

# **CE 435: Environmental Pollution Management**

**January 2018 Semester  
Level-4, Term II**

**Department of Civil Engineering  
Bangladesh University of Engineering and Technology  
(BUET)**

# CE 435: Syllabus

## Major topics:

**(1) Air pollution:** Dr. Muhammad Ashraf Ali

**(2) Water pollution:** Dr. Tanvir Ahmed

## Water Pollution:

Environmental pollution and its control; water pollution: sources and types of pollutants; waste assimilation capacity of streams; dissolved oxygen modeling; ecological balance of streams; industrial pollution; heavy metal contamination; detergent pollution and eutrophication; groundwater pollution; marine pollution; pollution control measures: water quality monitoring and management.

# CE 433: Syllabus

## **Air Pollution:**

Sources and types of pollutants; effects of various pollutants on human health, materials and plants; air pollution meteorology; global warming, climate change and ozone layer depletion; acid rain; air pollution monitoring and control measures; introduction to air quality models.

# Air Pollution

**Air pollution may be defined as any atmospheric condition in which substances are present at concentrations, above their normal ambient levels, to produce measurable adverse effects on people, animal, vegetation or materials.**

- **Key issues:**
  - Type of pollutant
  - Concentration in air
  - Time of exposure

# Composition of atmospheric gases in clean, dry air and ground level

Composition of atmospheric gases in clean, dry air at ground level:

Gas	Concentration (ppm by volume)	Concentration (% by volume)
Nitrogen (N <sub>2</sub> )	780,000	78.09
Oxygen (O <sub>2</sub> )	209,500	20.95
Argon (Ar)	9,300	0.93
Carbon dioxide (CO <sub>2</sub> )	320 <b>379 (2005)</b>	0.032
Neon	18	0.0018
Helium (He)	5.2	0.00052
Methane (CH <sub>4</sub> )	1.5 <b>1.774 (2005)</b>	0.00015
Krypton (Kr)	1.0	0.0001
Hydrogen (H <sub>2</sub> )	0.5	0.00005
Dinitrogen Oxide (N <sub>2</sub> O)	0.2 <b>0.319 (2005)</b>	0.00002
Carbon monoxide (CO)	0.1	0.00001
Xenon (Xe)	0.08	0.000008
Ozone (O <sub>3</sub> )	0.02	0.000002
Ammonia (NH <sub>3</sub> )	0.006	0.0000006
Nitrogen dioxide (NO <sub>2</sub> )	0.001	0.0000001
Nitric oxide (NO)	0.0006	0.00000006
Sulfur dioxide (SO <sub>2</sub> )	0.0002	0.00000002
Hydrogen sulfide (H <sub>2</sub> S)	0.0002	0.00000002

Trace gases comprising less than 1% of the atmosphere play a crucial role in the Earth's radiative balance and in the chemical properties of the atmosphere. The trace gas concentrations have changed dramatically over the last two decades.

# Components of Air Pollution Problem



# Categories of Air Pollution

- **Outdoor Air Pollution**



- **Indoor Air Pollution** (from cooking, heating, tobacco smoking, radon)



# Effects of Air Pollution: (a) Health

## Outdoor air pollution

- Globally, 1.2 million (Urban) and 3.7 million (urban plus rural) premature deaths each year due to outside air pollution.
- Compliance to WHO standard could avoid: 14,850 premature deaths (Dhaka 10,800); 6.54 mil hospital admissions or medical treatments (Dhaka 4.74 mil) in Bangladesh

## Indoor air pollution

- Around 2 million people die each year prematurely from illness attributable to indoor air pollution
- WHO estimates that globally acute respiratory infections from indoor air pollution are responsible for an estimated 900,000 deaths in children under 5 every year.
- About 3 billion people cook and heat using open fires, exposing them to air pollution.

