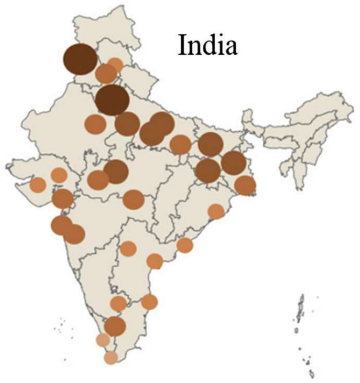
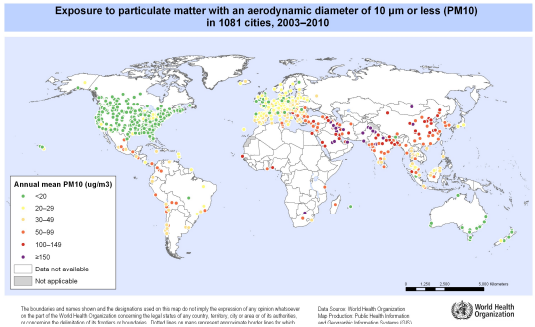
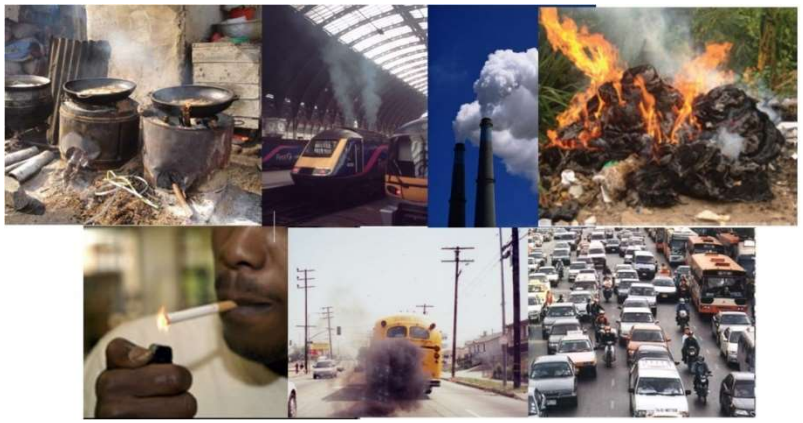



## Lecture 2

# Air Quality:

# Sources & Distribution



**Harish C. Phuleria**
CESE, IIT Bombay

Email: phuleria@iitb.ac.in

# Recap 1

- Air pollution affects:
  - Human health – acute effects and chronic effects
  - Climate – direct effects and indirect effects (clouds)
  - Visibility (reduced visibility mostly due to fine particles)
- Ozone is photochemically produced; good (in stratosphere blocking UV radiation) and bad (in troposphere causing respiratory illness)
- 1952 London smog: coal power plant emissions, trapping of pollutants in winter, >4,000 deaths in a week

# Recap 2

- Harvard six cities study: prospective cohort study (1974-1991) of effect of air pollution on mortality in six US cities, linear positive association of fine particle levels with mortality
- Global burden of air pollution: 5.5 million deaths due to air pollution worldwide in 2013; India accounts ~1/4$^{th}$ of total deaths from household air pollution (solid biomass fuels) and ambient air pollution (power plants, transportation, open burning)
- The Air Act, 1981; Six criteria air pollutants, with two averaging times for short-and long-term health effects, NAAQS established

# National Ambient Air Quality Standards: (NAAQS) India

**Ambient Concentration**

**Type of area**

**Averaging interval /Exposure duration**

| S. No. | Pollutant | Time Weighted Average | Concentration in Ambient Air | | |
|---|---|---|---|---|---|
| | | | Industrial, Residential, Rural and Other Area | Ecologically Sensitive Area (notified by Central Government) | Methods of Measurement |
| (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | Sulphur Dioxide ($SO_2$), µg/m³ | Annual | 50 | 20 | - Improved West and Gaeke<br>-Ultraviolet fluorescence |
| | | 24 Hours | 80 | 80 | |
| 2 | Nitrogen Dioxide ($NO_2$), µg/m³ | Annual* | 40 | 30 | - Modified Jacob & Hochheiser (Na-Arsenite)<br>- Chemiluminescence |
| | | 24 hours** | 80 | 80 | |
| 3 | Particulate Matter (size less than 10µm) or $PM_{10}$ µg/m³ | Annual* | 60 | 60 | - Gravimetric<br>- TOEM<br>- Beta attenuation |
| | | 24 hours** | 100 | 100 | |
| 4 | Particulate Matter (size less than 2.5µm) or $PM_{2.5}$ µg/m³ | Annual* | 40 | 40 | - G... attenuation |
| | | 24 hours** | 60 | | |
| 5 | Ozone ($O_3$) µg/m³ | 8 hours** | | 100 | - UV photometric<br>- Chemilminescence<br>- Chemical Method |
| | | 1 hour** | 180 | 180 | |
| 6 | Lead (Pb) | | 0.50 | 0.50 | - AAS /ICP method after sampling on EPM 2000 or equivalent filter paper<br>- ED-XRF using Teflon filter |
| | | 24 hours** | 1.0 | 1.0 | |
| 7 | Carbon Monoxide CO mg/m³ | 8 hours** | 02 | 02 | - Non Dispersive Infra Red (NDIR) spectroscopy |
| | | 1 hour** | 04 | 04 | |

http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php

# Criteria air pollutants

1. **Nitrogen Dioxide: $NO_2$**
   - brownish gas, irritates the respiratory system
   - originates from combustion ($N_2$ in air is oxidized)
   - $NO_x$ sum of NO & $NO_2$

2. **Ozone: ground level $O_3$**
   - primary co… …ban smog
   - … $NO_x$ + light → $O_3$ + PAN (Peroxyacetyl nitrate)

**Have you heard of LA smog?**

3. **Carbon monoxide: CO**
   - reduces bloods ability to carry $O_2$
   - product of incomplete combustion

| Pollutant | Averaging time | Ambient Conc. (NAAQS) |
|---|---|---|
| $NO_2$ ($\mu g/m^3$) | Annual | 40 |
| | 24 Hours | 80 |
| $O_3$ ($\mu g/m^3$) | 8 Hours | 100 |
| | 1 Hour | 180 |
| CO ($mg/m^3$) | 8 Hours | 2 |
| | 1 Hour | 4 |

# Criteria air pollutants

## 4. Lead: Pb

- cause learning disabilities in children , toxic to liver, kidney, blood forming organs
- tetraethyl lead – anti knock agent in gasoline; leaded gasoline has been mostly phased out

| Pollutant | Averaging time | Ambient Conc. (NAAQS) |
|---|---|---|
| Pb ($\mu g/m^3$) | Annual | 0.5 |
| | 24 Hours | 1 |
| $PM_{10}$ ($\mu g/m^3$) | Annual | 60 |
| | 24 Hours | 100 |
| $PM_{2.5}$ ($\mu g/m^3$) | Annual | 40 |
| | 24 Hours | 60 |
| $SO_2$ ($\mu g/m^3$) | Annual | 50 |
| | 24 Hours | 80 |

## 5. Particulate Matter: $PM_{10}$ (and $PM_{2.5}$)

- respiratory & cardiovascular disorders

## 6. Sulfur Dioxide: $SO_2$

- formed when fuel (coal, oil) containing S is burned and metal smelting
- precursor to acid rain along with $NO_x$

**Recall London smog !**

# Today's Learning Objectives !

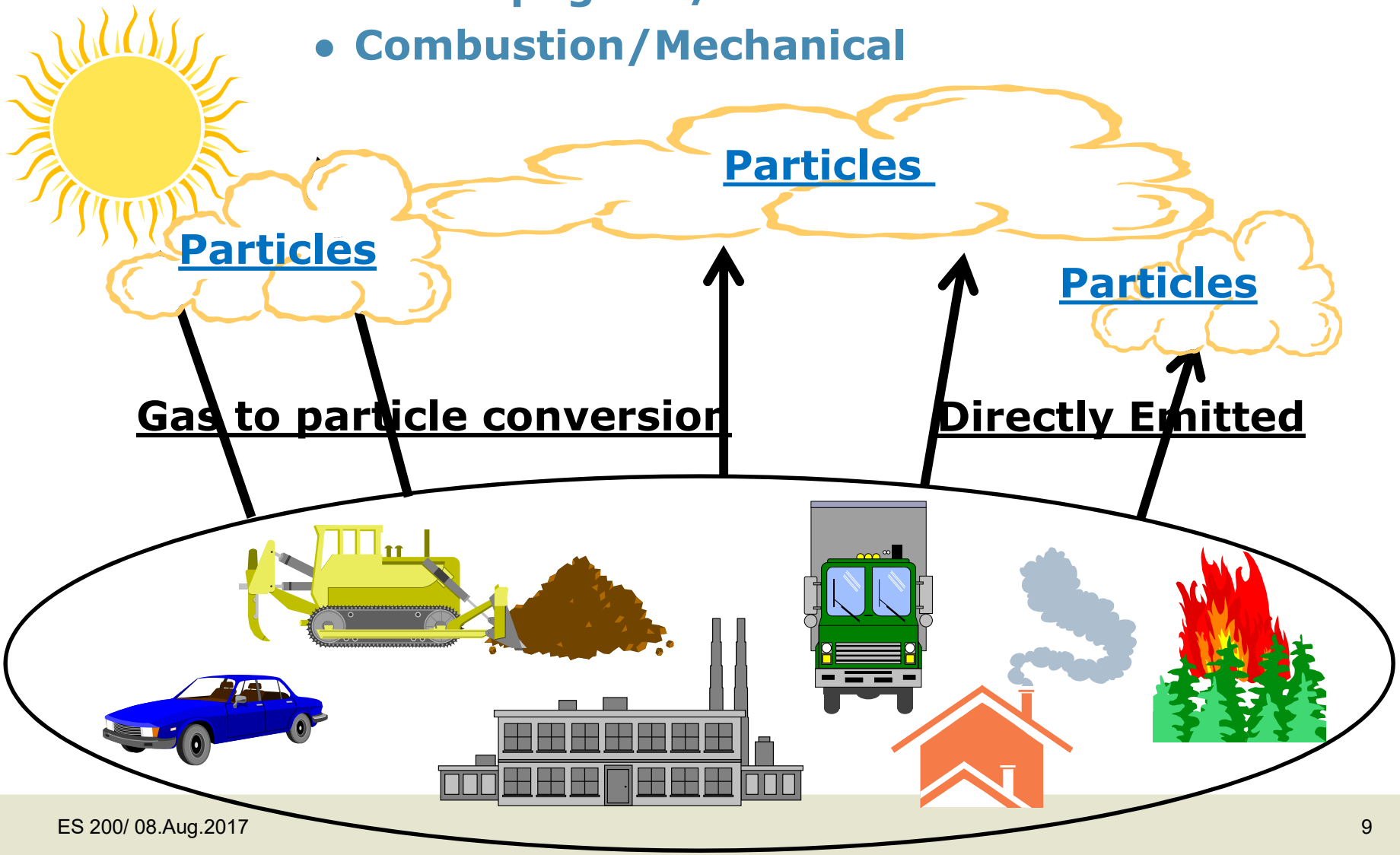
- To understand sources of air pollutants & their spatial and temporal variability

