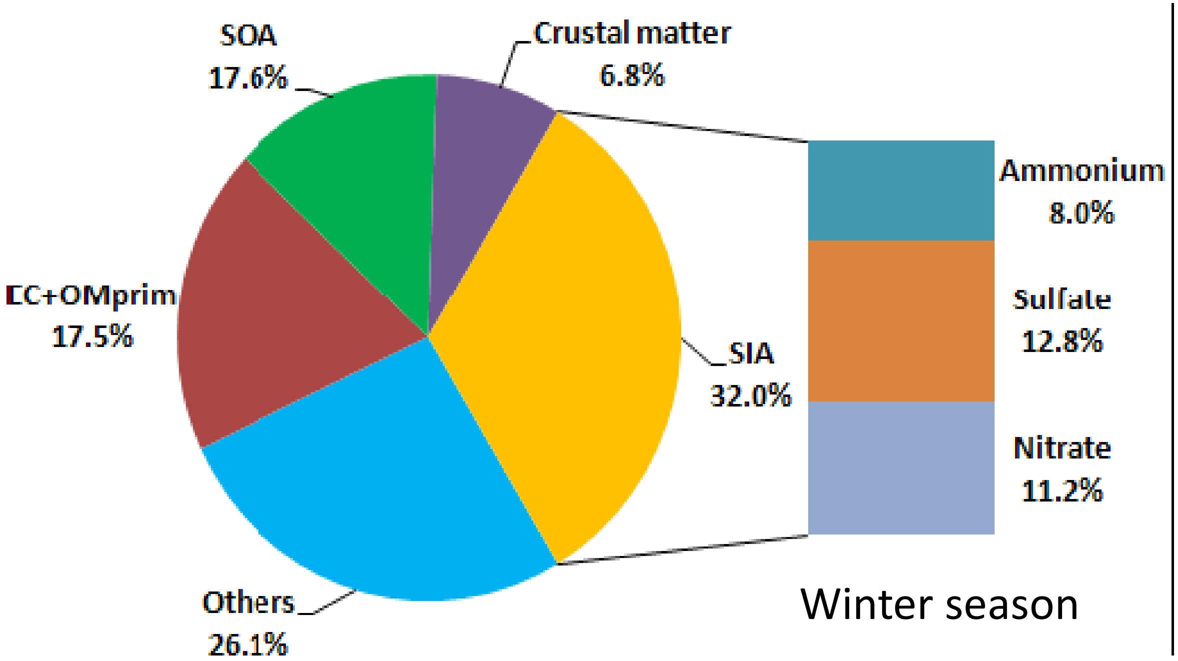
(i) Reactive Organic Gases (ROGs) (alkanes, alkenes, aromatics and phenols) oxidize to form semi-volatile organic compounds (SVOC).

(ii) Low vapor pressure SVOCs (lowers the vapor pressure of the organic gas) partition to the aerosol phase.



Relative composition of sources in $PM_{2.5}$ in Kanpur

- Upto 18% of Secondary Organic Aerosol (SOA) found in Kanpur area.
- Elemental carbon remain 17%, it means fuel combustion activities – there is no change.
- Temperature and humidity affect the transformations.



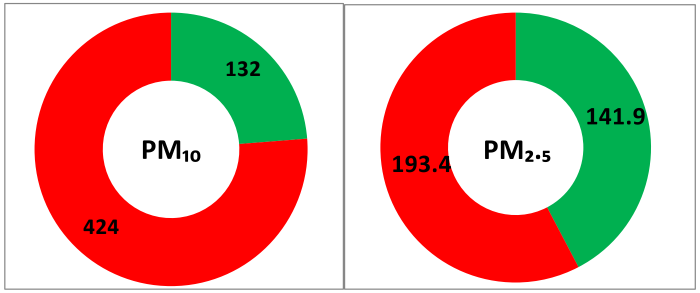
[Behera and Sharma, 2010]

10. Secondary Organic Aerosols

- Controlling Evaporative Loss during fuel unloading and Re-Fueling through Vapour Recovery System at petrol pumps

Parameter	Mean Modeled Concentration (µg/m³)		
	Existing	Controlled	% Reduction in AP Level
PM_{10}	48.9	9.7	80.2
$PM_{2.5}$	40.1	8.0	90.0

- The evaporative losses from solvent industries should also be minimized.

