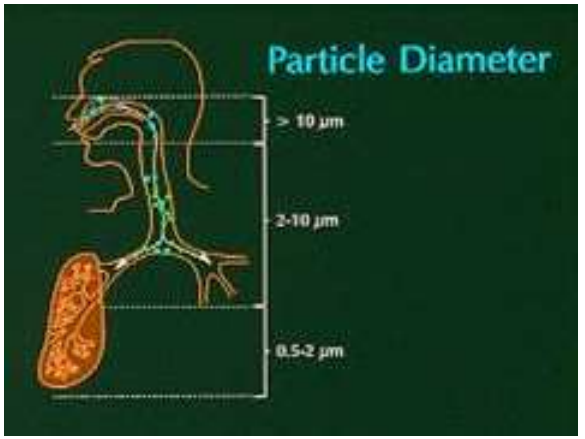
# Module C:

# Air Quality

## Sources, Distribution, Impacts, Monitoring, Modeling, Control

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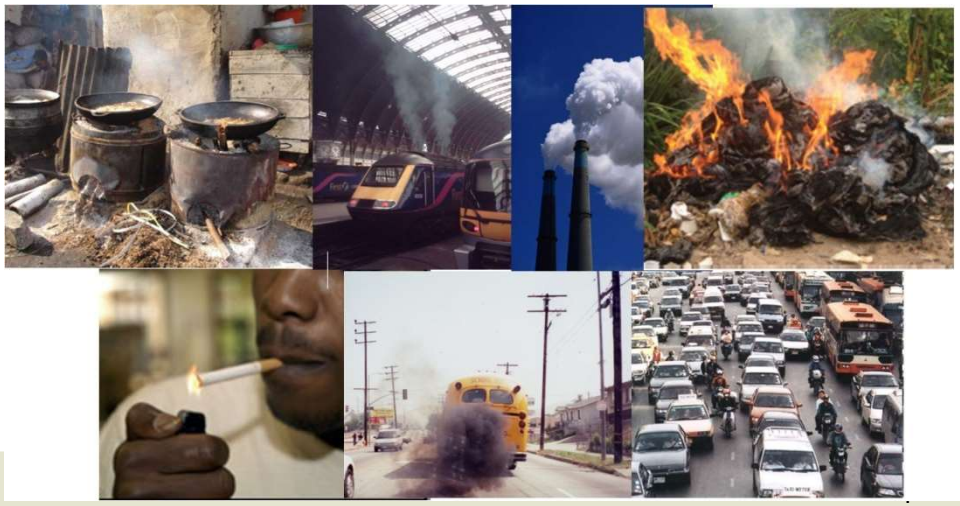


# Goal !

**You will be able to explain key concepts of air pollution and air quality management**

**Expectation:**

- To memorize key concepts and definitions
- To describe physico-chemical phenomena, and
- To apply the understanding on current air quality problems

# Learning Objectives !

1. To learn about the criteria air pollutants, air quality regulations, and their impact on human health and climate
2. To understand sources of air pollutants & their spatial and temporal variability
3. To understand particle composition & size distribution
4. To learn about monitoring methods and thus able to quantify pollutants' concentrations
5. To explain effects of meteorology and the physics of dispersion of pollutants in the atmosphere
6. To learn about air quality modeling methods
7. To learn about air pollution control methods from mobile and stationary sources