- To understand particle composition & size distribution

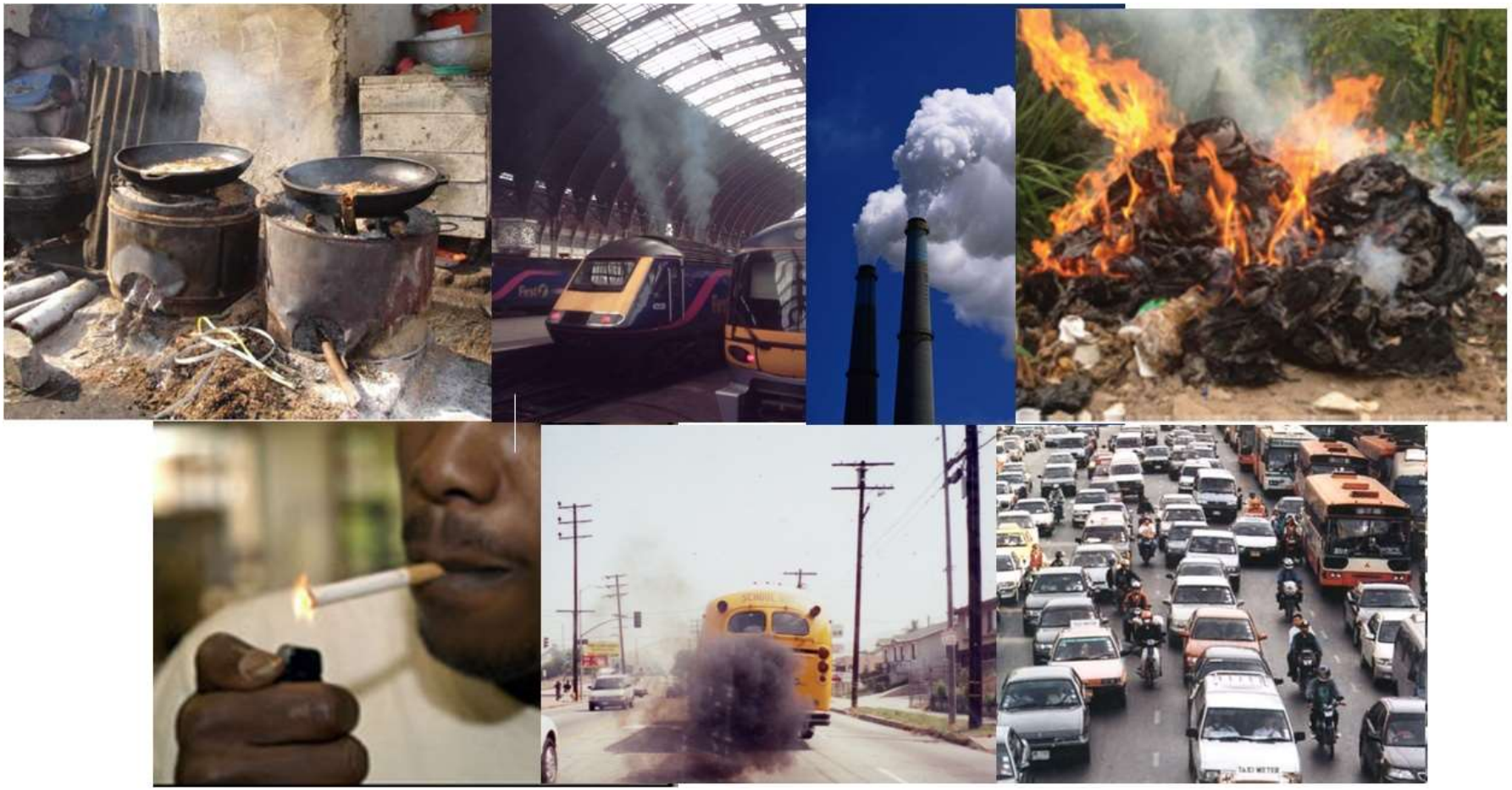
# Where did you last experience an air pollution problem ???