# Effects of Air Pollution: (a) Health (contd.)

## Historical perspective:

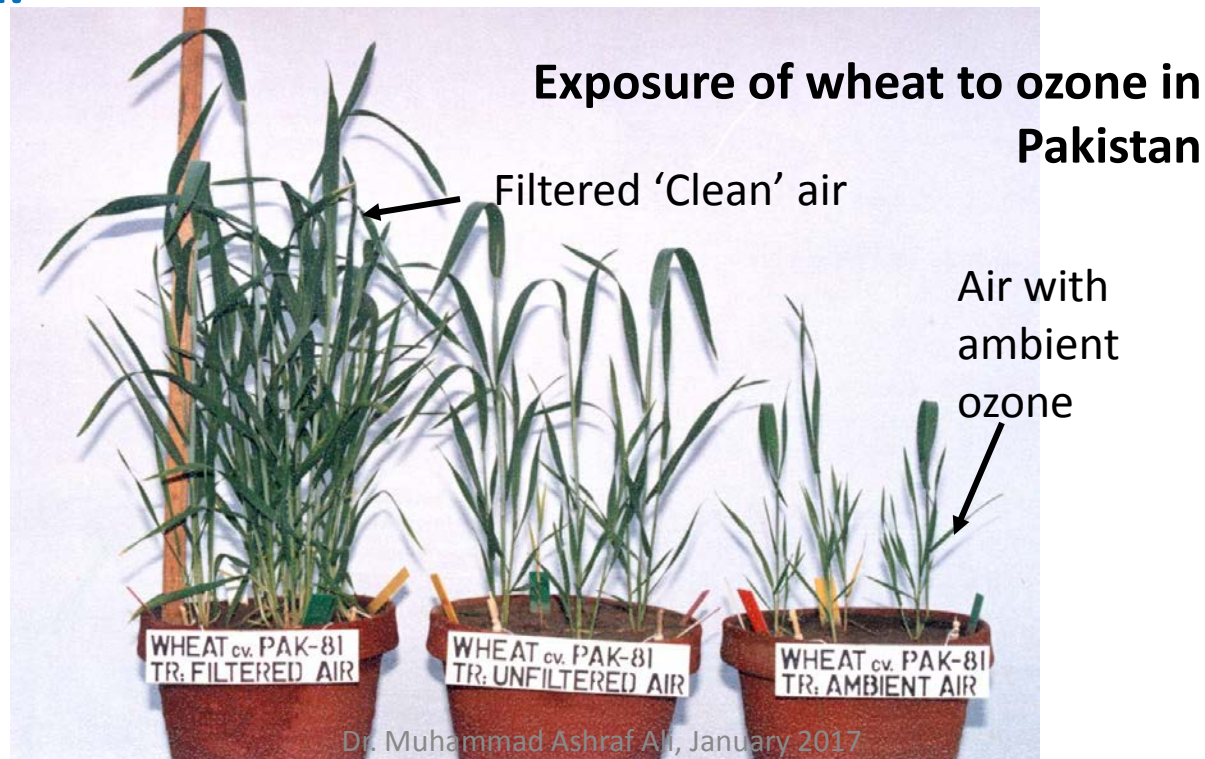
### Reported disease morbidity and mortality occurring during air pollution episodes

Year and Month	Location	Excess deaths reported	Reported Illness
1873, Dec. 9-11	London, England		
1880, Jan. 26-29	London, England		
1892, Dec. 28-30	London, England		
1930, December	Meuse Valley, Belgium	63	6000
1948, October	Donora, Pennsylvania	17	6000
1948, Nov. 26- Dec. 1	London, England	700-800	
1952, Dec. 5-9	London, England	4000	
1953, November	New York, USA		
1956, Jan. 3-6	London, England	1000	
1957, Dec. 2-5	London, England	700-800	
1958	New York, USA		
1959, Jan. 26-31	London, England	200-250	
1962, Dec. 5-10	London, England	700	
1963, Jan 7-22	London, England	700	
1963, Jan. 9-Feb.12	New York, USA	200-400	
1966, Nov. 23-25	New York, USA		


Source: Peavy et al. (1985)

# Effects of Air Pollution: (b) Agriculture

- Tropospheric  $O_3$  is an important greenhouse gas. It also affects the yield of many crops and has adverse impacts on diversity and growth of plant communities.
- Elevated  $O_3$  concentrations have been estimated to cause yield losses of nearly 40 million tons for all crops for Asian region.