# Evaluation !!!

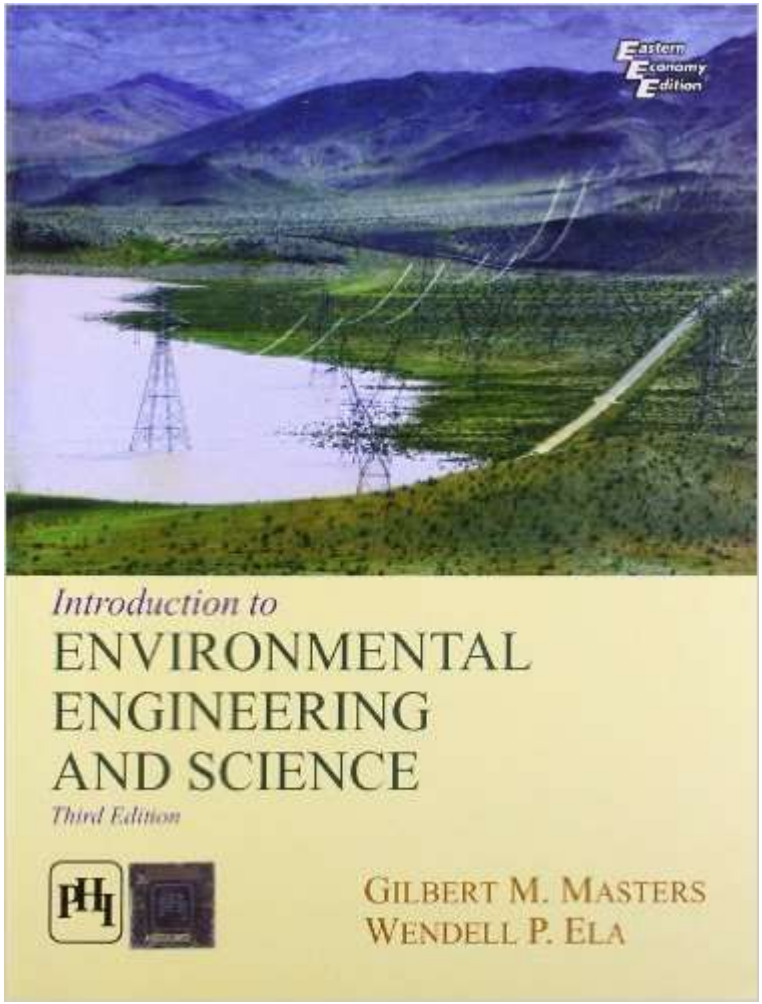
**When:**

- This module starts from today...
- There will be a total of seven lectures

**Evaluation:**

- Final Exam – 60%
- Quiz – 40%
  **Quiz will be on 6th Nov**

# Textbook

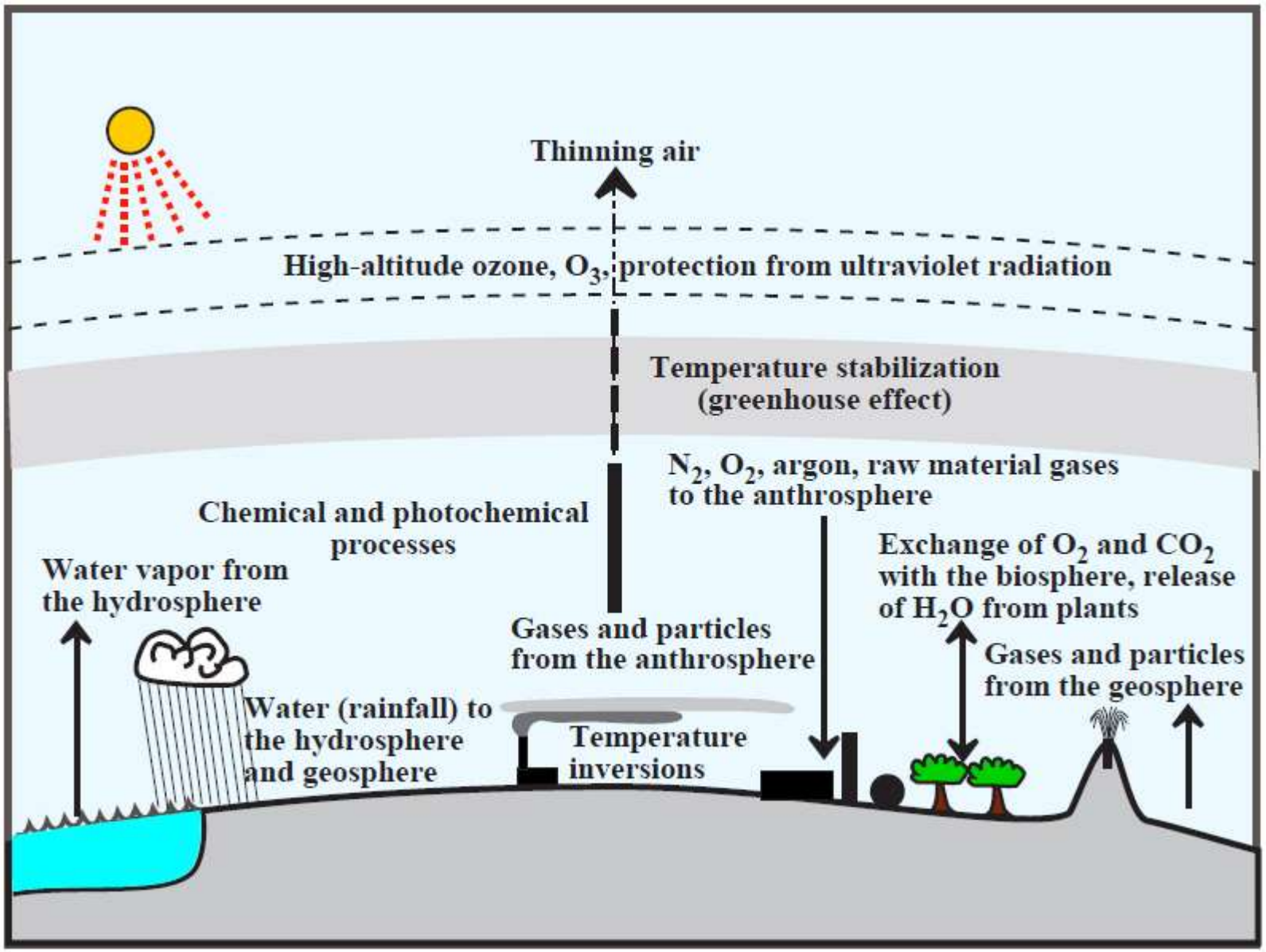



**Will provide relevant articles or chapters from other books, as necessary**

# Today's Learning Objective !

- To learn about the criteria air pollutants, air quality regulations, and their impact on human health and climate

# Atmosphere






http://www.asdlib.org/onlineArticles/ecourseware/Manahan/EnvChBasicsCondensedLect.pdf

# Air Pollution !

- Not a new phenomena: Smoke from Burning of Coal
- Problems in many urban areas in late 1800s and early 1900 due to coal use
- 1000's of deaths attributed to air pollution episode in London (Great Smog) in December 1952
  - large emissions of pollutants
  - restricted air volume
  - failure to recognize problem
- Photochemical smog: CO + $NO_x$+ HC + Light →
  VOCs+$O_3$ + PAN (Peroxyacetyl nitrate)
- Bhopal gas tragedy: 2–3 December 1984