# Sources of air pollutants

- Primary/Secondary
- Anthropogenic/Natural
- Combustion/Mechanical

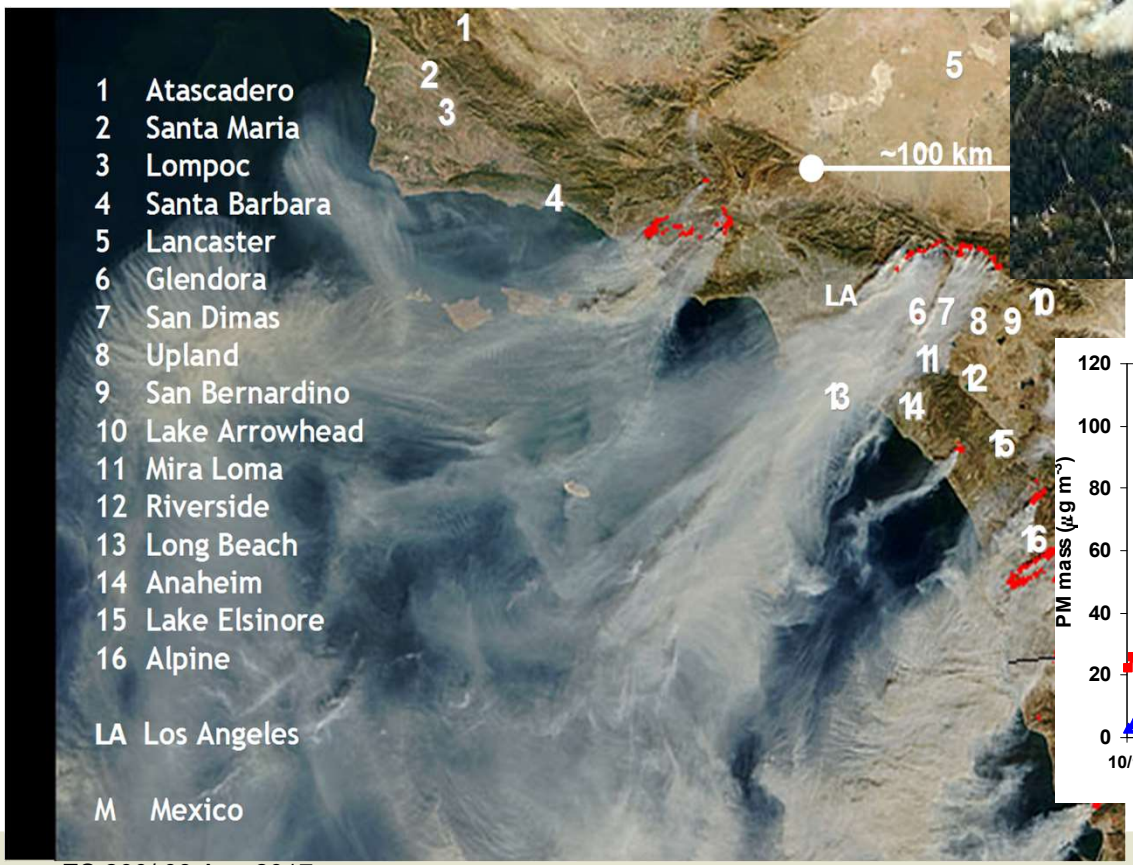


# Anthropogenic air pollution sources

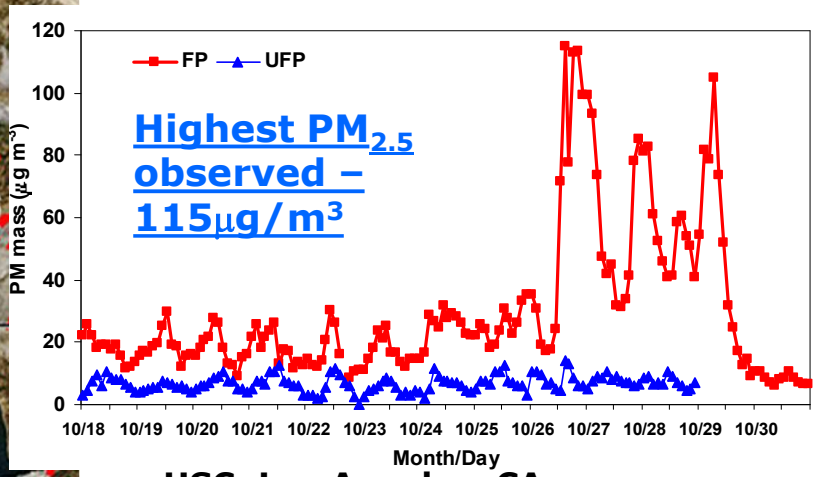


# Natural sources: Wildfires

**Southern California wildfires Oct 2003**



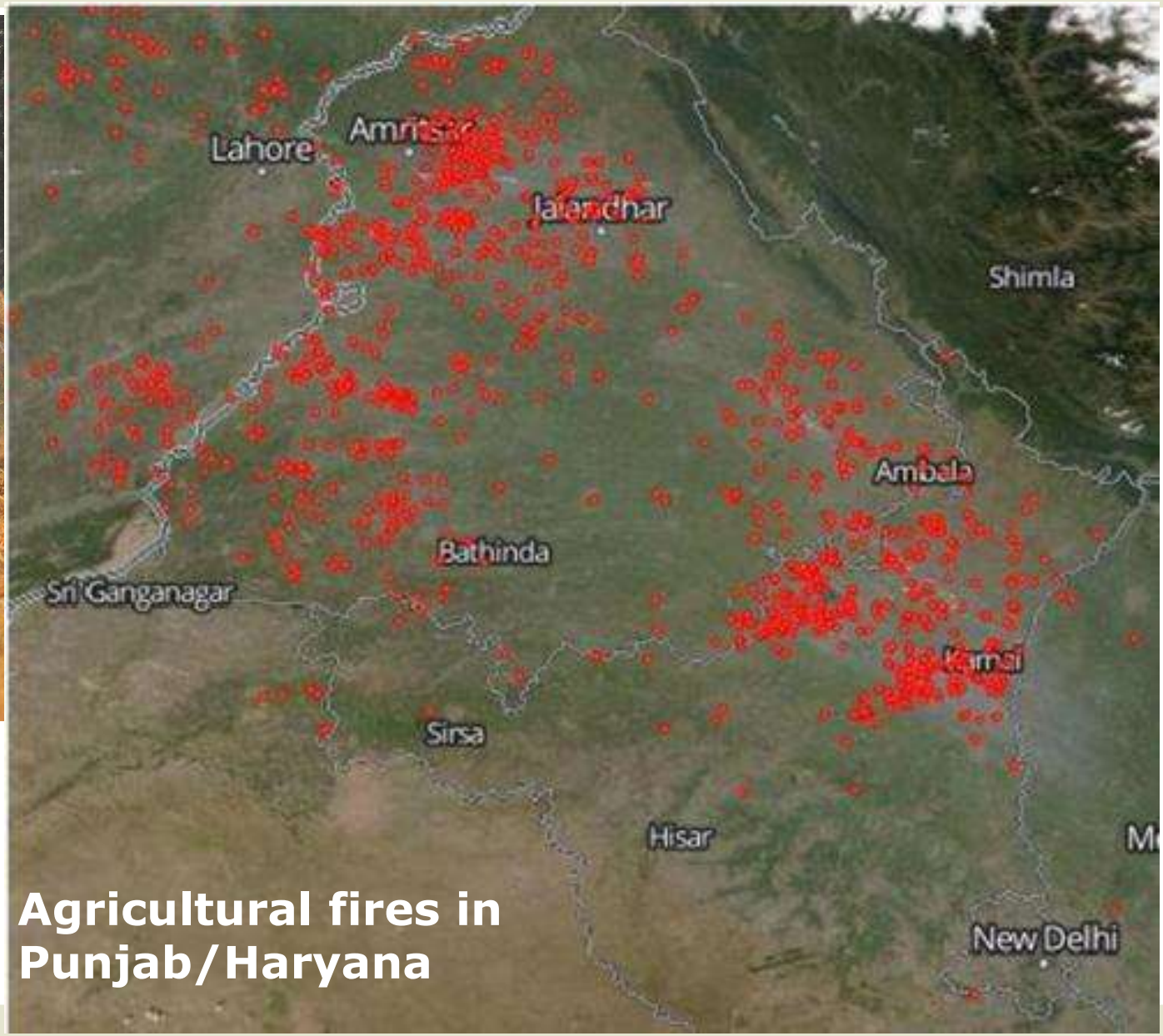





USC, Los Angeles, CA

Phuleria et al., 2005

# Prescribed fires (anthropogenic)




**Agricultural fires in Punjab/Haryana**



**http://www.downtoearth.org.in/news/crop-burning-punjab-haryana-s-killer-fields-55960**

# Natural sources: Wind-blown dust

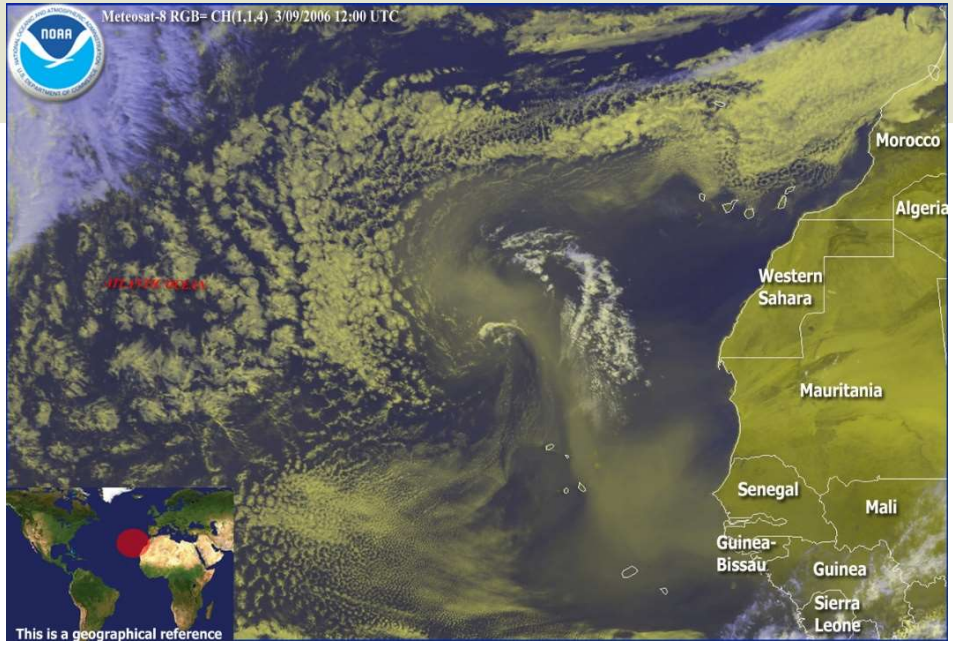



**Image taken at 12:00 UTC. Large dust storm blowing off the NW coast of Africa**

**(NOAA, 2006)**

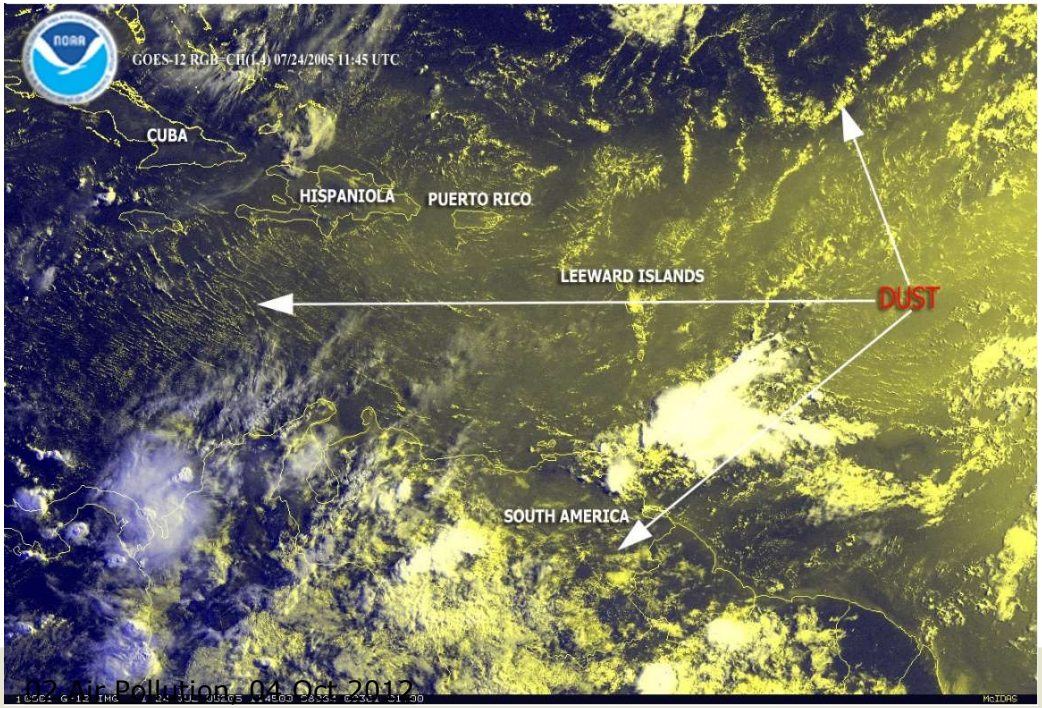
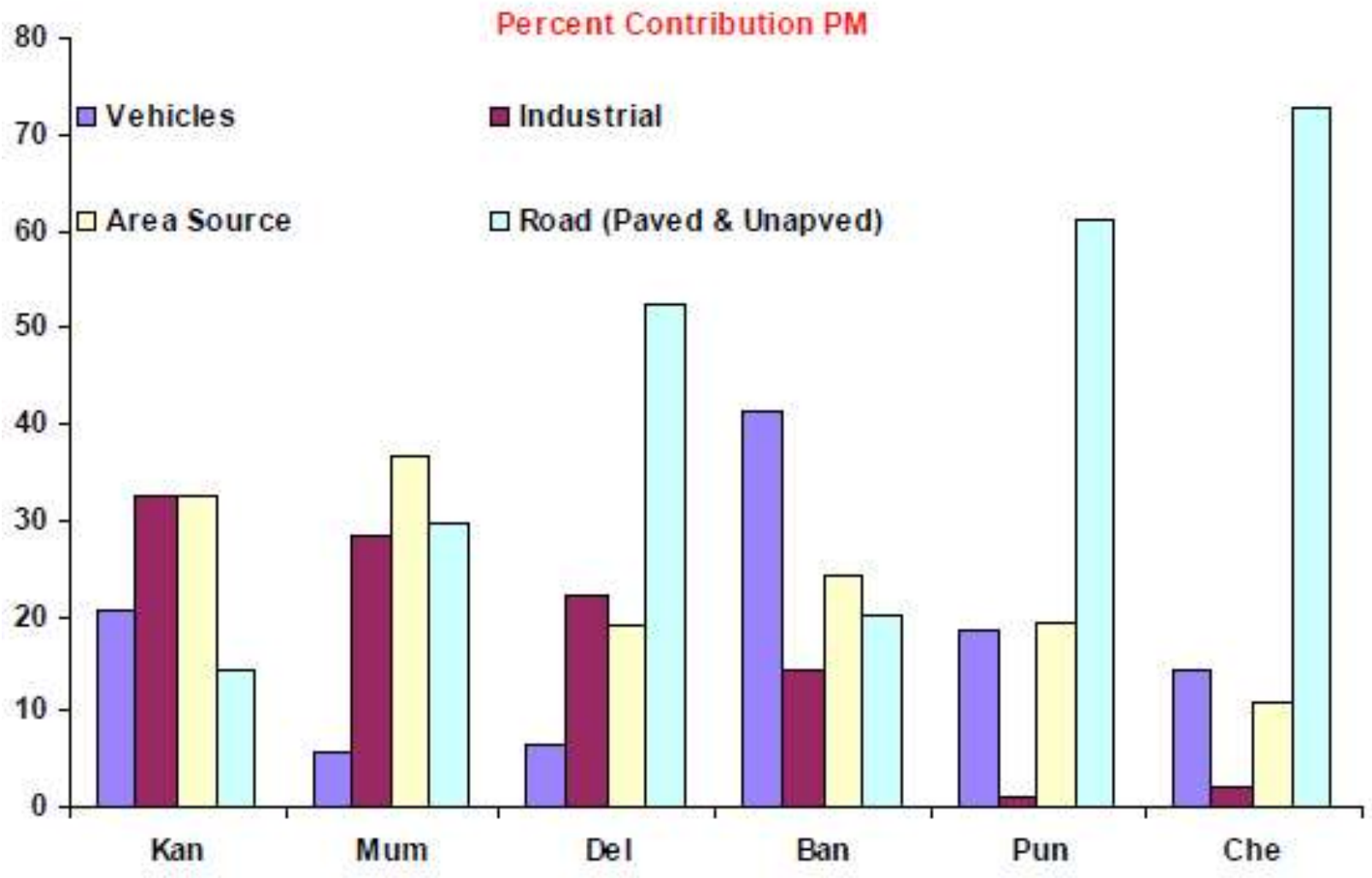



**Image taken at 7:45 EDT. Saharan dust stretching from Atlantic ocean westward; appears as yellowish brown hue and can cause hazy conditions later**

