Air and Water Pollution

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Air Pollution

- Air pollution is defined as “any solid, liquid or gaseous substance (including noise) present in the atmosphere in such concentrations as may be or tend to be injurious to human being or other living creatures or plants or property or environment.” (Section 2b of Air (Prevention and Control of Pollution) Act, 1981).

- Environmental pollutants (of air, water, land)
  - Deposited matter: soot, smoke, tar, dust, grit etc.
  - Aerosols
  - Suspended Particulate Matter (SPM), not included in revised NAA QS,2009 of India
  - Respirable Suspended Particulate Matter (RSPM) or PM10 (thoracic fraction)
  - Gases: oxides of nitrogen (NO, NO\textsubscript{2}), sulphur (SO\textsubscript{2}), carbon monoxide, halogens, halogenated carbons like CFCs and chlorine, bromine, iodine, ozone, ammonia, benzene.
  - Acid droplets: sulphuric acid, nitric acid etc.
  - Fluorides
  - Metals: mercury, lead, iron, zinc, nickel, tin, cadmium, chromium, arsenic etc.
Air Pollution

- **Agrochemicals**: biocides (pesticides, herbicides, fungicides, nematicides, bacteriacides, weedicides) and fertilizers
- **Complex organic substances**: Benzene, ether, acetic acid, benzopyrene etc.
- **Photochemical oxidants**: Photochemical smog, ozone, peroxymethyl nitrate (PAN), peroxynitrate (PBN), nitrogen oxides, aldehydes, ethylene etc.
- **Solid wastes**
- **Radioactive wastes**
- **Noise**
### Environmental Pollutants

<table>
<thead>
<tr>
<th>Order of priority</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_2$+suspended particles</td>
<td>Air</td>
</tr>
<tr>
<td>Strontium, caesium</td>
<td>Food</td>
</tr>
<tr>
<td>Ozone</td>
<td>Air</td>
</tr>
<tr>
<td>DDT and other organochlorine compounds</td>
<td>Biota, man</td>
</tr>
<tr>
<td>Nitrites, nitrites</td>
<td>Drinking water</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>Air</td>
</tr>
<tr>
<td>Mercury compounds</td>
<td>Food, water</td>
</tr>
<tr>
<td>Lead and cobalt</td>
<td>Food, Air</td>
</tr>
<tr>
<td>Petroleum hydrocarbons</td>
<td>Sea</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>Air</td>
</tr>
<tr>
<td>Fluorides</td>
<td>Water (fresh water)</td>
</tr>
<tr>
<td>Asbestos</td>
<td>Air</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Drinking water</td>
</tr>
<tr>
<td>Mycotoxins and microbial contaminants</td>
<td>food</td>
</tr>
</tbody>
</table>

Source: Sharma, 2016
Critically Polluted areas of India

• Critically polluted areas (CPAs) are those where air, water and land pollution exceed the assimilative capacity of the environment, affecting human health.

• Identification of CPAs started in 1989 by CPCB and SBCBs.

• It was based mostly on the observations made by SPCBs, and 24 critically polluted areas were identified, including Vapi and Ankleshwar in Gujarat and Ludhiana in Punjab (All these areas were found to be industrial hubs).

• CPCB in collaboration with IIT-Delhi and experts from other premier institutes, developed a scientific method to rank and evaluate polluted areas in 2009. This was called as Comprehensive Environmental Pollution Index (CEPI).

• 88 industrial clusters (having power plants, mining areas, chemical, pharma and dye factories) were evaluated by CEPI on the basis of land, water, air pollution, ecological damage and waste management.

• 43 of these CPAs scored higher than 70 points, which showed highly critically polluted state.
Top ten critically polluted areas of India

Source: MoEF (2012)
Composition and structure of Atmosphere

• Pure dry air consists of nitrogen (78%), oxygen (21%), making up 99% of it.
• The remaining 1% of it consists of argon (0.93%), carbon dioxide (0.03%), hydrogen, helium and ozone.
• Earth's atmosphere extends more than 560 kilometers above the planet's surface and is divided into four layers, each of which has distinct thermal, chemical, and physical properties.