https://www.youtube.com/watch?v=UH5LPwdVnqI

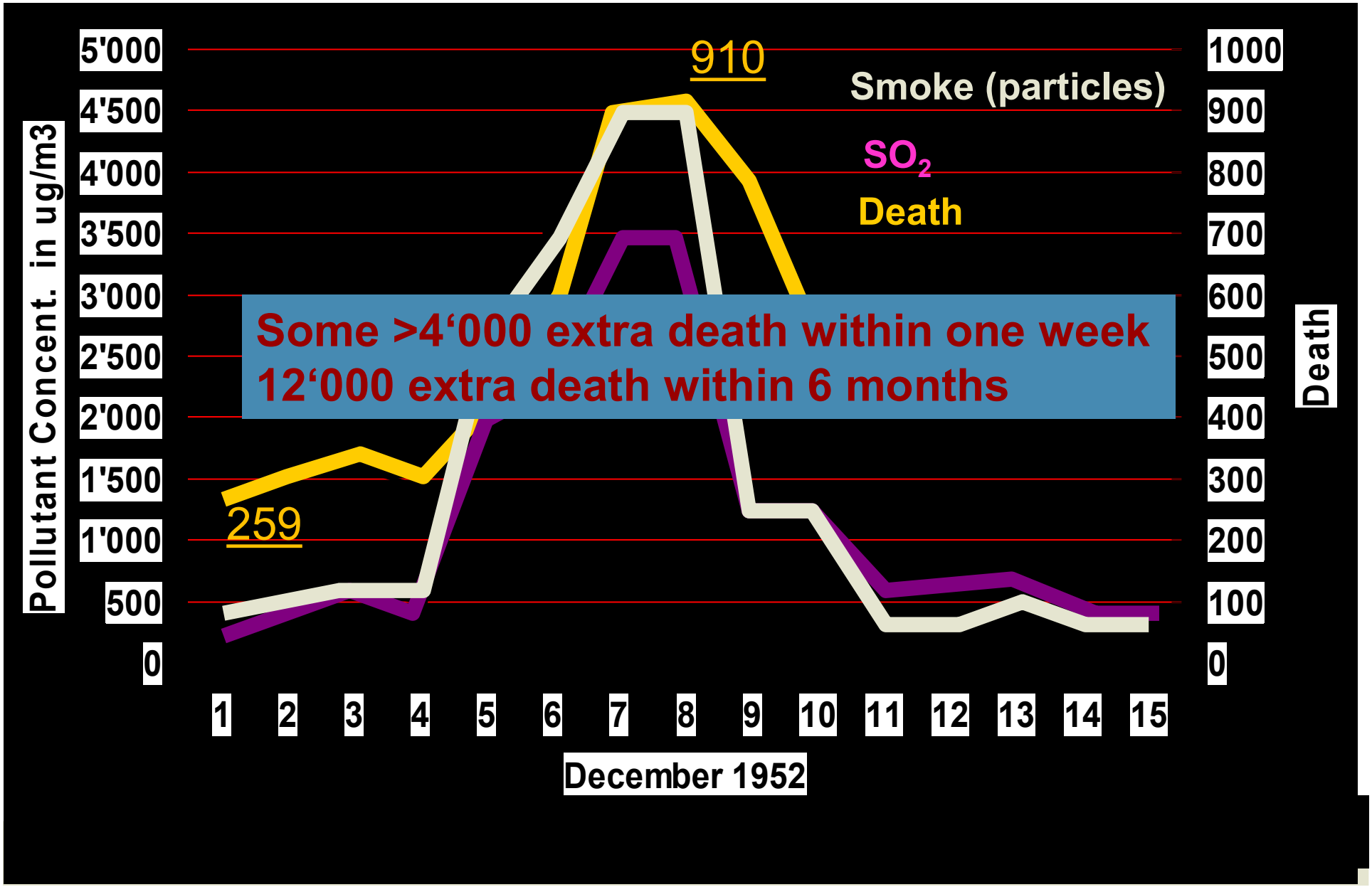
# London Smog, December 1952

Watch the London Smog 1952 "Killer Fog"

http://www.youtube.com/watch?v=eUQ9tPc8YbM

# London smog, 1952

# London-Smog, December 1952

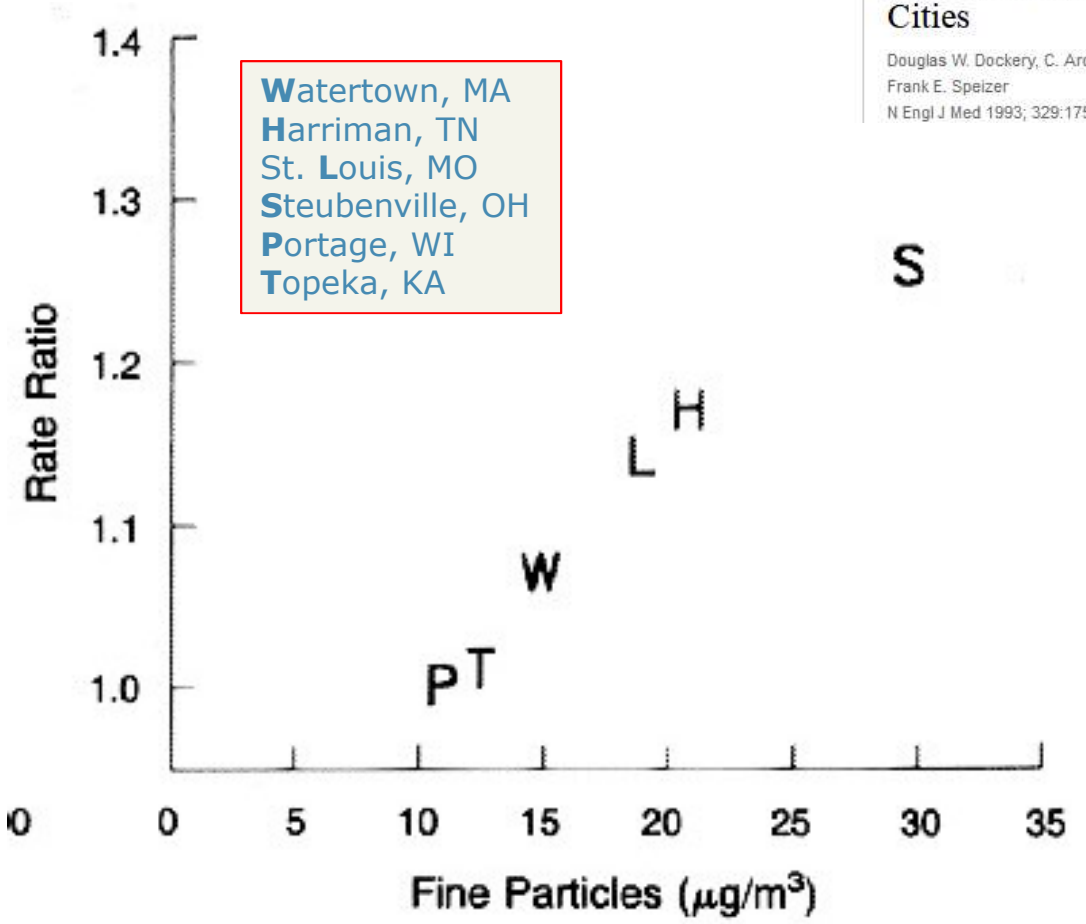


# Why study/assess air quality?

That was 20th century, …with advancement in technology and preventive measures and enforced regulations, the question is:

**Is air pollution still a relevant problem?**

# Health effects of air pollution





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ORIGINAL ARTICLE

An Association between Air Pollution and Mortality in Six U.S. Cities

Douglas W. Dockery, C. Arden Pope, Xiping Xu, John D. Spengler, James H. Ware, Martha E. Fay, Benjamin G. Ferris, Jr., and Frank E. Speizer

N Engl J Med 1993; 329:1753-1759 | December 9, 1993 | DOI: 10.1056/NEJM199312093292401

- 1974 – 1991 prospective cohort study of effect of air pollution on mortality in six cities in USA
- Mortality was most strongly associated with the levels of inhalable, fine and sulfate particles
- Air pollution was positively associated with mortality due to lung cancer and cardiopulmonary disease