**(NOAA, 2005)**

# Sources of $PM_{10}$ in Indian cities

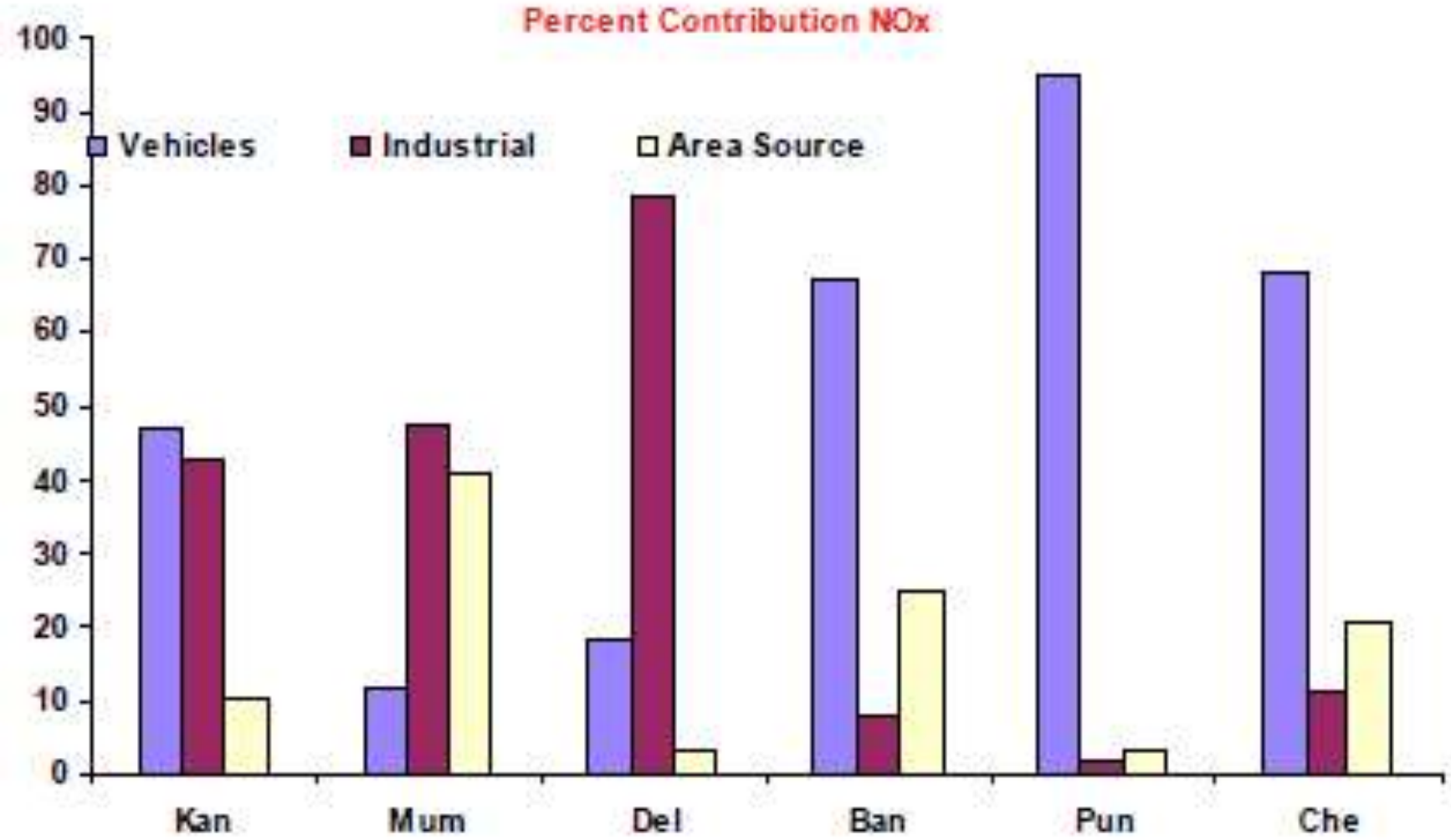
for pm 10 main contribution
is of road






**(CPCB report, 2011)**

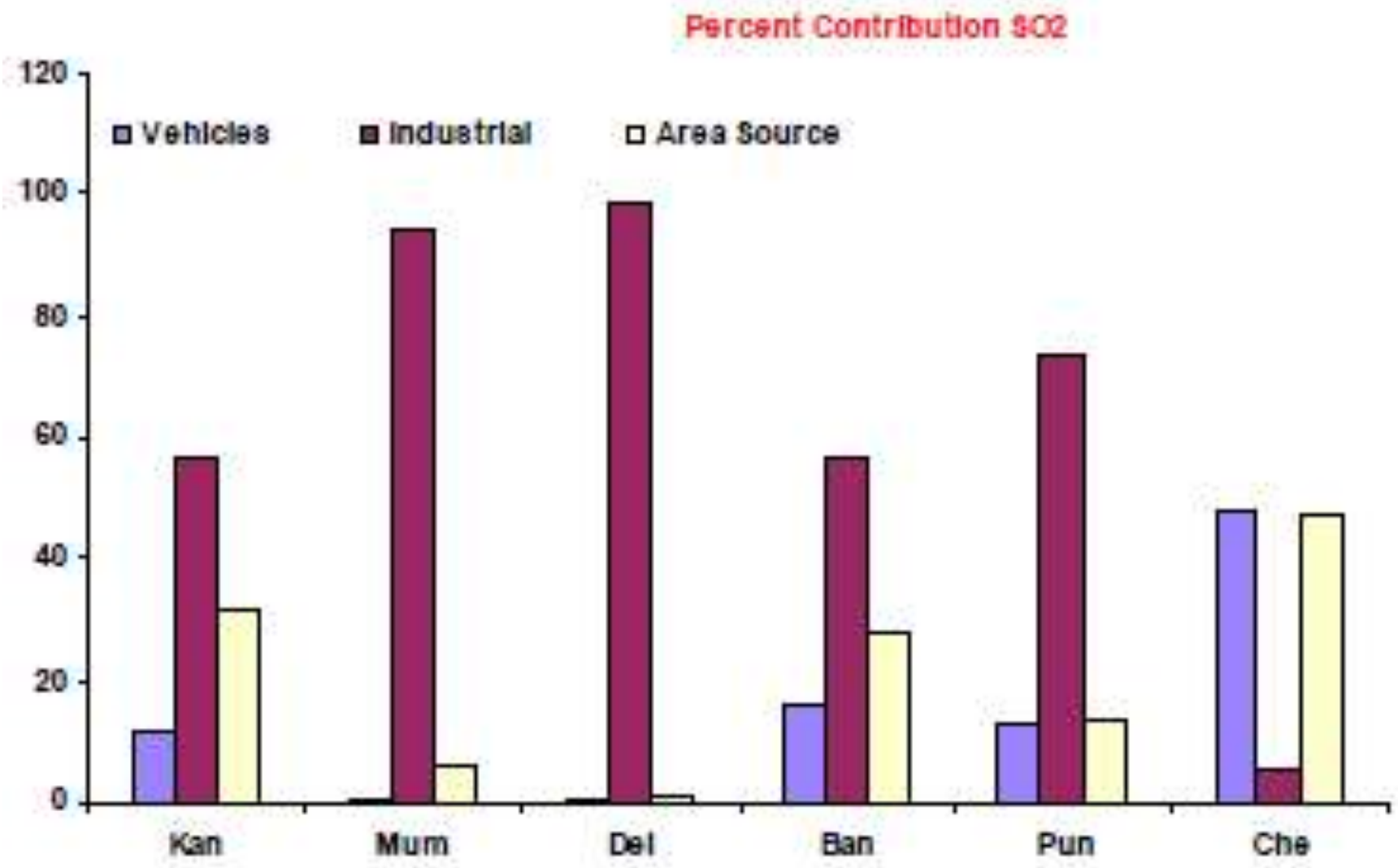
# $NO_x$ sources in Indian cities





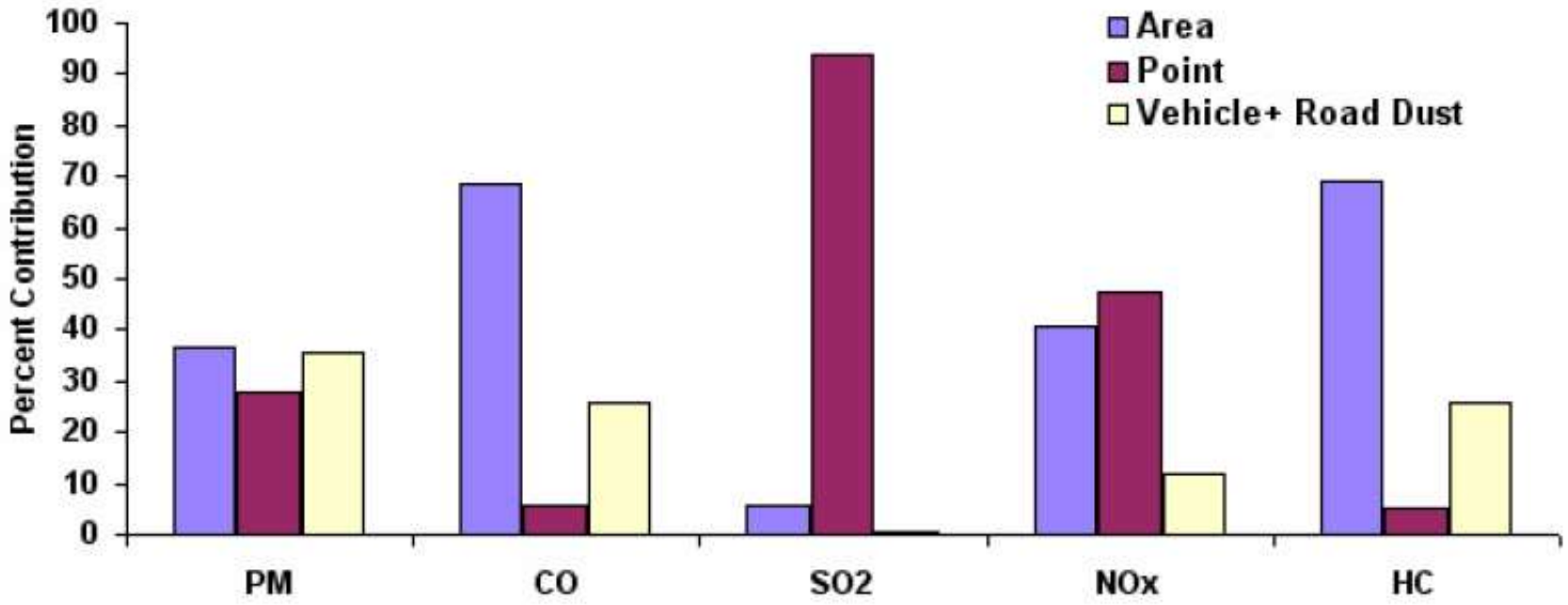

**(CPCB report, 2011)**

# $SO_2$ sources in Indian cities




(CPCB report, 2011)

# Air pollution sources in Mumbai




| a) Area Source |
|---|
| Bakeries |
| Crematoria |
| Open eat outs |
| Hotel restaurants |
| Domestic sector |
| Open burning |
| Landfill Open Burning |
| Construction Activity |
| Locomotive (Cen.+ Wes. Rly) |
| Aircraft |
| Marine vessels |

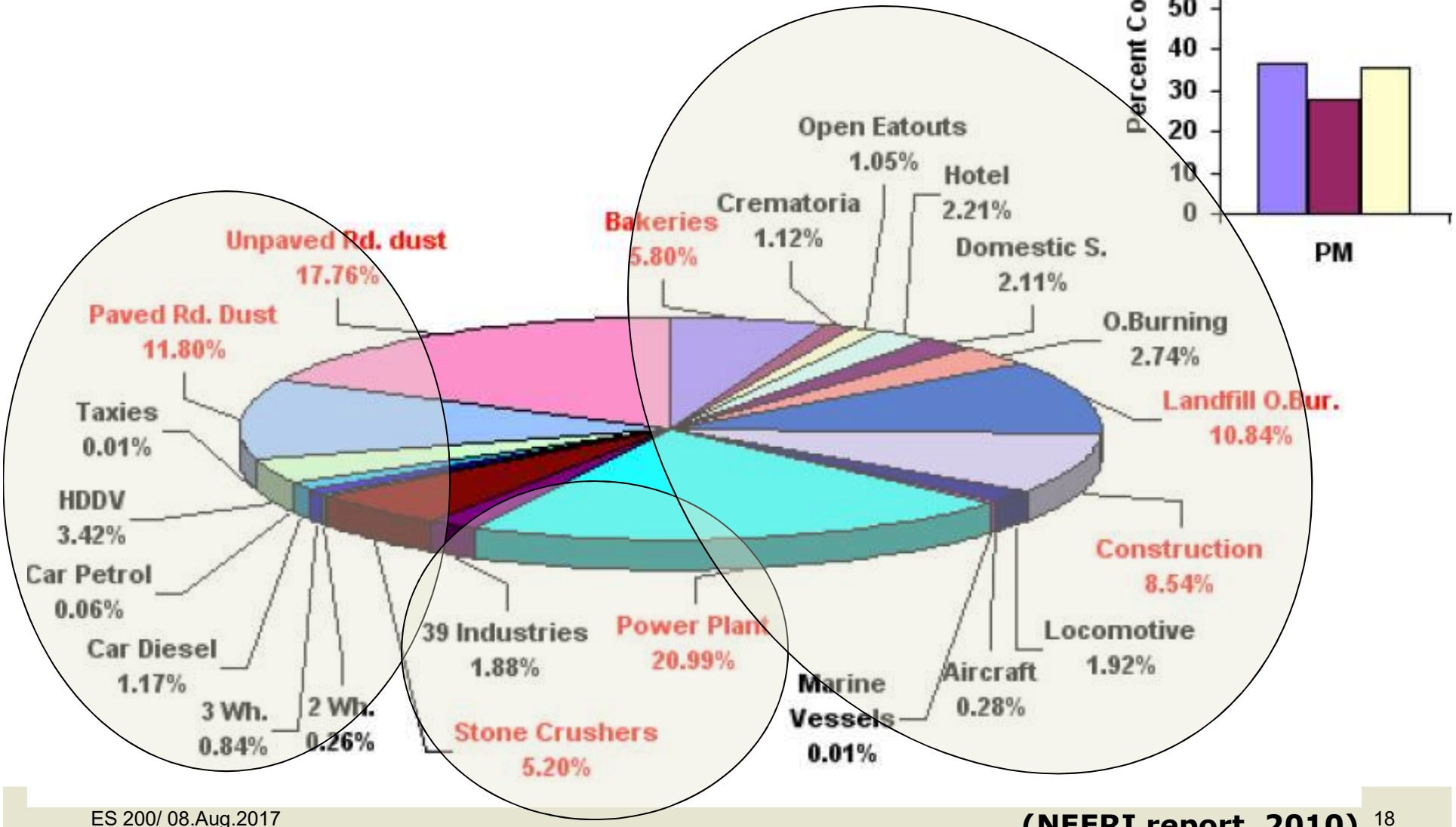
| B) Industrial Source |
|---|
| Power plant |
| 39 Industries |
| Stone crushers |

| C) Line Source |
|---|
| 2 wheelers |
| 3 wheelers |
| Car diesel |
| Car petrol |
| HMV |
| Taxies |
| Paved Road dust |
| Unpaved Road dust |

**(NEERI report, 2010)**

# $PM_{10}$ sources in Mumbai

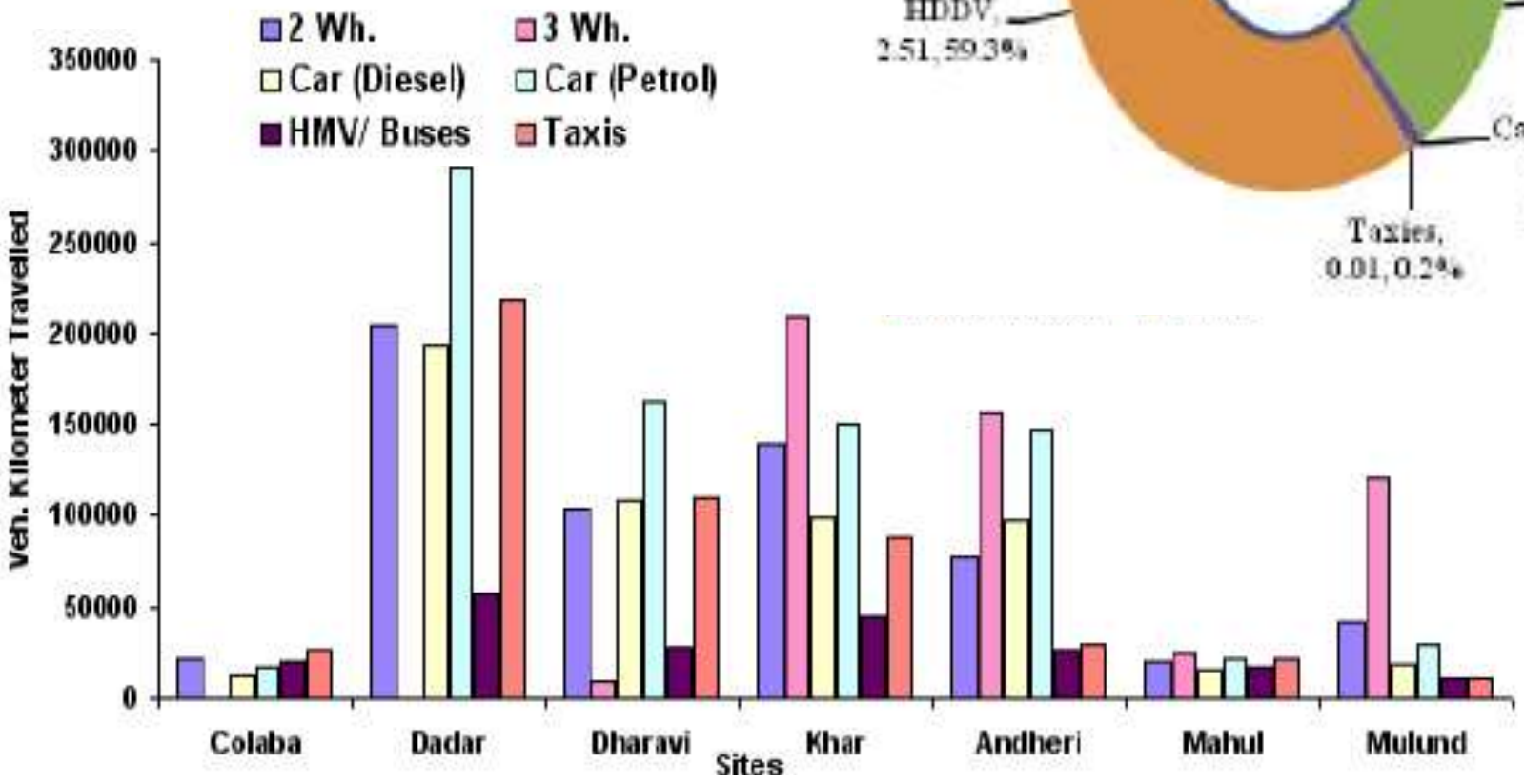
## Source attribution based on total emissions