Source: https://www.learner.org/courses/envsci/unit/text.php?unit=2&secNum=2
Sources of Air Pollution and Pollutants

- Industrial chimney waste: $SO_2$ and $NO_x$, dust, acid vapours, SPM.
- Thermal Power plant: fly ash, $SO_2$, other gases and hydrocarbons.
- Automobiles:
  - Accounts for 70% of all CO, 50% of all hydrocarbons, 30-40% of all oxides, and 30% of all SPM.
  - Chief sources of emissions in automobiles are: exhaust system, fuel tank, carburetor and crankcase.
  - Exhaust produces unburnt hydrocarbons, CO, $NO_x$, and lead oxides, along with traces of aldehydes, esters, ethers, peroxides and ketones (which combine to form smog in presence of light).
Air Pollutants

• Carbon Compounds

• CO$_2$
  • Released from burning of fossil fuels
  • Thermal power plants release 50 M tons of CO$_2$ each year
  • May lead to greenhouse effect
  • Natural green house effect: the layer of CO$_2$ in the troposphere allows sunlight to enter, but prevents it to re-radiate in outer space.
  • Increase in CO$_2$ concentration in the atmosphere, along with water vapors, adds to the already increased temperatures, called as enhanced greenhouse effect.

• CO
  • Sources: automobiles, stoves, furnaces, open fires, forest fires, bush burning, coal mines, power plants etc.
  • Constitutes 80% of vehicular pollution and 60% of all pollution.
  • Causes difficulty in breathing, headache, irritation of mucous membranes.
  • Causes hypoxia (leading to death)
Air Pollutants (contd.)

• Suphur Compounds
• $SO_2$
  • burning of fossil fuels, thermal power plants, smelting of iron, petroleum refineries, automobiles
  • Causes intense irritation to eyes and respiratory tract
  • Damages higher plants causing necrotic leaves
  • Effects stomatal pores, stomatal frequency, trichomes as well as chloroplast structure
  • Erosion of building material, limestones etc.
• $H_2S$
  • Decaying vegetation and animal matter (in aquatic ecosystems), sulphur springs, volcanic eruptions, coal pits and sewers.
  • Causes headache, nausea, collapse, coma and final death in different concentrations.
  • This gas readily passes through alveolar membrane of the lungs and penetrates bold stream. Death occurs due to respiratory failure.
Air Pollutants (contd.)

- Nitrogen Oxides

- NO
  - Industries producing nitric acid and other chemicals, automobile exhaust.
  - Readily converts into nitrogen di oxide.
  - Responsible for several photochemical reactions in the atmosphere, like formation of PAN, Ozone, carbonyl compounds etc.

- NO₂
  - Chief constituent of photochemical smog.
  - Causes irritation of alveoli, leading to symptoms resembling emphysema (inflammation) upon prolonged exposure to 1 ppm level.
  - Lung inflammation is followed by edema and final death.
Pollutants (contd.)

- Acid rains
  - Oxides of sulphur and nitrogen, produced by combustion of fossil fuels, smelters, power plants, automobile exhaust etc., are swept up into atmosphere and may travel thousands of kilometers.
  - The longer they stay there, more likely are they to be oxidized into acids.
  - Sulphuric acid and nitric acid are the two main acids, which dissolve in water and may fall as acid rain or stay there in clouds and fog.
  - This is a man made phenomenon, increased due to industrialization.
  - Acid rain is a cocktail of sulphuric and nitric acids.
  - These acids may travel long distances during their journey in the atmosphere, and may undergo physical and chemical transformations to produce more hazardous products.
  - They increase land acidity, cause acidification of lakes and streams, affect crop productivity and human health, other than damaging buildings.
Air Pollutants (contd...)

• Tropospheric or bad ozone
  • Ozone formed in the troposphere by the \( \text{SO}_2 \), \( \text{NO}_2 \), aldehydes, in the presence of UV radiations, poses threats to human health and crop growth, and is termed bad ozone.

• Halogenated carbons (CFC, HCFC, HFC)
  • CFCs deplete ozone layer, along with nitrogen oxides (coming from fertilisers), and hydrocarbons. The chlorine in CFCs is responsible for depletion of ozone.
  • CFCs are used in aerosol propellants, refrigerators, air conditioning, plastic foam and solvents for cleaning electrical components.
  • The second generation coolants (HCFCs) also damage ozone (less than CFCs).
  • The HFCs (do not contain chlorine) are the third generation coolants, pose no harm to ozone layer.
  • But HFCs are super-greenhouse gases with extremely high global warming potential.
Pollutants (contd.)

• Particulate matter (PM)
  • On the basis of emission: Primary PM (same chemical form in which it was emitted, Ex: Dust, ash etc.); Secondary PM (formed by chemical reaction the atmosphere, ex: sulphates, nitrates etc.)
  • On the basis of size

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Size range</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSPM (PM_{10}) (thoracic fraction)</td>
<td>&lt;= 10 µm in diameter</td>
</tr>
<tr>
<td>Fine particles (PM)_{2.5} (respirable fraction)</td>
<td>&lt;=2.5 µm in diameter</td>
</tr>
<tr>
<td>Ultrafine particles (UFP)</td>
<td>&lt;=0.1 µm in diameter</td>
</tr>
</tbody>
</table>
Methods of prevention and control of air pollution

Five separate possibilities for prevention of air pollution

*Source: Sharma, 2016*
Methods of prevention and control of air pollution

1. Source Correction
   a) This is the easiest method where we stop the pollution at source; also called as prevention
   b) Change of raw materials or a modification of the process.