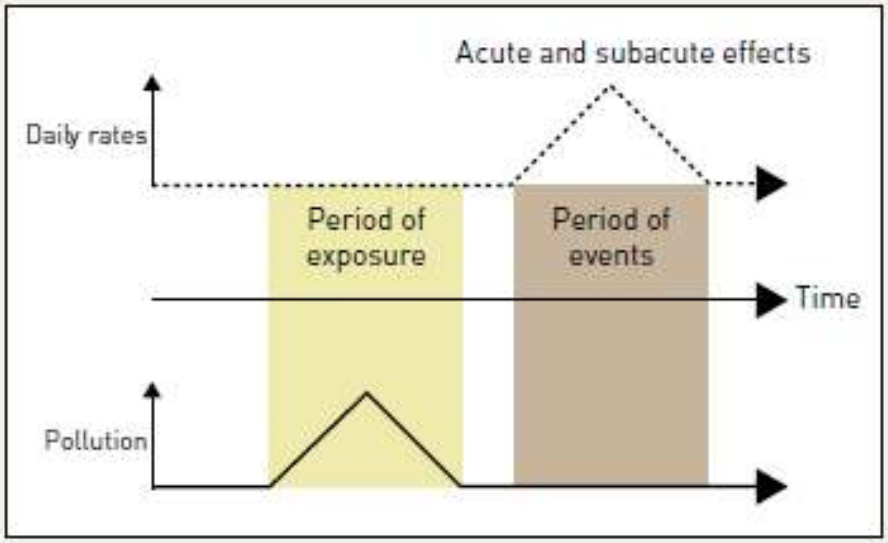


**Dockery et al., 1993**

# Health effects assessment?

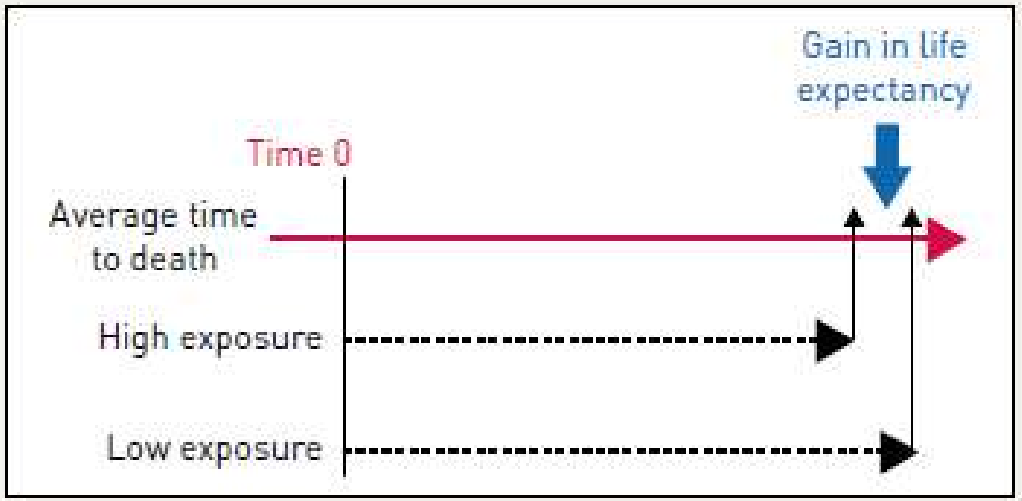
## Acute health effects

Short-term studies attempt to find association between change in concentrations during some time period and changes in outcome rates the same day or a few days after exposure




## Chronic health effects

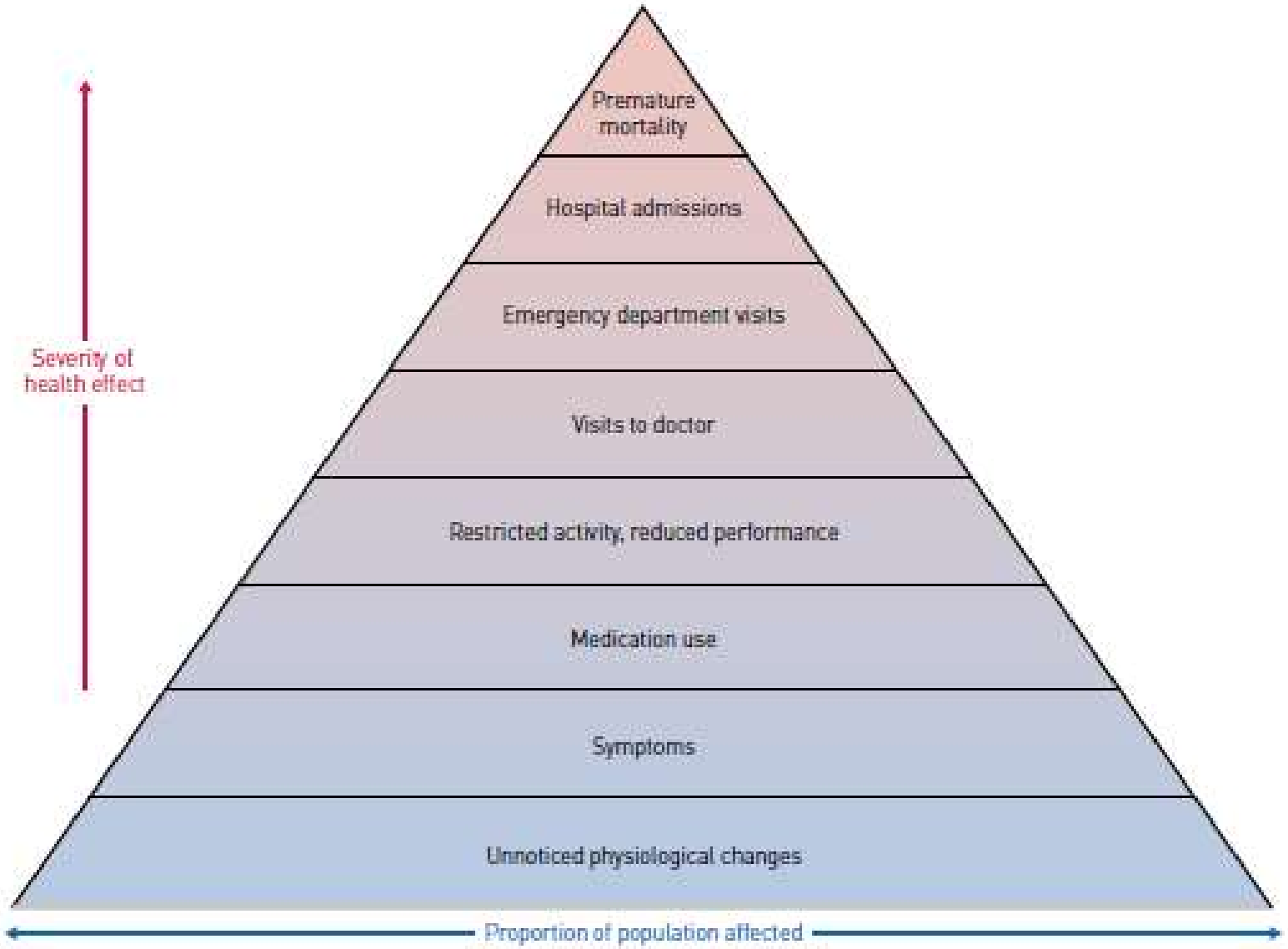
Cohort studies follow a population through time and compare outcomes (e.g. time to death) among people with different level of exposure