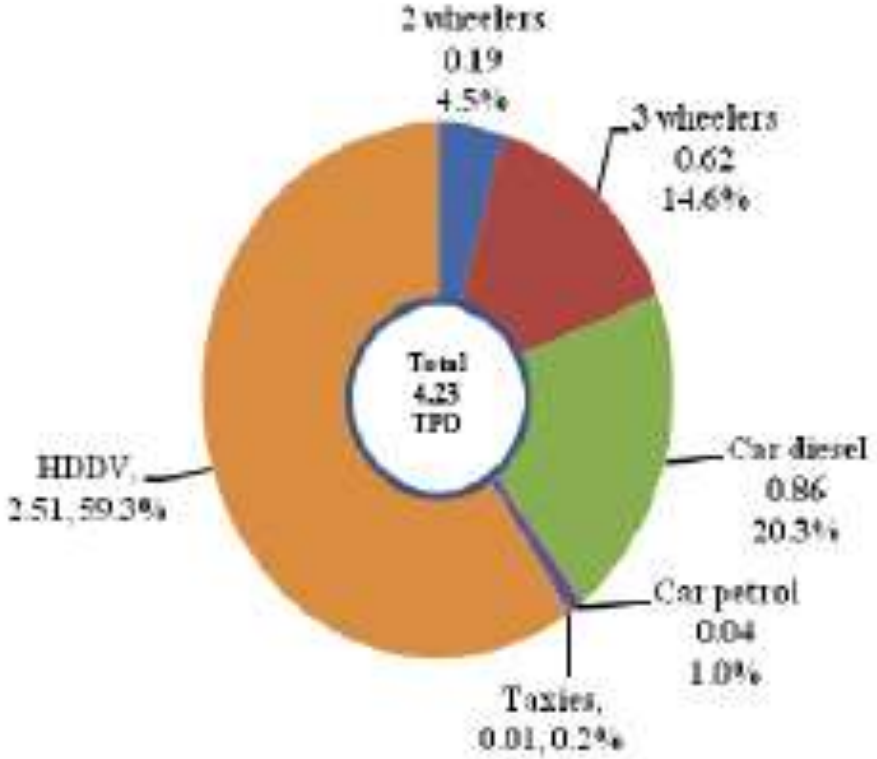





**(NEERI report, 2010)**

# $PM_{10}$ vehicular sources in Mumbai

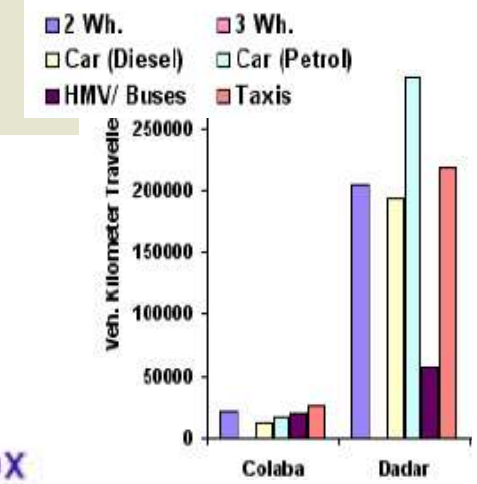


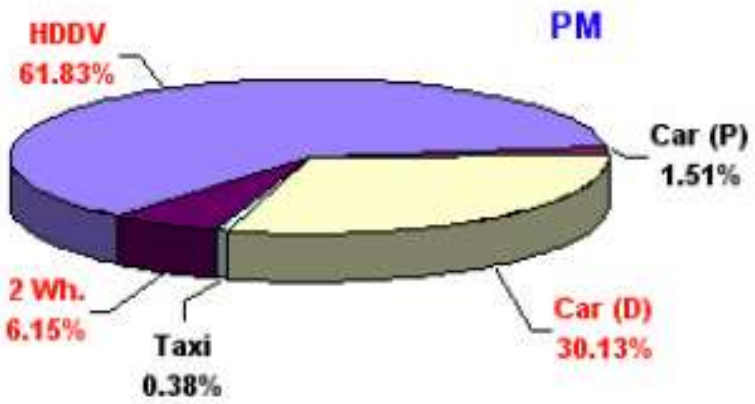



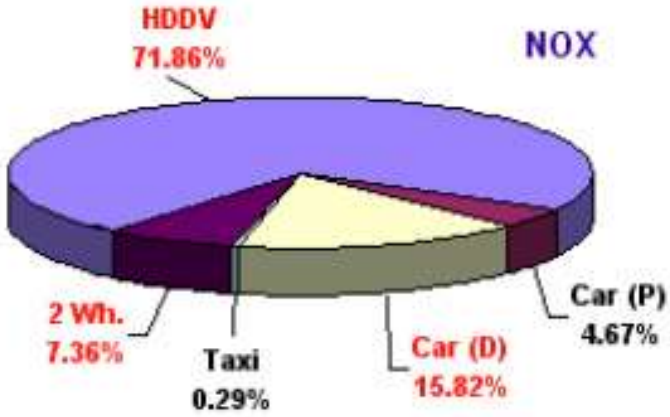


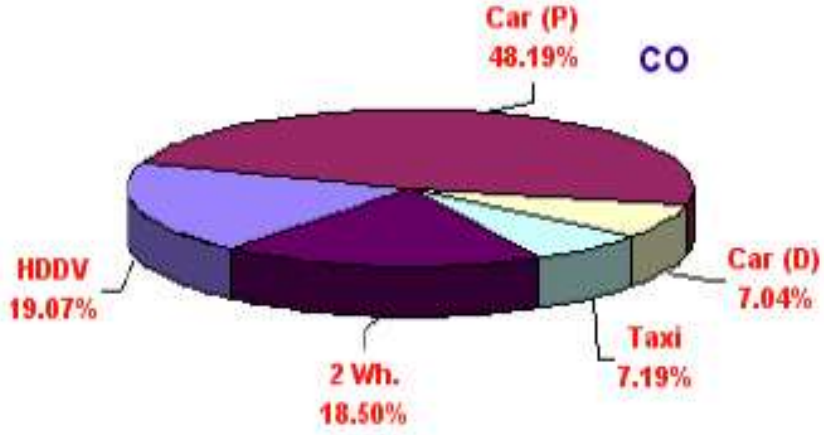

**(CPCB report, 2011 & NEERI report, 2010)**

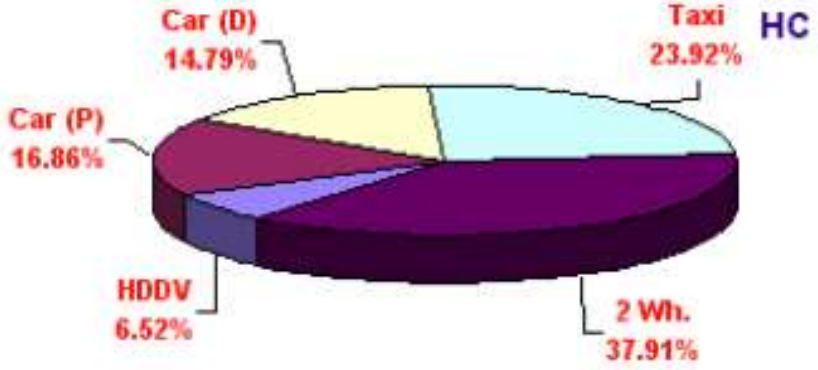
# $PM_{10}$ vehicular sources in Dadar, Mumbai






**(CPCB report, 2011 & NEERI report, 2010)**

# Indoor air pollutants and sources

- Criteria pollutants – e.g. CO, $NO_2$ and $PM_{2.5}$ (cookstoves and heater smoke)
- Asbestos (from old building material)
- Radon
- Household chemicals (e.g. detergents and household cleaners, aerosol sprays, shoe polish, paints, glues etc.)
- Cigarette smoke or ETS
- Outdoor pollutants infiltrating indoors

Prabir Mallik/The World Bank

# Spatial and Temporal distribution

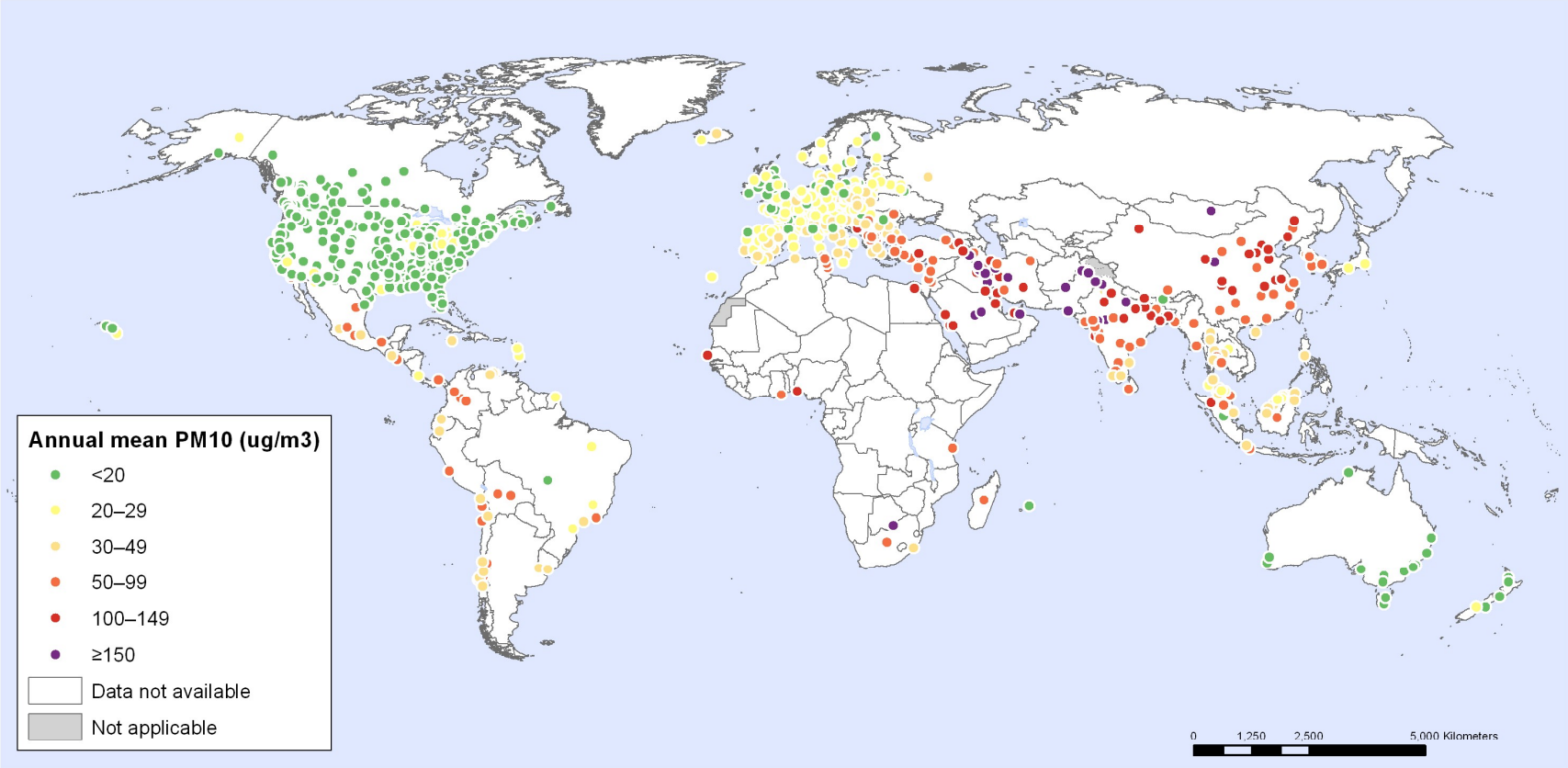
- **Spatial variation** – on which scale?:
  - local urban area/city level
  - state or national level
  - regional or global level

- **Temporal variation** – again on what time resolution?:
  - hourly basis
  - daily basis
  - weekday basis
  - seasonal basis
  - annual basis
  - diurnal basis