# Effects of Air Pollution: (c) Climate

- In the troposphere,  $O_3$  is an important greenhouse gas.  $O_3$  is formed in the atmosphere by photochemical reaction involving a number of precursor gases ( $CO$ ,  $CH_4$ ,  $VOC$ ,  $NO_x$ ).  

- Black carbon (BC) causes warming of the atmosphere. When deposited on ice and snow, BC reduces the albedo of these surfaces, increasing both atmospheric warming and melting rate caused by increased absorption of heat by the darker snow and ice around the world.
- Sulfate particles on the other hand have a cooling effect

# Effects of Air Pollution: (d) Material

- **Air pollutants can affect material by soiling or chemical deterioration.**
- **Acid/alkaline particles/gases, especially those containing sulfur, corrode materials such as paint, masonry (esp. marble), metals, electrical contacts, and textiles.**
- **Ozone deteriorates rubber.**

# Overview of Emissions:

**Primary Pollutants:** Substances that are emitted directly into the atmosphere (e.g., NO<sub>2</sub> and CO when fuels are burned)

**Secondary Pollutants:** Substances created in the atmosphere by various physical, chemical and photochemical reactions.

# Processes Leading to Emission of “Primary Pollutants”:

- **Combustion:** mainly of fossil fuel for the purpose of heating/cooling, transportation, industry, and energy conversion. **Accounts for great majority of emission.**
- **Evaporation:** Volatile substances like gasoline, paint and cleaning fluid enter into the atmosphere by evaporation.
- **Grinding and abrasion:** Such as dust kicked up with land is plowed, or brick/stone chips are made

# Combustion (“Primary Pollutants”):

(a) Pure hydrocarbon/fuel (complete combustion):



(b) Pure hydrocarbon/fuel (incomplete combustion):



(c) Combustion in air:



(d) Combustion of fuel containing impurities in air:



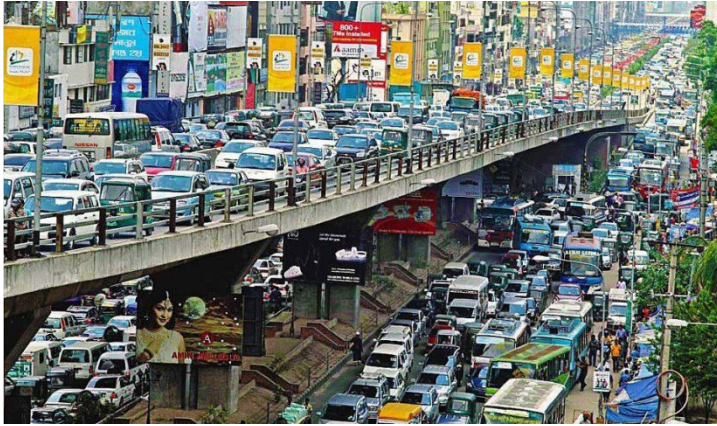
# “Secondary Pollutants”:

HC/VOCs + NO<sub>x</sub> + Sunlight → Photochemical smog (O<sub>3</sub>, etc.)

SO<sub>2</sub> → H<sub>2</sub>SO<sub>4</sub> → Sulfate particles

# Major Sources of “Outdoor Pollution”:

(1) Mobile sources/transportation: include both on-road vehicles and off-road vehicles (rail, ship)



(2) Stationary sources: utility, industrial, institutional and commercial facilities, e.g., power plant, brick kiln, refineries, cement industry.



Dr. Muhammad Ashraf Ali, January 2017

# Major Sources of “Outdoor Pollution”:

(3) Area sources: include many individually small activities, gasoline service stations, small paint shops, cooking in slum areas.