**Künzli et al., 2010**

# Health effects of air pollution






**Künzli et al., 2010**

# Health effects of air pollution: Acute effects

| |
|---|
| Daily mortality |
| Respiratory hospital admissions |
| Cardiovascular hospital admissions |
| Emergency room visits for respiratory and cardiac problems |
| Primary care visits for respiratory and cardiac conditions |
| Use of respiratory and cardiovascular medications |
| Days of restricted activity |
| Work absenteeism |
| School days missed |
| Self-medication |
| Avoidance behaviour |
| Acute symptoms |
| Physiological changes, *e.g.* in lung function |



**Künzli et al., 2010**

# Health effects of air pollution: Chronic effects

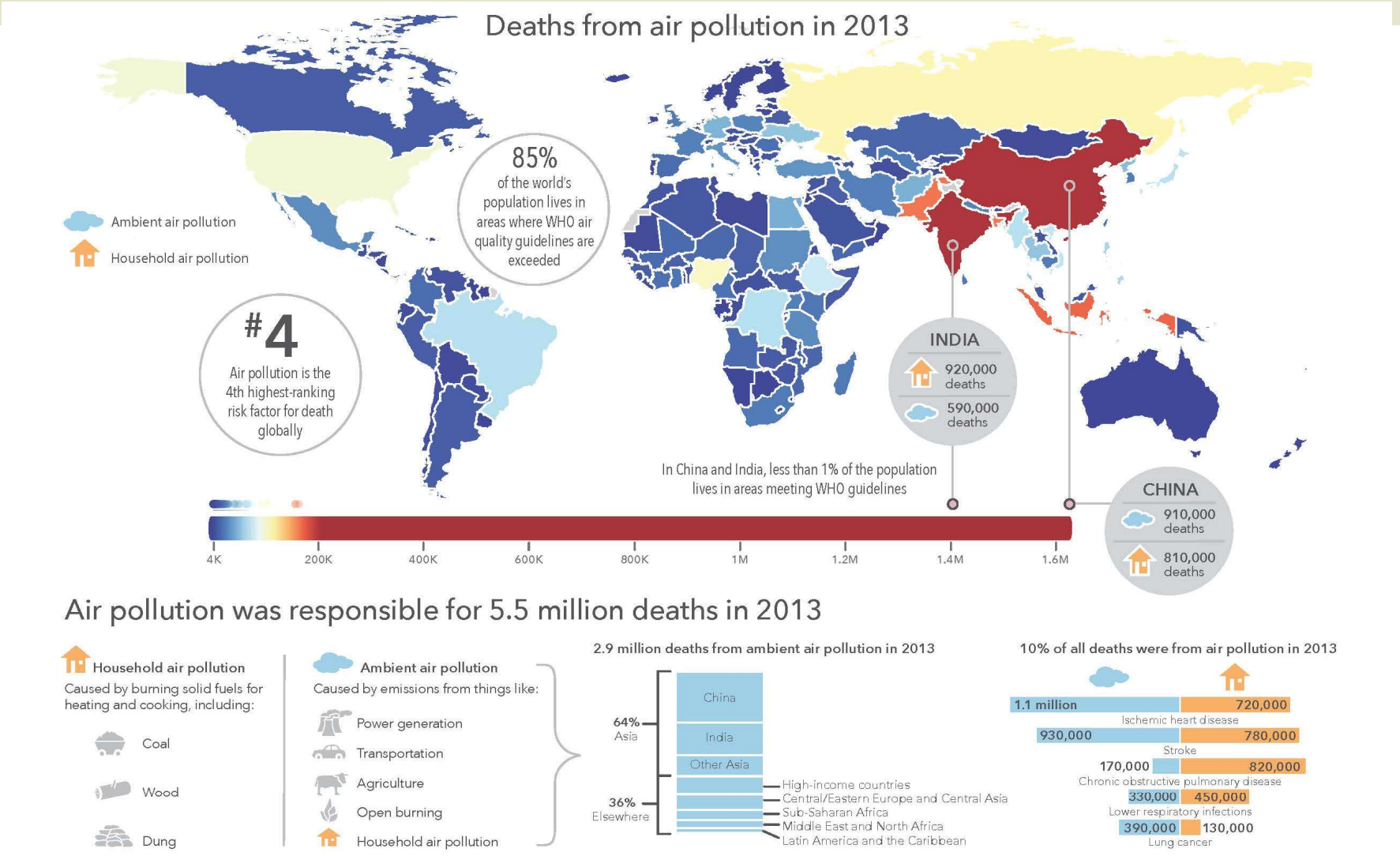
| |
|---|
| Mortality from chronic cardiorespiratory disease |
| Chronic respiratory disease incidence and prevalence (asthma, COPD) |
| Chronic change in physiological function (*e.g.* lung function) |
| Lung cancer |
| Chronic cardiovascular disease |

| Other effects |
|---|
| Low birth weight |
| Pre-term delivery |
| Adversely affected cognitive development in infants |