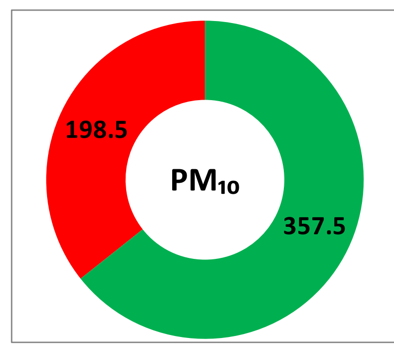


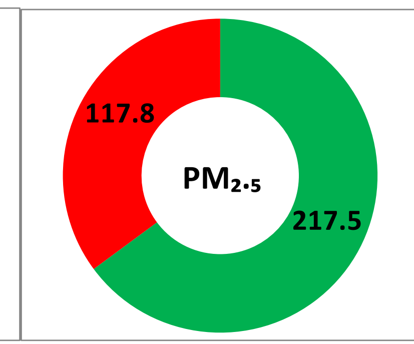
11. Biomass Burning

- Managing crop residue burning in Haryana, Punjab and other local biomass burning.

Parameter	Mean Modeled Concentration (µg/m^3)		
	Existing	Controlled	% Reduction in AP Level
PM_{10}	97.0	9.7	90
$PM_{2.5}$	84.0	8.4	90

- Biomass contribution in PM_{10} in the month of November could be as high as 140 µg/m^3 and about 120 µg/m^3 for $PM_{2.5}$ (mean of contribution in entire winter season: 97 µg/m^3 and 86 µg/m^3) respectively.
- In all likelihood, the PM from biomass burning is contributed from CRB prevalent in Punjab and Haryana in winter.



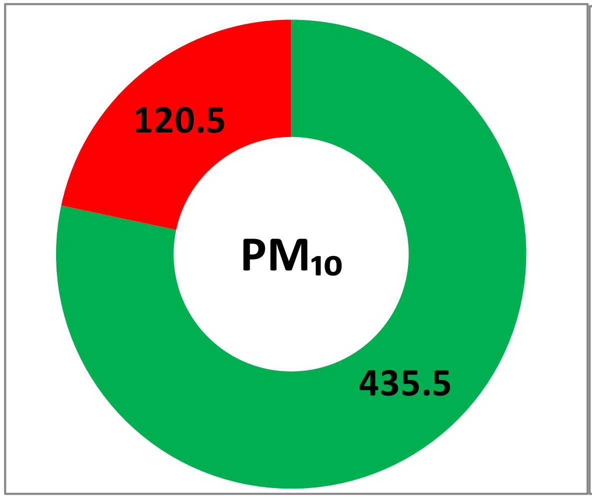


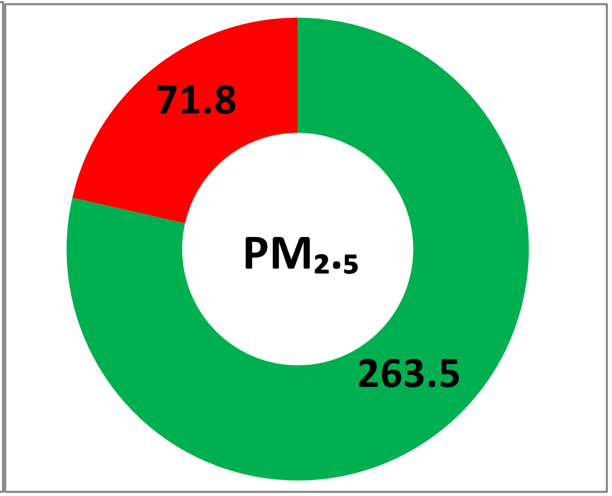
12. Fly Ash

- Control at other sources (hotels/restaurants and rapid mix plants, fly ash ponds etc)
- Install Wind Breaker at construction and fly ash pond sites.
- Keep fly ash pond moist and possibly maintained about 1mm of water layer over the entire fly ash pond