(4) Incineration/ burning of wastes: household and commercial waste, agricultural burning, industrial/hazardous waste burning



(5) Miscellaneous: re-suspension from road, forest fire, volcanic eruption, pollen grains, evaporation of chemicals, certain bacterial/virus

# Classification of Pollutants:

## (A) According to Origin:

- (1) Primary Pollutants:** emitted directly into the atmosphere and are found in the form in which they were emitted, e.g., CO, SO<sub>2</sub>, NO<sub>2</sub>.
- (2) Secondary Pollutants:** derived from primary pollutants by chemical/photo-chemical reactions in the atmosphere, e.g., Ozone (O<sub>3</sub>), peroxy-acetyl nitrate (PAN)  
HC/VOCs + NO<sub>x</sub> + Sunlight → Photochemical smog (O<sub>3</sub>, etc.)

# Classification of Pollutants:

## (B) According to Chemical Composition:

- (1) **Inorganic:** CO, SO<sub>2</sub>, NO<sub>2</sub>, H<sub>2</sub>SO<sub>4</sub>, NH<sub>3</sub>
- (2) **Organic:** Hydrocarbons (HC), Aldehydes and Ketones, VOCs, PCBs, PAHs

## (C) According to State of Matter:

- (1) **Gaseous:** CO, SO<sub>2</sub>, NO<sub>2</sub>, H<sub>2</sub>SO<sub>4</sub>, NH<sub>3</sub>, VOCs, O<sub>3</sub>
- (2) **Particulates/ Aerosols:**
  - Dust, smoke, fume, fly ash (solid)
  - Mist, spray (liquid)
  - Pollen, bacteria, virus (natural)

# Important Terms:

**Criteria Pollutants:** Six major air pollutants that cause health effects, and for which health-based standards/guidelines have been established. These are: **Particulate Matter (PM), Pb, CO, NO<sub>2</sub>, SO<sub>2</sub>, and O<sub>3</sub>**

**Air toxins:** Pollutants that are known or suspected to cause cancer or other serious health effects. Examples include: Benzene (from gasoline); Perchloroethylene (from dry cleaners); Methylene Chloride (used as solvent and paint stripper)

# Important Terms (contd.):

## Short Lived Climate Pollutants (SLCPs):

SLCPs refer to four types of pollutants:

- Black Carbon (BC) (soot);
- Methane (CH<sub>4</sub>);
- Tropospheric Ozone (O<sub>3</sub>); and
- Some Hydrofluorocarbons (HFCs).

These are relatively short-lived in the atmosphere, and have significant adverse impacts on:

- Health (due to BC, also O<sub>3</sub>)
- Agriculture (crop yield) and ecosystem productivity (due to O<sub>3</sub>), and
- Near-term (20-40 yrs) global (e.g. warming)/ regional climate (e.g. monsoon pattern)

# SLCPs: Lifetimes in the Atmosphere

Substance	Lifetime
Carbon dioxide	Decades to centuries and about 20 per cent will persist for many millennia
Ozone	4 – 18 days
Methane	12 years
Black carbon	3-8 days
HFCs	Average of mix: 15 years

# Units of Measurement

- **Particulate Matter (PM):** mass/unit volume of air  
(e.g.,  $\text{mg}/\text{m}^3$ ;  $\text{mg}/\text{m}^3$ )
- **Gaseous Pollutants:**
  - (a) mass/unit volume (e.g.,  $\text{mg}/\text{m}^3$ ;  $\text{mg}/\text{m}^3$ )
  - (b) ppm = ppmv  
= volume of pollutant per million volume of air mixture

# Units of Measurement (contd.)

Relationship between two units for “gaseous pollutants”:

Ideal Gas Law:  $PV = nRT$ ;  $R = 0.082056 \text{ L. atm .mol}^{-1}. \text{K}^{-1}$