# Outdoor $PM_{10}$ distribution across the globe

## Spatial distribution on global scale

**Exposure to particulate matter with an aerodynamic diameter of 10 µm or less (PM10) in 1081 cities, 2003–2010**

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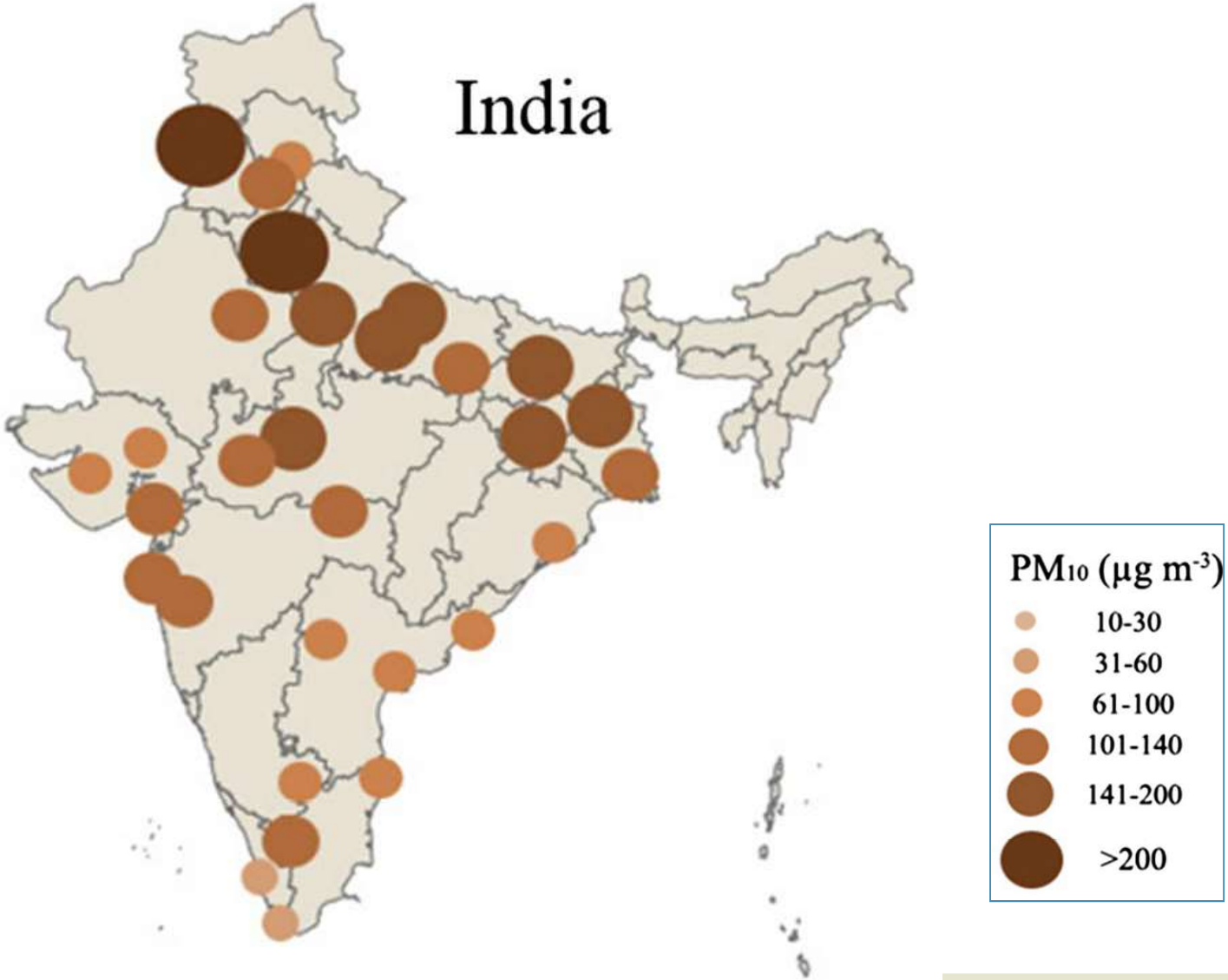
Data Source: World Health Organization
Map Production: Public Health Information and Geographic Information Systems (GIS)
World Health Organization

World Health Organization

# Outdoor $PM_{10}$ distribution across India

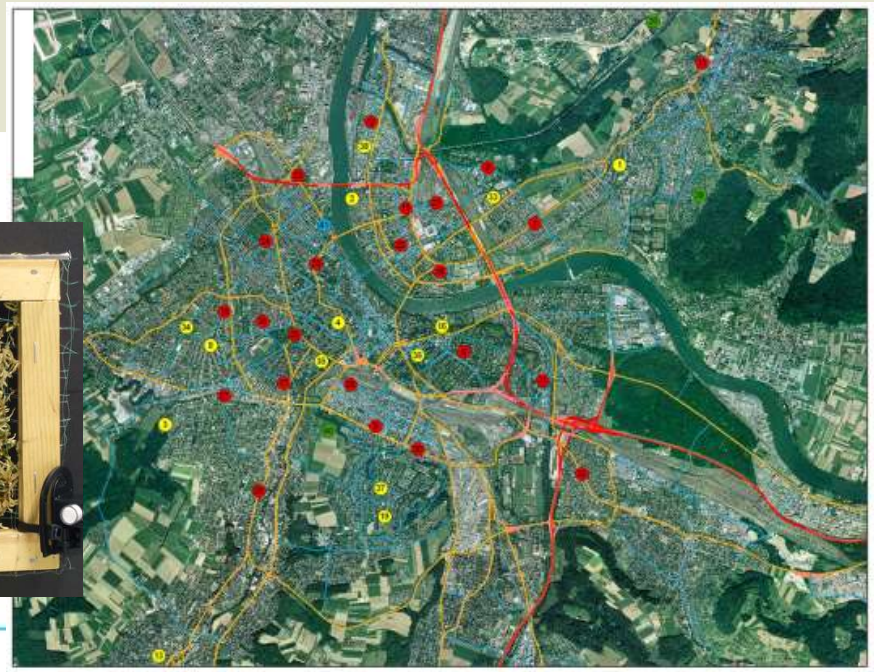
## Spatial distribution on National scale




(Mukherjee et al., 2017)

# Spatial distribution: PAHs in Urban Basel

## Spatial distribution on urban scale

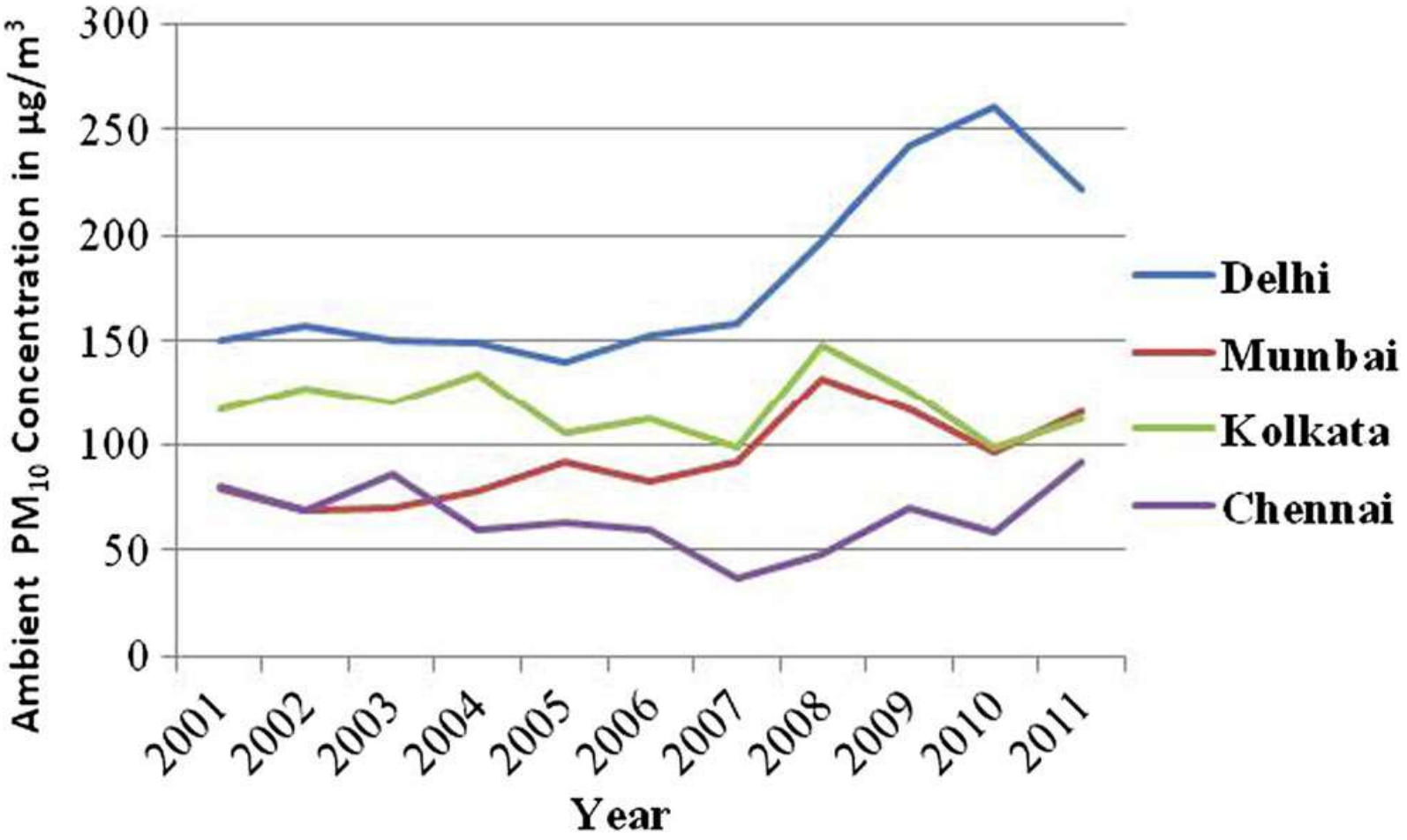





(Phuleria et al., 2013)

# Spatio-temporal variation: $PM_{10}$ in major Indian cities (Six-cities study)

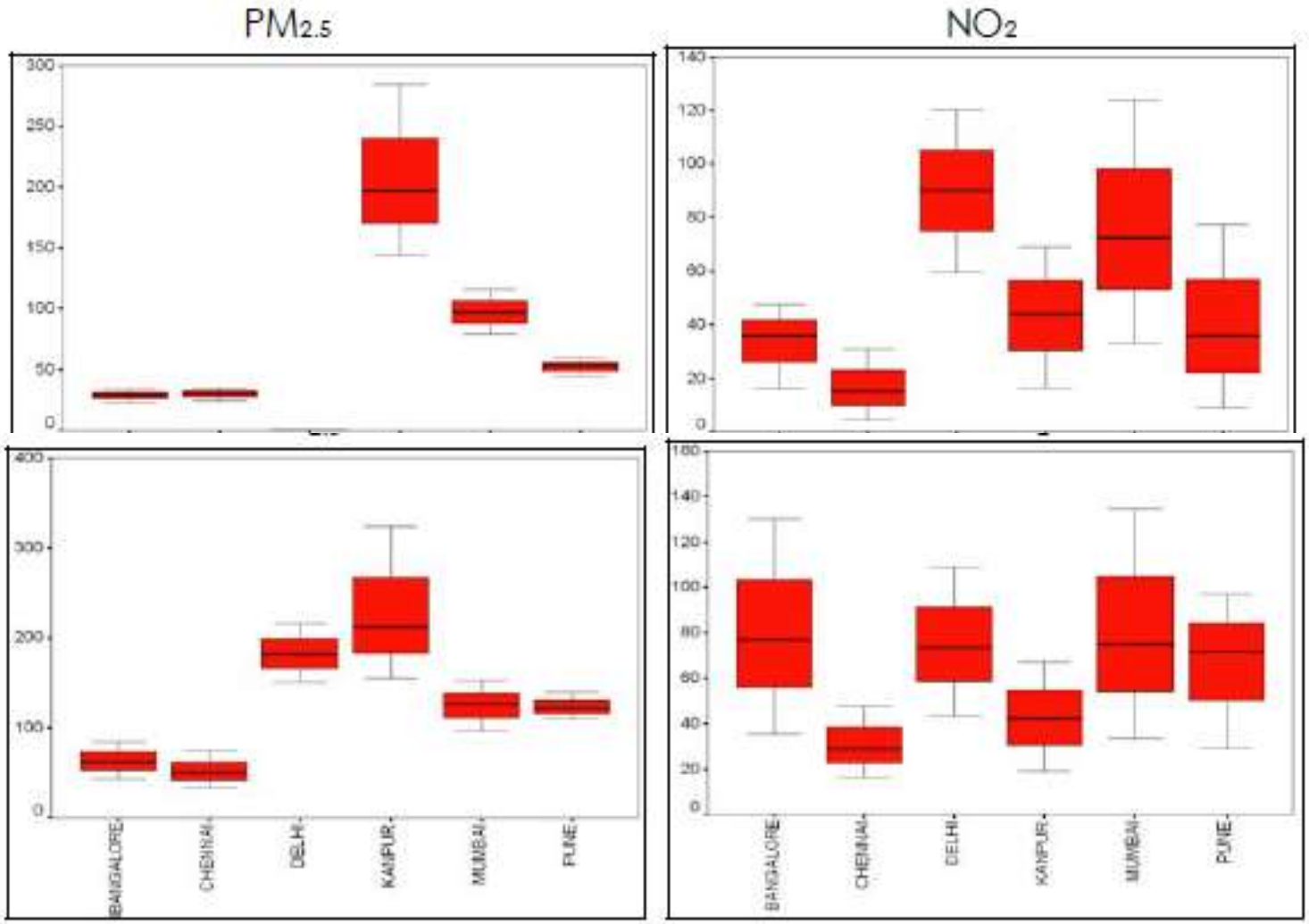
## Spatial distribution on national scale; Temporal distribution annual




(Gargava & Rajagopalan, 2016)