13. Control outside Delhi in NCR

- Control option should be implemented in NCR in similar manner as in Delhi





Action Plan for NCT of Delhi

A. Immediate Actions

Source	Option No.	Description Option	2016	2017	2018	2019	2020-2023	Percent improvement in AQ
Hotels/ Restaurants	1	Stop use of Coal						80.56
Domestic Cooking	2	LPG to all						50.00
MSW Burning	3	Stop MSW burning: Improve collection and disposal (landfill and waste to energy plants)						100.00
Construction and Demolition	4	Vertically cover the construction area with fine screens						50.00
		Handling and Storage of Raw Material: completely cover the material						
		Water spray and wind breaker						
		Store the waste inside premises with proper cover						
Concrete Batching	5	Water Spray						40.00
		Wind Breaker						
		Bag Filter at Silos						
		Enclosures, Hoods, Curtains, Telescopic Chutes, Cover Transfer Points and Conveyer Belts						
Road Dust and Soil dust	6.1	Vacuum Sweeping of major roads (Four Times a Month)						70.00
		Carpeting of shoulders						
		Mechanical sweeping with water wash						
	6.2	plant small shrubs, perennial forages, grass covers in open areas						--
Note: for implementation year 2016 may begin from July 2016								

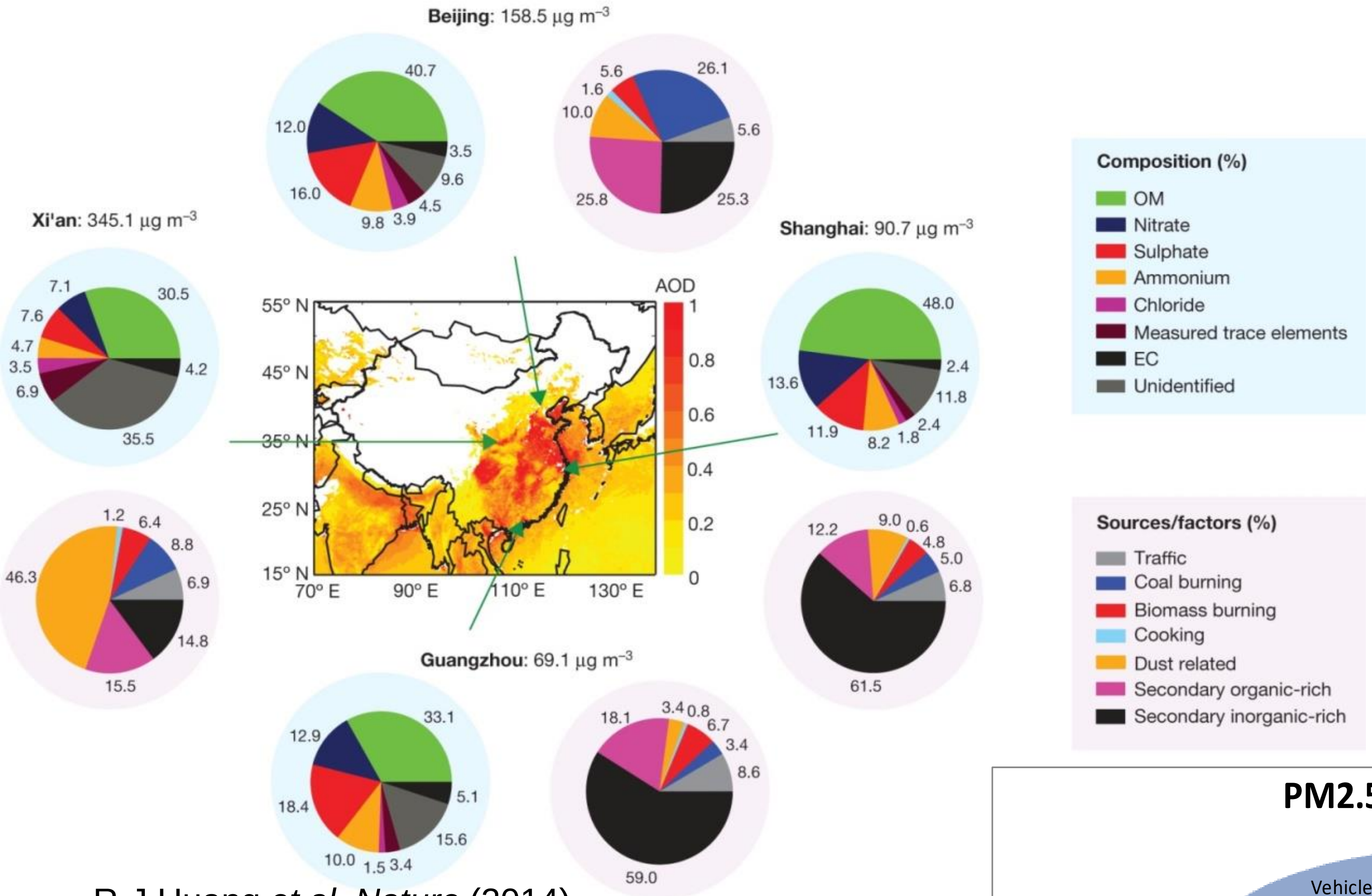
Action Plan for NCT of Delhi

B. Time-bound Actions

Source	Option No.	Description Option	2016	2017	2018	2019	2020-2023	Percent improvement in AQ
Vehicles	7.1	Electric/Hybrid Vehicles: 2% of 2-Ws, 10% of 3-Ws and 2% 4Ws wef July 2017: New residential and commercial buildings to have charging facilities						50.0
	7.2	Retrofitment of Diesel Particulate Filter: wef July 2018						