Volume of 1 mole of an ideal gas at STP ( $P=1 \text{ atm}$ ,  $T=273.15 \text{ K}$ ),

$$V = (nRT)/P = 22.414 \text{ L}$$

Now,  $1 \text{ ppm} = (1 \text{ m}^3 \text{ pollutant})/(10^6 \text{ m}^3 \text{ air})$

$$\begin{aligned} 1 \text{ mg/m}^3 &= (1 \text{ mg pollutant})/(1 \text{ m}^3 \text{ air}) \\ &= (10^6 \text{ mg pollutant})/(10^6 \text{ air}) \end{aligned}$$

Now, at STP,  $10^6 \text{ mg pollutant}$

$$\begin{aligned} &= 10^6 \text{ mg} \times 10^{-3} \text{ (g/mg). (mol/MW g). (22.414 L/mol). (10}^{-3} \text{ m}^3/\text{L)} \\ &= (22.414/\text{MW}) \text{ m}^3 \end{aligned}$$

$$\therefore 1 \text{ mg/m}^3 = [(22.414/\text{MW}) \text{ m}^3 \text{ pollutant}]/[10^6 \text{ m}^3 \text{ air}]$$

$$\therefore 1 \text{ mg/m}^3 = (22.414/\text{MW}) \text{ ppm}$$

# Units of Measurement (contd.)

Relationship between two units for “gaseous pollutants” (contd.):

$$\therefore 1 \text{ mg/m}^3 = (22.414/\text{MW}) \text{ ppm}$$

At any Temperature (T) and Pressure (P),

$$10^6 \text{ mg pollutant} = [22.414/\text{MW}] \cdot [T/(273 \times P)] \quad [\text{since, } P_1V_1/T_1 = P_2V_2/T_2]$$

$$\therefore 1 \text{ mg/m}^3 = (22.414/\text{MW}) \cdot [T/(273 \times P)] \text{ ppm}$$

In other words,

$$\text{Conc. in mg/m}^3 = \text{Conc. in ppm} \times [\text{MW}/22.414] \cdot (273 \text{ P}/\text{T})$$

# Conversion of Units

**Ex. 1:** Bangladesh national ambient air quality standard for CO is  $10 \text{ mg/m}^3$  (8-hr). Express the standard in ppm.

**Ex. 2:** Bangladesh national ambient air quality standard for  $\text{NO}_2$  is  $100 \text{ } \mu\text{g/m}^3$  (annual). Express the standard in ppm.

# Regulations/ Standards:

## Two Types of Standards:

(1) Emission Standard

(2) Air Quality Standard

**Emission Standard:** A source cannot emit more than a specified mass of pollutant over a period of time. This is based on technology, economics, relation to airborne concentration.

The objective of emission standard is to control pollutant sources so that ambient pollutant concentrations are reduced to levels considered safe from public health point of view

# Regulations/ Standards:

## Emission Standard (contd.):

Bangladesh Environment Conservation Rules (1997, amended in 2005) has set emission standards for motor vehicle, industries, etc.

### Example of emission standards:

**Ex. 1. Petrol/gas driven motor vehicle (<8 seater): Standard at the time of registration:**

CO : 2.2 gm/km

HC + NO<sub>x</sub> : 0.5 gm/km

**Ex. 2. Gas-fired power plant: Standard for NO<sub>x</sub> emission:**

≥ 500 MW Power Plant : 50 ppm

200-500 MW Power Plant : 40 ppm

< 200 MW Power Plant : 30 ppm

# Regulations/ Standards:

## Air Quality Standards:

Airborne concentration of a pollutant cannot exceed a specified value over a certain “averaging period”. Air quality standards are based only on (health) effects.

### Why “averaging period”?:

Because higher the concentration, shorter the “exposure time” required for undesirable effects. A pollutant at a certain concentration may be harmful over longer exposure time, but relatively harmless over shorter exposure time.