**Künzli et al., 2010**

# Global burden of air pollution



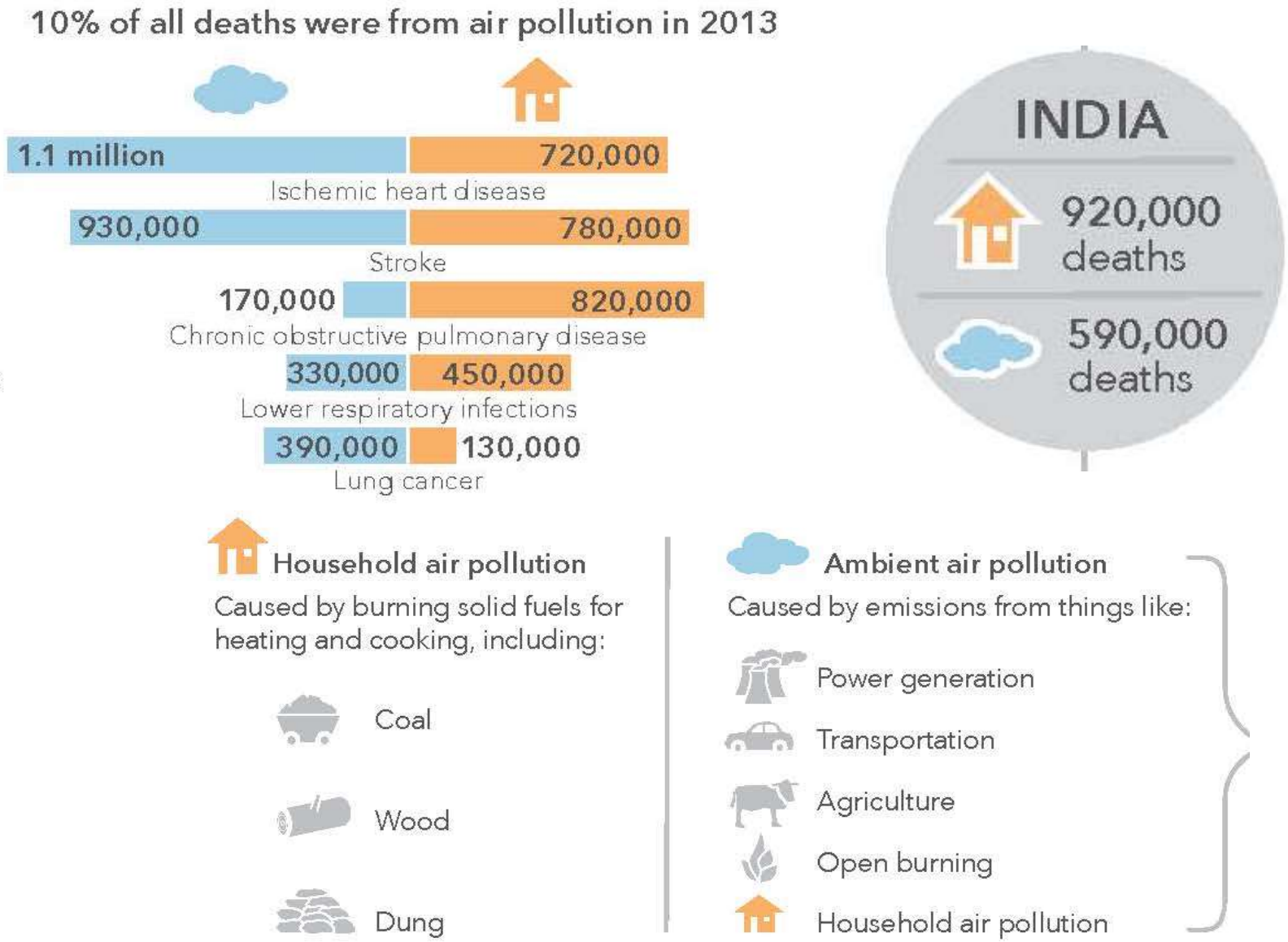


Source:
1. Forouzanfar MH, et al. Global, regional, and national comparative risk assessment of 79 behavioral, environmental and occupational, and metabolic risks or clusters of risks in 188 countries, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet*. 2015 Dec 5;386(10010):2287-323.
2. Brauer M, et al. Ambient air pollution exposure estimation for the Global Burden of Disease 2013. *Environmental Science & Technology*. 2016 Jan 5;50(1):79-88.

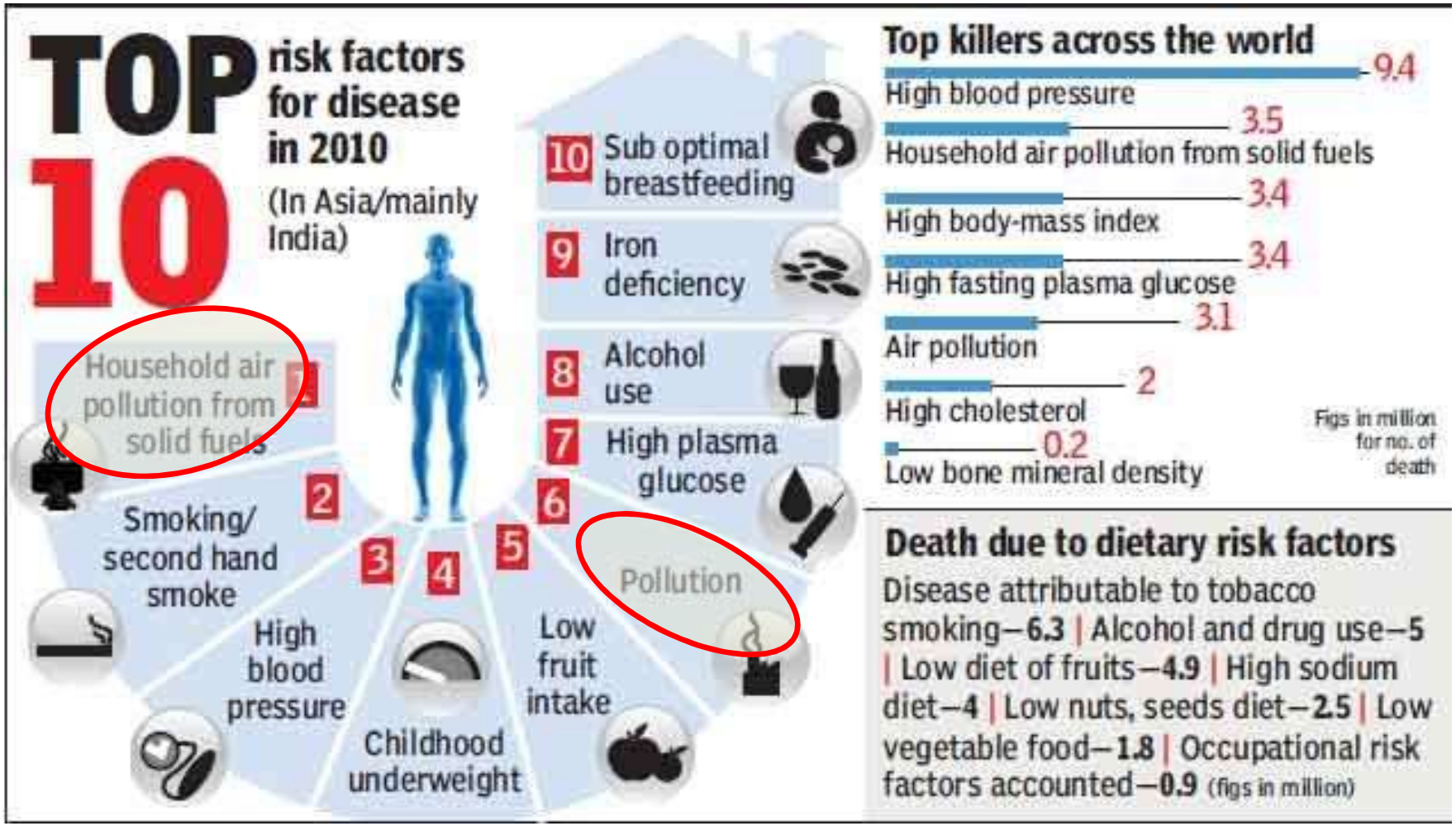

IHME | UNIVERSITY of WASHINGTON

**http://www.healthdata.org/news-release/poor-air-quality-kills-55-million-worldwide-annually**

# Global burden of air pollution



# Air pollution leading risk factor for diseases/deaths in India …and worldwide




http://urbanemissions.blogspot.in/2014_02_01_archive.html

# Air quality and lung cancer in India

## Lung cancer cases peaked in '09-'11


- Delhi, Jharkhand, West Bengal and Maharashtra **have worst air quality**
- **Highest number of lung cancer cases during 2009-11** reported in Delhi, Mumbai and Kolkata
- Half of urban population breathes air that **exceeds the accepted standard of PM10**