	7.3	Implementation of BS – VI for all diesel vehicles including heavy duty vehicles (non-CNG buses and trucks) and LCVs (non-CNG): wef January 2019						
	7.4	Inspection/ Maintenance of Vehicles						
	7.5	Ultra Low Sulphur Fuel (<10 PPM); BS-VI compliant: wef January 2018						
	7.6	2-Ws with Multi Point Fuel Injection (MPFI) system or equivalent: wef January 2019						
Industry and DG Sets	8.1	Reduce sulphur content in Industrial Fuel (LDO, HSD) to less than 500 PPM						30.00
	8.2	Minimize uses, uninterrupted power supply, Banning 2-KVA or smaller DG sets						--
Secondary Particles	9.1	De-SOx-ing at Power Plants within 300 km of Delhi						90.0
	9.2	De-NOx-ing at Power Plants within 300 km of Delhi						90.1
Secondary Organic Aerosols	10	Controlling Evaporative emissions: Vapour Recovery System at petrol pumps (Fuel unloading and dispensing)						80.0
Biomass Burning	11	Managing crop residue burning in Haryana, Punjab and other local biomass burning, Potential alternatives: energy production, biogas generation, commercial feedstock for cattle, composting, conversion in biochar, Raw material for industry: wef July 2016						90.0
Fly Ash	12	Wind Breaker, Water Spraying, plantation, reclamation						--

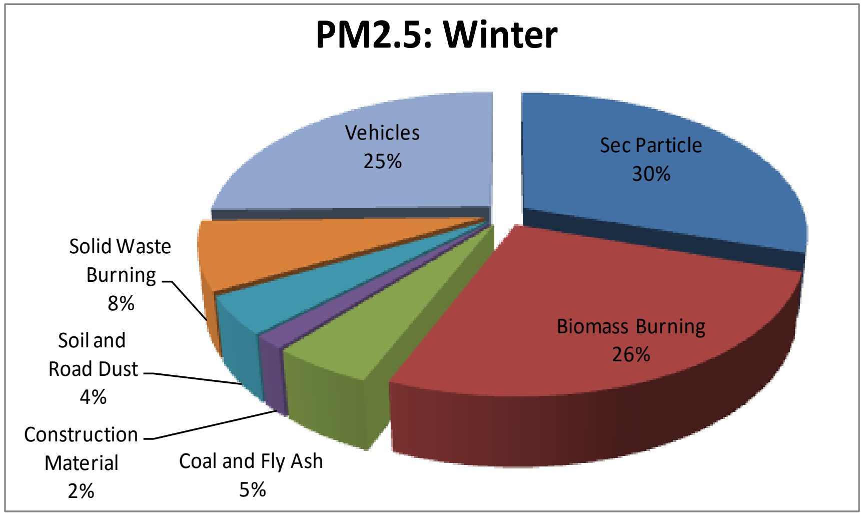
Note: for implementation year 2016 may begin from July 2016

Comparison: Delhi Vs Beijing, Shanghai, Xi'am, Guangzhou



R-J Huang *et al. Nature* (2014)

"In response to the severe haze events of 2013, the Chinese State Council quickly released the 'Atmospheric Pollution Prevention and Control Action Plan' on 10 September 2013 which aims to reduce PM2.5 by up to 25% by 2017 relative to 2012 levels, and is backed by US $277 billion in investments from the central Government."



THANK YOU