# Spatio-temporal variation: $PM_{2.5}$ & $NO_2$ in Indian cities (Six-cities study)

## Spatial distribution between cities and site types; Temporal distribution annual



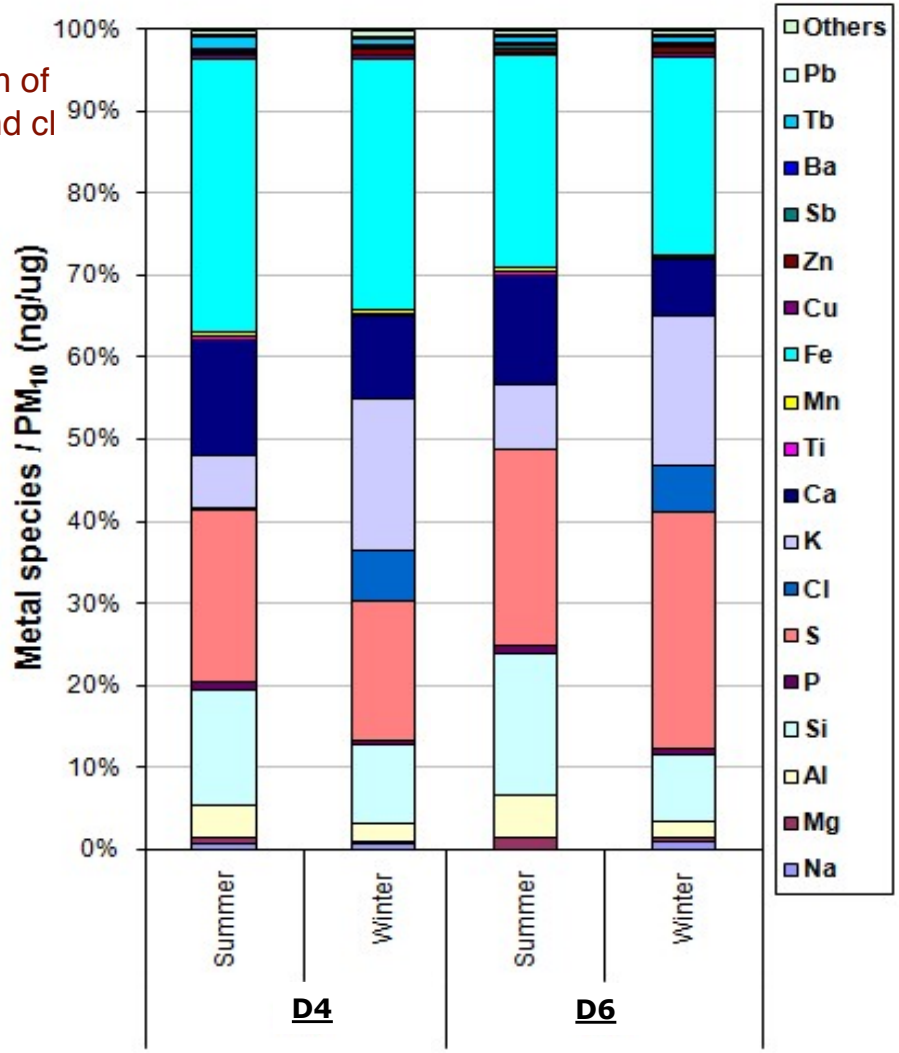


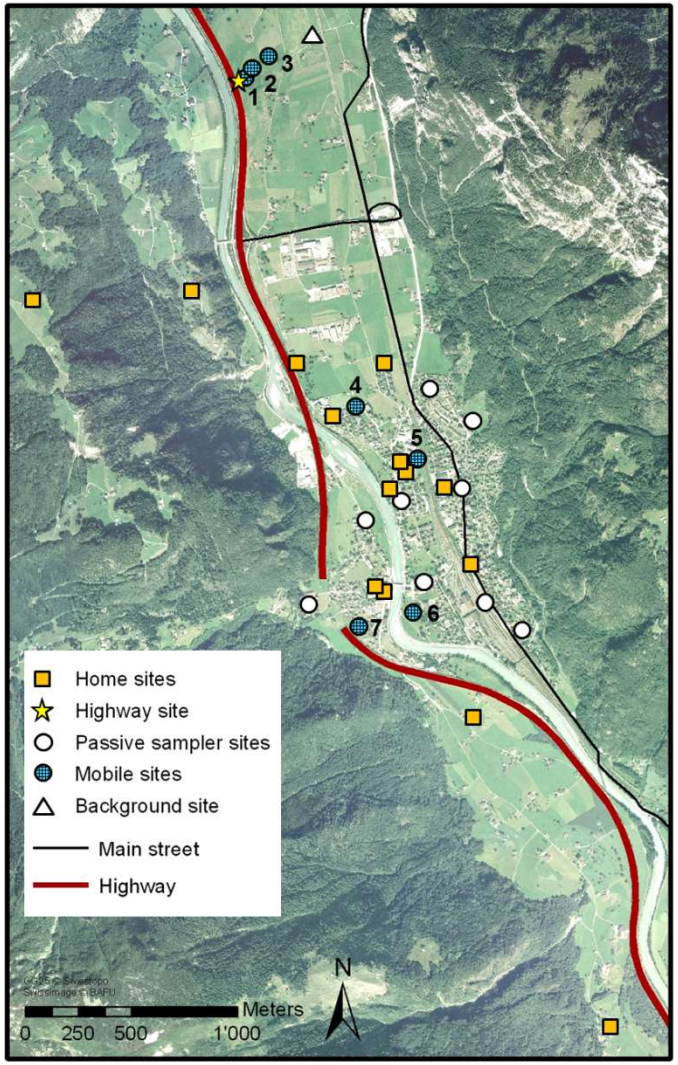

**(CPCB report, 2011)**

# Spatio-seasonal distribution: Trace metals in Erstfeld 2008-09

## Spatial distribution on town/village scale; Temporal distribution seasonal

in winters concentration of potassium and cl increases

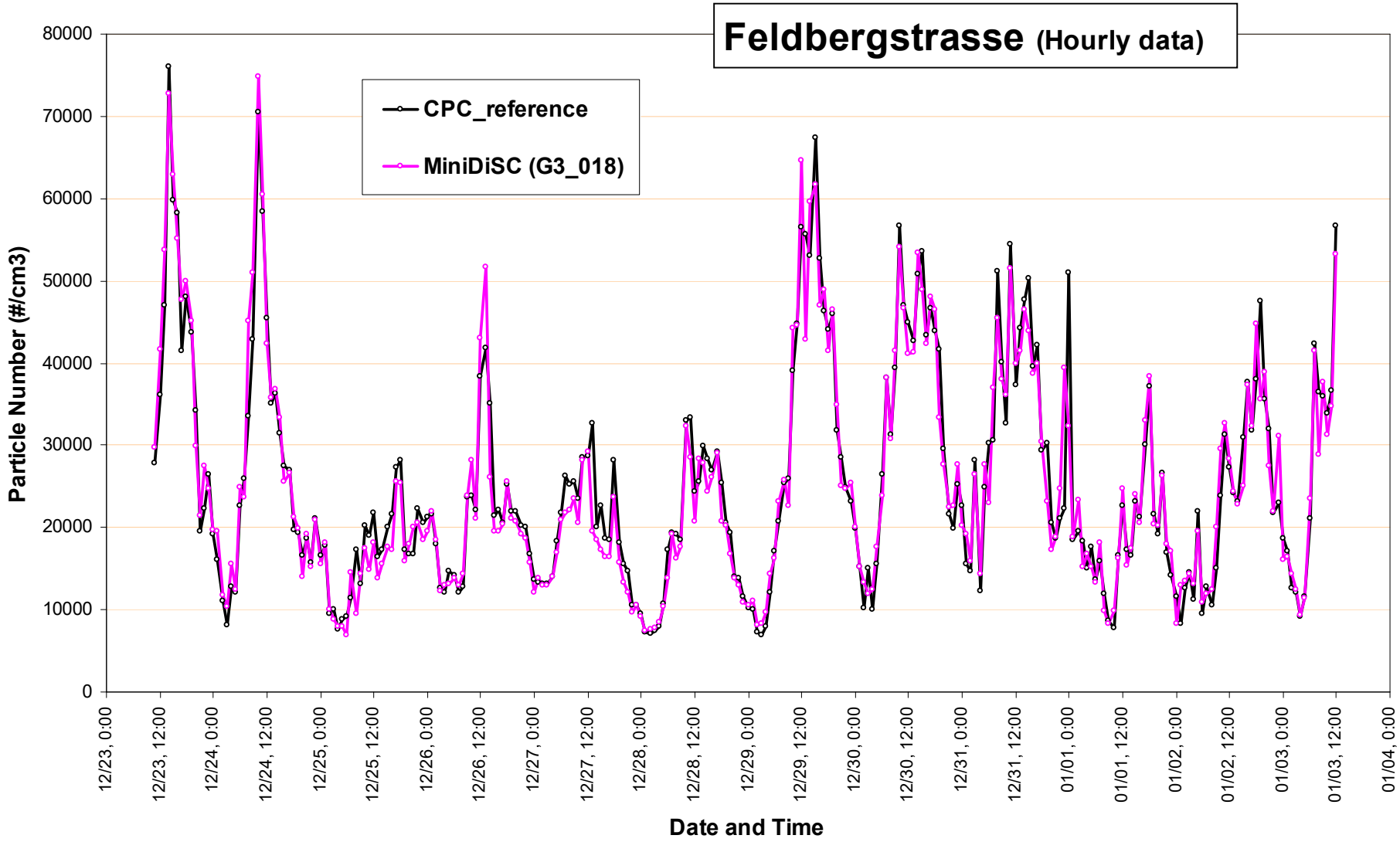



(Phuleria et al., 2011)

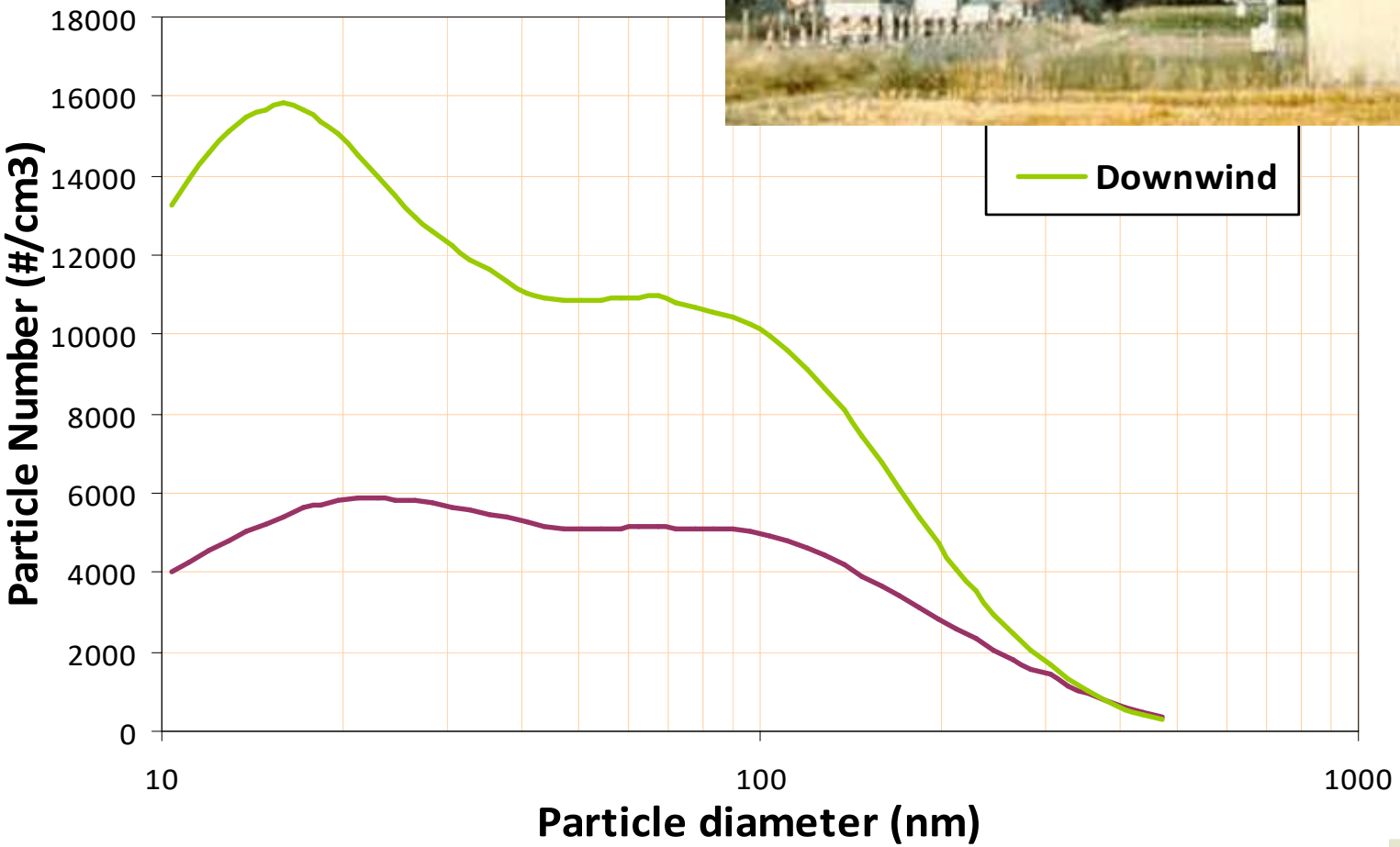
# Temporal distribution: Ultrafine Particle in Basel