### Example: Bangladesh standard for CO:

10 mg/m<sup>3</sup> (averaging period: 8 hr)

40 mg/m<sup>3</sup> (averaging period: 1 hr)

[measurement and reporting of a particular air pollutant should be consistent with the “averaging period” of that pollutant]

# Regulations/ Standards:

## Revised National Ambient Air Quality Standard (2005):

Pollutant	Standard	Averaging Period
CO	10 mg/m <sup>3</sup> (9 ppm) 40 mg/m <sup>3</sup> (35 ppm)	8 hr 1hr
Pb	0.5 µg/m <sup>3</sup>	Annual
NO <sub>2</sub>	100 µg/m <sup>3</sup> (0.053 ppm)	Annual
SPM	200 µg/m <sup>3</sup>	8 hr
PM <sub>10</sub>	50 µg/m <sup>3</sup> 150 µg/m <sup>3</sup>	Annual 24 hr
PM <sub>2.5</sub>	15 µg/m <sup>3</sup> 65 µg/m <sup>3</sup>	Annual 24 hr
O <sub>3</sub>	157 µg/m <sup>3</sup> (0.08 ppm) 235 µg/m <sup>3</sup> (0.12 ppm)	8 hr 1 hr
SO <sub>2</sub>	80 µg/m <sup>3</sup> (0.03 ppm) 365 µg/m <sup>3</sup> (0.14 ppm)	Annual 24 hr

# Regulations/ Standards:

## WHO Ambient Air Quality Guideline:

Pollutant	Standard	Averaging Period
PM <sub>10</sub>	20 µg/m <sup>3</sup> 50 µg/m <sup>3</sup>	Annual 24 hr
PM <sub>2.5</sub>	10 µg/m <sup>3</sup> 25 µg/m <sup>3</sup>	Annual 24 hr

# Air Quality Index (AQI)

AQI is a tool that simplifies reporting air quality to the general people. It has been adopted by the USEPA and is used by many cities for reporting to the public an overall assessment of a given day's air quality.

The AQI converts concentration of 5 “criteria pollutants” (PM, CO, SO<sub>2</sub>, NO<sub>2</sub> and O<sub>3</sub>) into a single index (number) between 0 and 500 and assigns a descriptive term (e.g., Good, Moderate) to that value.

# Air Quality Index (AQI) (contd.)

## AQI Categories (USEPA):

AQI Value	Descriptor	Color Code
0 – 50	Good	Green
51 – 100	Moderate	Yellow
101 – 150	Unhealthy for for sensitive Group	Orange
151 – 200	Unhealthy	Red
201 – 300	Very unhealthy	Purple
> 300	Hazardous	Maroon

**In general, an Index value of 100 for a particular pollutant roughly corresponds to its concentration equal to the air quality standard**

# Air Quality Index (AQI) (contd.)

Bangladesh AQI, adopted from USEPA, is similar, but slightly different.

## AQI Categories (Bangladesh):

<b>AQI Value</b>	<b>Descriptor</b>	<b>Color Code</b>
<b>0 – 50</b>	<b>Good</b>	<b>Green</b>
<b>51 – 100</b>	<b>Moderate</b>	<b>Yellow Green</b>
<b>101 – 150</b>	<b>Caution</b>	<b>Yellow</b>
<b>151 – 200</b>	<b>Unhealthy</b>	<b>Orange</b>
<b>201 – 300</b>	<b>Very Unhealthy</b>	<b>Violet</b>
<b>301 – 500</b>	<b>Extremely Unhealthy</b>	<b>Red</b>

**In general, an Index value of 100 for a particular pollutant roughly corresponds to its concentration equal to the air quality standard**

# Air Quality Index (AQI) (contd.)

## Purpose of AQI:

- (1) To inform people about air quality conditions in a simple format
- (2) Promote public interest and action to reduce emissions.