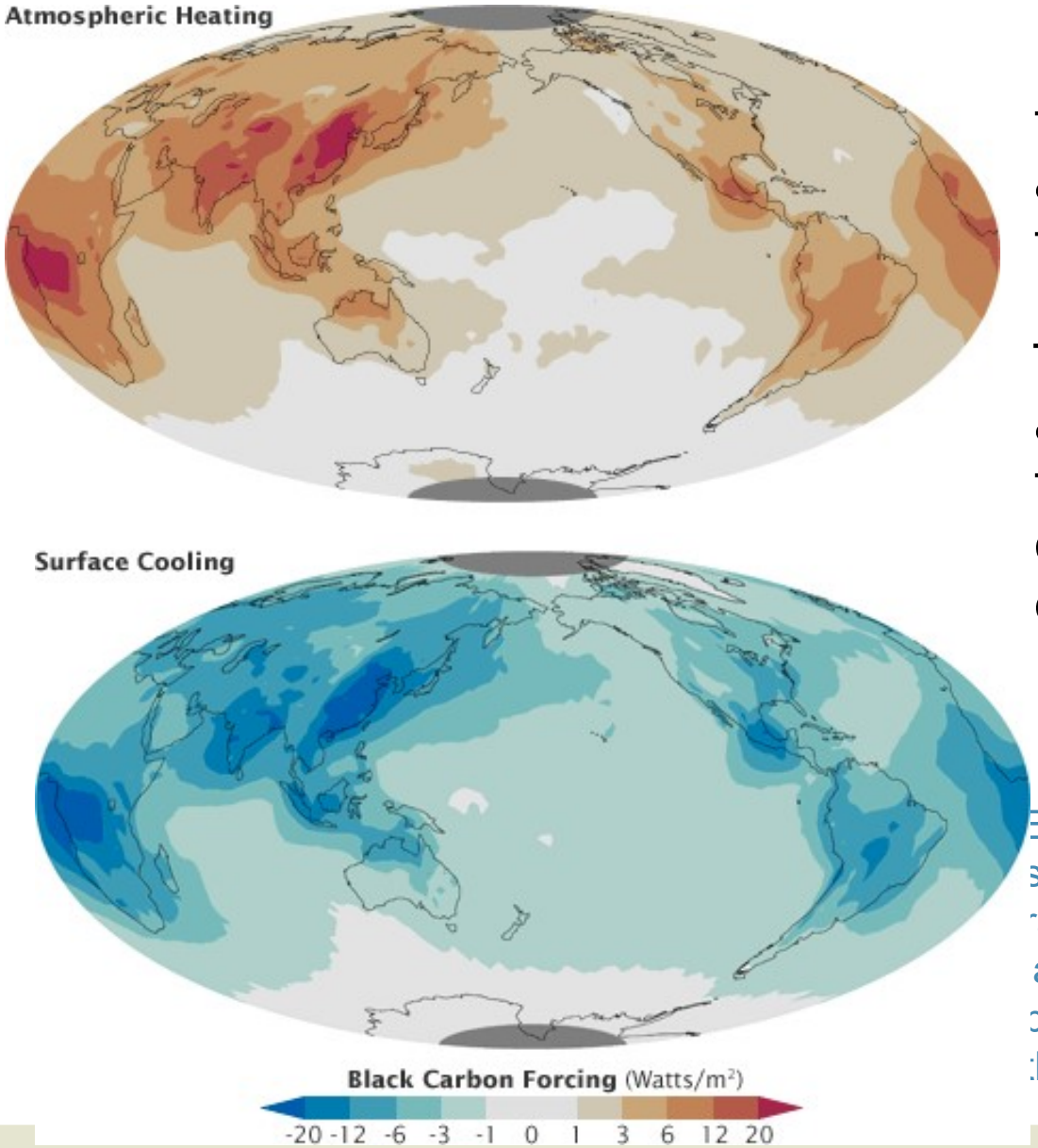
Analysis of three pollutants ($SO_2$, $NO_2$ and particulate matter) **at 450 air monitoring locations in 190 cities/towns across the country shows**

One-third of urban population lives in cities/towns with **PM10 levels classified as 'critical'**



http://www.metrojournalist.com/worst-air-pollution-in-delhi-kolkata-iar/

# Air pollution affects climate: Direct effects




Sun provides the energy that drives Earth's climate, but not all of the energy that reaches the top of the atmosphere finds its way to the surface.

That's because aerosols—and clouds seeded by them—reflect about a quarter of the Sun's energy back to space.

Black carbon aerosols, similar to the soot in a chimney, absorb sunlight rather than reflecting it. This warms the layer of the atmosphere carrying the black carbon, but also shades and cools the surface below.



https://earthobservatory.nasa.gov/Features/Aerosols/page3.php

# Air pollution affects climate: Indirect effects

Whereas aerosols can influence climate by scattering light and changing Earth's reflectivity, they can also alter the climate via clouds. On a global scale, these aerosol "indirect effects" typically work in opposition to greenhouse gases and cause cooling

Brighter clouds, in turn, block sunlight from reaching Earth's surface, shading the planet and producing net cooling. This cloud brightening effect—called the "cloud albedo effect"—may have a big impact on the climate,



**https://earthobservatory.nasa.gov/Features/Aerosols/page4.php**

# Air pollution affects visibility !

- Visibility is most adversely affected by fine aerosols
- Fog affects the visibility severely, and so do mist and haze. What is the difference?