## Temporal distribution hourly



# Spatial distribution:
# Partcle size distribution in Haerkingen

## Spatial distribution on urban scale

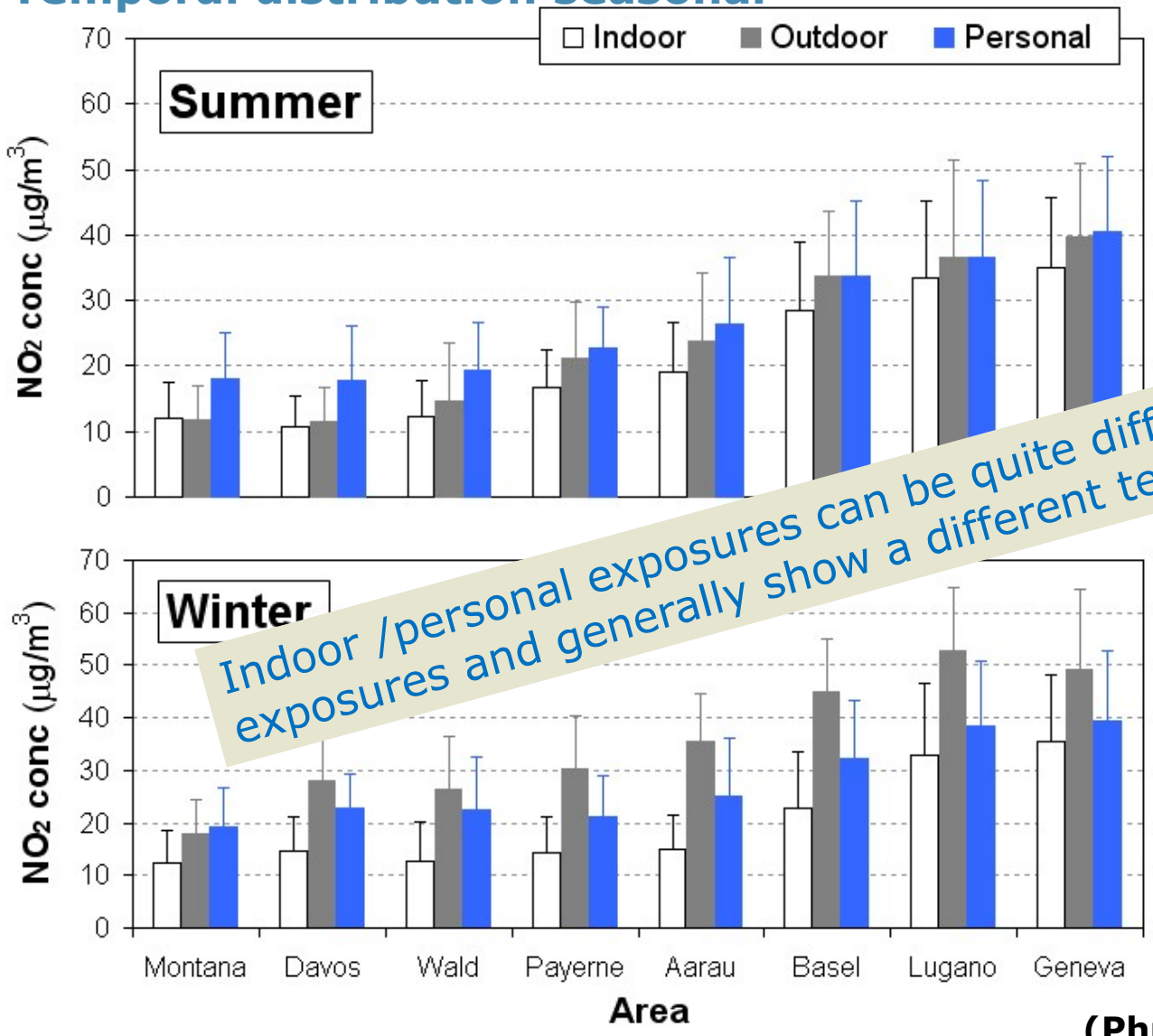



# Diurnal variation: Ultrafine particles in Harkingen

## Temporal distribution diurnal

# Outdoor, Indoor & Personal $NO_2$ levels

## Spatial distribution on national scale; Temporal distribution seasonal




| Pooled | |
|---|---|
| Indoor | 21.3 ± 12.3 |
| Outdoor | 24.6 ± 14.2 |
| Personal | 27.0 ± 12.4 |

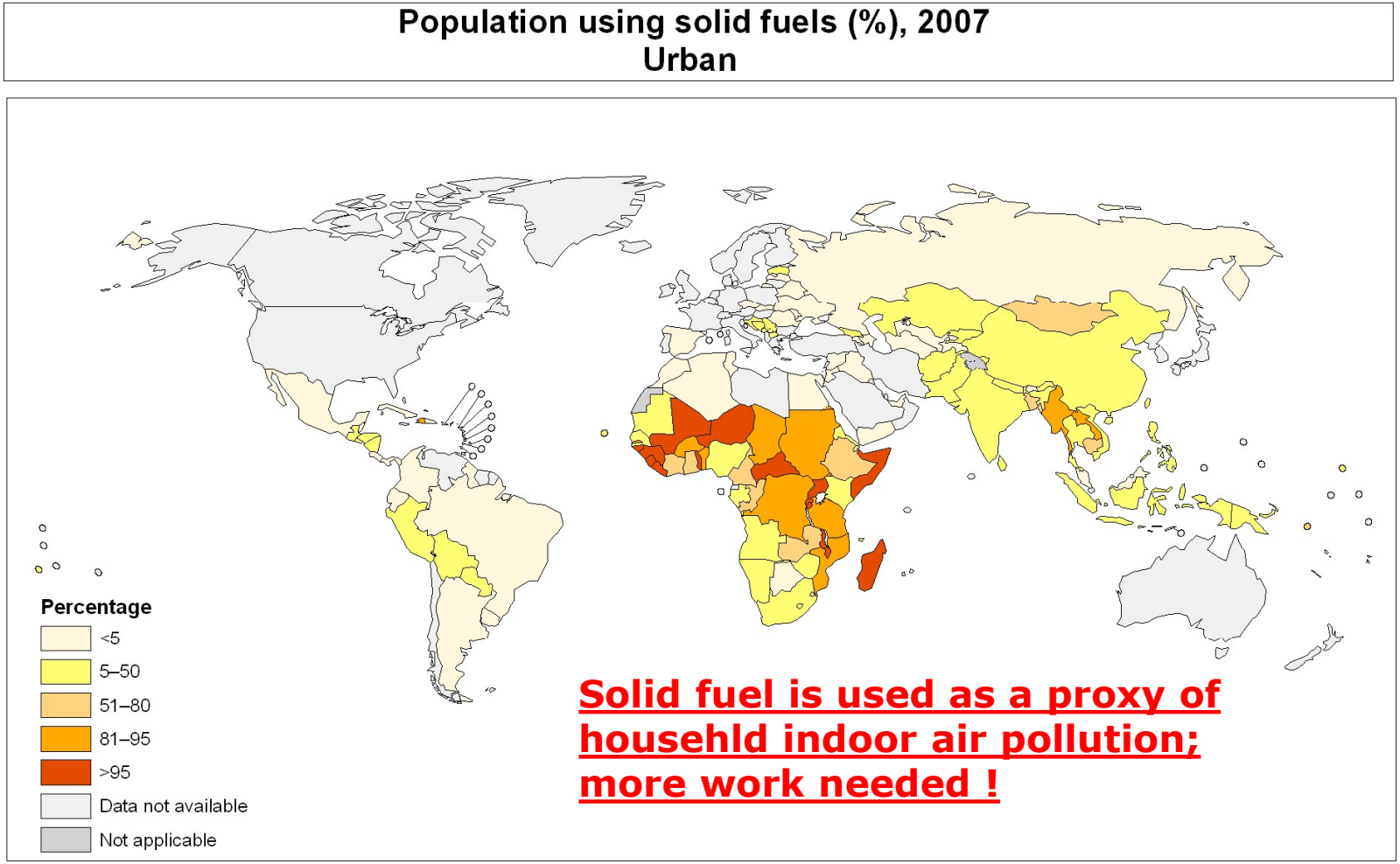
| Pooled | |
|---|---|
| Indoor | 20.1 ± 12.4 |
| Outdoor | 36.8 ± 15.4 |
| Personal | 27.9 ± 12.5 |

Indoor /personal exposures can be quite different than outdoor exposures and generally show a different temporal variation

**(Phuleria et al., 2011)**

# Indoor air pollution across the globe: Urban areas

## Spatial distribution on global scale

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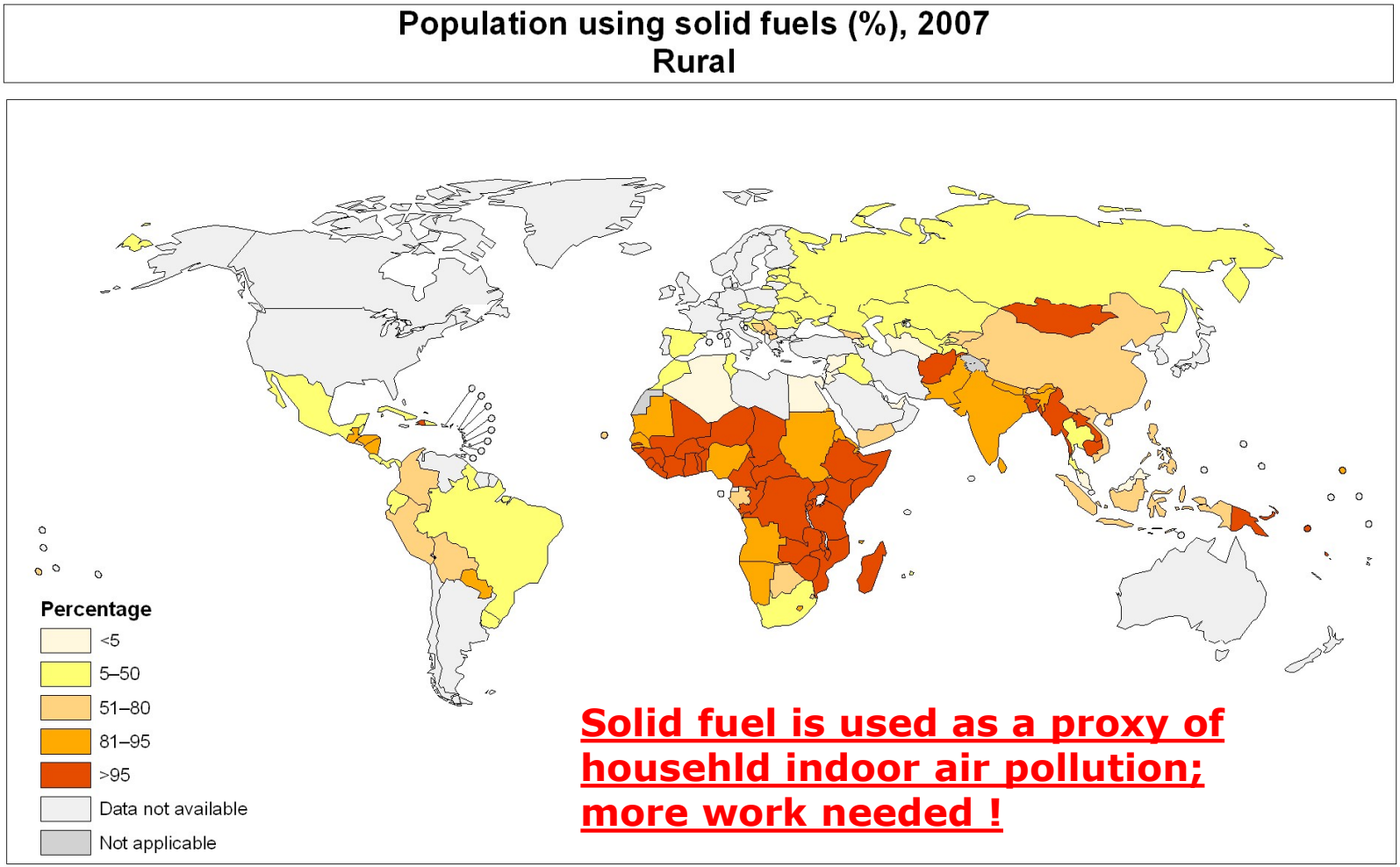
Map Production: Public Health Information and Geographic Information Systems (GIS)
World Health Organization



(WHO, 2011)

# Indoor air pollution across the globe: Rural areas

## Spatial distribution on global scale

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World Health Organization





(WHO, 2011)