2. Collection of pollutants
   a) If collected, it is easier to recycle or treat air pollutants
   b) Recycling of blowby gases in the internal combustion engines, could facilitate re-ignition of these gases and their emission through car’s exhaust system (successful example).

3. Cooling
   a) Exhaust gases are usually very hot; Can be cooled through dilution, quenching or use of heat exchange oils.

4. Treatment
   a) Settling chambers: remove large particles
   b) Cyclones: used as pre-cleaners to remove heavy particles
   c) Bag filters: operate like vacuum cleaners; sensitive to high temp. and humidity
   d) Wet collectors: spray towers
   e) Electrostatic precipitators: require electricity; remove submicron particulates
   f) Gas scrubbers: dissolving gases (similar to wet scrubbers)
   g) Adsorption: activated carbons; organic compounds
   h) Incineration: for combustible vapours
   i) Catalytic combustion: catalysts to adsorb or chemically change pollutants
Methods of prevention and control of air pollution

5. Dispersion

a) The problem of air pollution involves three parts: source, movement of pollutant and recipient.

b) The concentration of pollutant at the recipient is affected by atmospheric dispersion (how the pollutant is diluted with clean air).

c) This dispersion occurs horizontally as well as vertically.

d) Diffusion is the process of spreading out the emission over an area and thus reducing the concentration of the specific pollutants.
Water

• Unusual properties of water:
  - Water molecules have dipolar nature (i.e. slightly positive charge at one end and slightly negative charge at the other end).
  - Dipolar nature
    - Makes water molecules to be attracted to each other (Figure 1).
    - Explains high boiling point of water.
    - Explains why large amount of energy is required for vaporization of water.
    - Explains high surface tension of water.
    - Causes them to adhere to the other surfaces (capillarity).
    - Makes them highly effective solvents.
  - Density of water is highest at 4 °C, making ice float on the surface of water (crucial for survival of aquatic life forms).
  - High difference between melting and boiling points of water cause it to remain a liquid in most parts of Earth.
  - Very high specific heat (helps oceans become the major moderating factors in maintaining the temperatures of the surface of the Earth).
  - High heat of vaporization: important in distributing heat from one part of the Earth to the other.
  - Solvent: effective medium both for transporting nutrients and eliminating wastes
  - Greenhouse effect: The water molecules absorb solar energy in their bending vibrations (of their bonds)

Figure 1: Dipolar molecule of water
Water Resource on Earth

- Earth
  - Water (70%)
    - Fresh water (3%)
      - Frozen (77%)
    - Sea water (97%)
      - Liquid state (23%)
      - Available for use by plants and animals (0.5%)
  - Land (30%)
Status of water resource

• The amount of water that is clean and drinkable is steadily decreasing because of pollution.

• It is estimated by WHO (2004) that more than a billion people, about 17 percent of the world's population, don't have access to clean water.

• With a vast population of about 1.2 Billion, India struggles for the allocation of almost all natural resources including water.

• 97 million people in India lack safe water and 814 million have no sanitation services.

• Possible SDGs in the context of India, should include, “Ensuring universal access to potable water and sanitation”, as one of its goals and “Access to reliable clean water supply to households including safe drinking water”, a possible sub-goal of it.

(Bakshi and Kumar, 2013)
# Water Demand in India

(Water Demand for various sectors in 2025 and 2050)

<table>
<thead>
<tr>
<th>Year</th>
<th>Irrigation</th>
<th>Drinking Water</th>
<th>Industry</th>
<th>Energy</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>688</td>
<td>56</td>
<td>12</td>
<td>5</td>
<td>52</td>
<td>813</td>
</tr>
<tr>
<td>2025</td>
<td>910</td>
<td>73</td>
<td>23</td>
<td>15</td>
<td>72</td>
<td>1093</td>
</tr>
<tr>
<td>2050</td>
<td>1072</td>
<td>102</td>
<td>63</td>
<td>130</td>
<td>80</td>
<td>1447</td>
</tr>
<tr>
<td></td>
<td>557</td>
<td>43</td>
<td>37</td>
<td>19</td>
<td>54</td>
<td>710</td>
</tr>
<tr>
<td></td>
<td>611</td>
<td>62</td>
<td>67</td>
<td>33</td>
<td>70</td>
<td>843</td>
</tr>
<tr>
<td></td>
<td>807</td>
<td>111</td>
<td>81</td>
<td>70</td>
<td>111</td>
<td>1180</td>
</tr>
</tbody>
</table>