# Air quality regulation in India

## Air Prevention and Control of Pollution Act (1981), Amended in 1987

**1952: London Smog** (that we talked about earlier)
**1956: The British Clean Air act**
**1963: The US Clean Air Act**
**1971: The Canadian Clean air Act**
**1981: The Air Act (India)**

A comprehensive legislation which makes provisions for:

- Central pollution control board (CPCB)
- State pollution control boards (SPCBs),
- power to declare pollution control areas,
- restrictions on certain industrial units,
- authority of the Boards to limit emission of air pollutants,
- power of entry, inspection, taking samples and analysis,
- penalties, offences by companies and Government, and
- cognizance of offences



**http://www.envfor.nic.in/legis/air/air1.html**

# Air Act, 1981

## Air Prevention and Control of Pollution Act (1981), Amended in 1987

- The Act specifically empowers State Government to designate air pollution control areas and to prescribe the type of fuel to be used in these designated areas
- Air pollution sources such as industry, vehicles, power plants, etc. not permitted to release criteria air pollutants or other toxic substances beyond a prescribed level (called as NAAQS)
- The Air Act apparently adopts an industry wide "best available technology" requirement for abiding the emission requirements



**http://www.envfor.nic.in/legis/air/air1.html**

# Criteria Air Pollutants

- US EPA, EEA and other national regulatory agencies use **six** "criteria pollutants" as indicators of **outdoor** air quality
- For each of them a maximum concentration above which adverse effects on human health may occur, is established - referred as NAAQS.

| Source | $SO_2$ µg·m$^{-3}$ | | | | $NO_2$ µg·m$^{-3}$ | | | PM10 µg·m$^{-3}$ | | PM2.5 µg·m$^{-3}$ | | Ozone µg·m$^{-3}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 year | 24 hr | 1 hr | 10 m | 1 year | 24 hr | 1 hr | 1 year | 24 hr | 1 year | 24 hr | 8 hr | 1 hr |
| WHO [21] | | 20 | | 500 | 40 | | 200 | 20 | 50[a] | 10 | 25[a] | 100 | |
| European Union (revised 2008) [50] | | 125[a] | 350[f] | | 40 | | 200[e] | 40 | 50[b] | 25 | | 120[f] | |
| Switzerland [51] | 30 | 100[d] | | | 30 | 80[d] | | 20 | 50[d] | | | | 120[d] |
| France [52] | 50 | 125[a] | 350[f] | | 40 | | 200[e] | 40 | 50[b] | | | | |
| Sweden [53] | | 100 | 200 | | 40 | 60 | 90 | 40 | 50 | | | | |
| UK [54] | | 125[a] | 350[f] | 266[b] | 40 | | 200[e] | 40 | 50[b] | 25 | | 100 | |
| Japan [55] | | 105 | 262 | | | 113 | | | 100 | | | | 118[c] |
| USA [56] | 78 | 366 | | | 100 | | | 50 | 150 | 15 | 65 | 157 | |
| California [57] | | 105[c] | 655 | | | | 470[c] | 20 | 50 | 12 | 65 | 137 | 180[c] |



**Künzli et al., 2010. Air Quality & Health**
**https://www.ersnet.org/publications/air-quality-and-health**

# National Ambient Air Quality Standards: (NAAQS) India

**Ambient Concentration**

**Type of area (Ind./Res. Or Eco sensitive)**

**Averaging interval /Exposure duration (Annual Or Daily)**

| 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 - Ultraviolet fluorescence |
| | | 24 hours** | 80 | 80 | |
| 2 | Nitrogen Dioxide ($NO_2$), µg/m³ | Annual* | 40 | | - Modified Jacob & Hochheiser (Na-Arsenite) - Chemiluminescence |
| | | 24 hours** | | 80 | |
| 3 | Particulate Matter (size less than 10µm) or $PM_{10}$ µg/m³ | Annual* | | 60 | - Gravimetric - TOEM - Beta attenuation |
| | | 24 hours** | 100 | 100 | |
| 4 | Particulate Matter (size less than 2.5µm) or $PM_{2.5}$ µg/m³ | Annual* | 40 | 40 | - Gravimetric - TOEM - Beta attenuation |
| | | 24 hours** | 60 | 60 | |
| | Ozone ($O_3$) µg/m³ | 8 hours** | 100 | 100 | - UV photometric - Chemilminescence - Chemical Method |
| | | 1 hour** | 180 | 180 | |
| 6 | Lead (Pb) µg/m³ | Annual* | 0.50 | 0.50 | - AAS /ICP method after sampling on EPM 2000 or equivalent filter paper - 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 | |
| 8 | Ammonia ($NH_3$) µg/m³ | Annual* | 100 | 100 | -Chemiluminescence -Indophenol blue method |
| | | 24 hours** | 400 | 400 | |

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… …oun 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 |

# LA smog and ozone !

In troposphere:

$$NO_2 + h\nu \longrightarrow NO + O$$

at $\lambda$ < 424 nm

$$O + O_2 + M \longrightarrow O_3 + M$$

$$O_3 + NO \longrightarrow NO_2 + O_2$$

If solely govern by above reactions, $O_3$ conc. too low to account for actual observations, therein comes the role of VOCs or HCs

$$CO + OH\cdot \xrightarrow{O_2} CO_2 + HO_2\cdot$$

$$HO_2\cdot + NO \longrightarrow NO_2 + OH\cdot$$

$$NO_2 + h\nu \longrightarrow NO + O$$

$$O + O_2 + M \longrightarrow O_3 + M$$

$$\text{Net}: \quad CO + 2O_2 + h\nu \longrightarrow CO_2 + O_3$$

**Ozone is important in stratosphere. What are the concerns & how it is produced there?**

# LA smog and ozone !

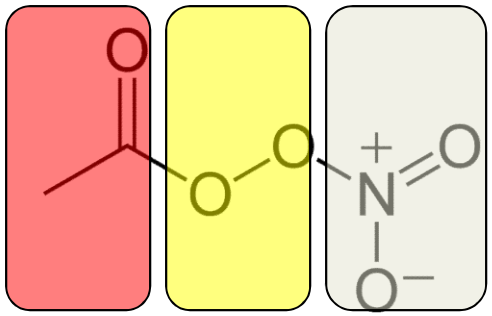
## PAN

- Peroxyacyl nitrates (PAN) were first discovered in 1950s as components of photochemical smog; PAN formed from reaction of OH and acetaldehyde:

$$CH_3CHO + OH\cdot \rightarrow CH_3CO + H_2O$$

$$CH_3CO + O_2 \rightarrow CH_3C(O)O_2\cdot$$

$$CH_3C(O)O_2\cdot + NO_2 + M \rightleftharpoons CH_3C(O)O_2NO_2 + M$$




- PAN is an eye irritant
- Lifetime of PAN ranges from 30 mins to 8 hours; acts as a reservoir for $NO_x$ allowing for its long range transport

# 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 !**