# Calculation of AQI (contd.)

- **AQI is calculated for 5 criteria pollutants:**
  - PM (PM<sub>10</sub>-24 hr; PM<sub>2.5</sub>-24 hr)
  - CO (8-hr)
  - SO<sub>2</sub> (24-hr)
  - NO<sub>2</sub> (annual)
  - O<sub>3</sub> (1-hr; 8-hr)
- **Each pollutant concentration is converted into an AQI number using the method followed by USEPA. The highest AQI number is the AQI value of the day.**
- **For example: On a particular day, if a certain area has an AQI value of 120 for PM<sub>2.5</sub> and 88 for SO<sub>2</sub>; then the AQI for that particular day is 120 and the “critical pollutant” is PM<sub>2.5</sub>**

# Calculation of AQI (contd.)

AQI is the highest value calculated for each pollutant as follows:

- Identify highest concentration among all monitors within each reporting area;
- Using following table, calculate AQI

Breakpoints							AQI
O <sub>3</sub> (ppm) 8-hr	O <sub>3</sub> (ppm) 1-hr (i)	PM <sub>2.5</sub> (µg/m <sup>3</sup> ) 24-hr	PM <sub>10</sub> (µg/m <sup>3</sup> ) 24-hr	CO (ppm) 8-hr	SO <sub>2</sub> (ppm) 24-hr	NO <sub>2</sub> (ppm) Annual	
0.000-0.064	--	0.0-15.4	0-54	0.0-4.4	0.000-0.034	(ii)	0-50
0.065-0.084	--	15.5-40.4	55-154	4.5-9.4	0.035-0.144	(ii)	51-100
0.085-0.104	0.125-0.164	40.5-65.4	155-254	9.5-12.4	0.145-0.224	(ii)	101-150
0.105-0.124	0.165-0.204	65.5-150.4	255-354	12.5-15.4	0.225-0.304	(ii)	151-200
0.125-0.374	0.205-0.404	150.5-250.4	355-424	15.5-30.4	0.305-0.604	0.65-1.24	201-300
(iii)	0.405-0.504	250.5-350.4	425-504	30.5-40.4	0.605-0.804	1.25-1.64	301-400
(iii)	0.505-0.604	350.5-500.4	505-604	40.5-50.4	0.805-1.004	1.65-2.04	401-500

(i) In some cases, in addition to calculating the 8-hr ozone index, the 1-hr ozone index may be calculated, and the maximum of the two values reported

(ii) NO<sub>2</sub> has no short-term air quality standard and can generate an AQI only above 200

(iii) 8-hr O<sub>3</sub> values do not define higher AQI values (≥301). AQI values of 301 or higher are calculated with 1-hr O<sub>3</sub> concentrations

# Calculation of AQI (contd.)

**The AQI report should contain:**

- **Reporting area**
- **Reporting date**
- **The “Critical Pollutant”**
- **The AQI (i.e., the highest index value)**
- **Category descriptor (and color format)**
- **Pollutant-specific sensitive group (see table, next page)**
- **Name and index value of other pollutants, particularly those with index value > 100.**

# Calculation of AQI (contd.)

**Pollutant-specific “sensitive group”:**

When this Pollutant has an Index Value > 100	Sensitive Group
Ozone	Children/people with asthma
PM <sub>2.5</sub>	People with respiratory/heart disease; specially children and the elderly
PM <sub>10</sub>	People with respiratory disease
CO	People with heart disease
SO <sub>2</sub>	People with asthma

# Calculation of AQI (contd.)

**Problem 1:** On a particular day, the following air quality data have been recorded at a monitoring station in Dhaka:

$PM_{2.5} = 190 \mu\text{g}/\text{m}^3$  (24-hr);  $PM_{10} = 280 \mu\text{g}/\text{m}^3$  (24-hr);  $O_3 = 0.095 \text{ ppm}$  (8-hr)

**Calculate and report AQI.**

**Solution:** AQI for  $PM_{2.5} = 240$ ; AQI for  $PM_{10} = 163$ ; AQI for  $O_3 = 127$

**Reporting area: Dhaka**

**Reporting date:**

**Critical Pollutant:**

**AQI =**

**Description: Very Unhealthy (Purple)**

**Sensitive Group: People with respiratory/heart disease;  
esp. elderly, children**

**Other pollutants with Index > 100:**