Source: National Mission on Sustainable Habitat (2011)

The projected demand share for 2050 is dominated by agriculture (70%), followed by households (9%) and industries (7%) (NITI Aayog, 2017).
Water resources in India

<table>
<thead>
<tr>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated annual precipitation (including snowfall)</td>
<td>4000 Km³</td>
</tr>
<tr>
<td>Run-off received from upper riparian countries</td>
<td>500 Km³</td>
</tr>
<tr>
<td>Average annual natural flow in rivers and aquifers</td>
<td>1869 Km³</td>
</tr>
<tr>
<td>Estimated utilizable water</td>
<td></td>
</tr>
<tr>
<td>• Surface</td>
<td>690 Km³</td>
</tr>
<tr>
<td>• Ground</td>
<td>433 Km³</td>
</tr>
<tr>
<td>Estimated utilizable water</td>
<td>1123 Km³</td>
</tr>
</tbody>
</table>

Source: MoWR (2008)
## Water Supply in India
(Per capita supply norms)

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Classification of Towns/Cities</th>
<th>Recommended Water Supply Levels (lpcs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Towns provided with piped water but without sewerage system</td>
<td>70</td>
</tr>
<tr>
<td>2.</td>
<td>Cities provided with piped water supply where sewerage systems in existing/contemplated</td>
<td>135</td>
</tr>
<tr>
<td>3.</td>
<td>Metropolitan and Mega cities provided with piped water supply where sewerage system is</td>
<td>150</td>
</tr>
<tr>
<td></td>
<td>existing/contemplated</td>
<td></td>
</tr>
</tbody>
</table>

*The Unaccounted for Water (UFW) is not included here which is considered at 15% in India* [Source: CPHEEO Manual (1999)]
Water Pollutants

• **Pathogens**
  • Disease causing organisms that grow and multiply within the host, causing infection. Examples: Viruses, bacteria, protozoa, helminthes
  • WHO estimates that 80-100% of the illnesses caused by cholera, typhoid, and guinea worm infection could be eliminated in developing countries with improved water supply and sanitation disposal of excreta (UNEP, 1993).

• **Oxygen demanding wastes**
  • The substances that oxidise in the receiving body of water. These are usually biodegradable organic substances, present in municipal wastewaters, or certain industrial effluents (food processing, paper production etc.)
  • When decomposed by bacteria, these wastes utilise the dissolved oxygen (DO) in water. Survival of aquatic life forms is threatened by the decrease in DO.
  • The COD (chemical oxygen demand) is the amount of energy required to oxidise the waste chemically
  • The BOD is the amount of oxygen required to decompose the waste biologically by microorganism.

*BOD is the most important measure of organic pollution, and its reduction an indicator of performance*
Water Pollutants (Contd...)

• **Nutrients**
  - When present in sufficient amounts so as to cause excessive growth of aquatic plants like algae. (Algal blooms, eutrophication of lakes).

• **Salts**
  - Salinity is usually measured as the concentration of *Total Dissolved Solids (TDS)*
  - TDS is an important indicator of usefulness of water for various applications

<table>
<thead>
<tr>
<th>Type of water</th>
<th>TDS (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater</td>
<td>&lt;1500</td>
</tr>
<tr>
<td>Brackish water</td>
<td>&lt;5000</td>
</tr>
<tr>
<td>Saline water</td>
<td>&gt;5000</td>
</tr>
<tr>
<td>Sea water</td>
<td>30,000 to 34,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use of water (consumption)</th>
<th>TDS (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking water</td>
<td>&lt;500</td>
</tr>
<tr>
<td>Poultry</td>
<td>&lt;2860</td>
</tr>
<tr>
<td>Pigs</td>
<td>&lt;4290</td>
</tr>
<tr>
<td>Cattle</td>
<td>&lt;10,100</td>
</tr>
<tr>
<td>Crops</td>
<td>&lt;2100</td>
</tr>
</tbody>
</table>
Water Pollutants (Contd…)

• **Thermal Pollution**
  - Increase in temperature of water increases demand of oxygen in water (increased metabolic rates of organisms), and reduces the dissolved oxygen in water.

• **Heavy metals**
  - Examples: mercury (Hg), Lead (Pb), Cadmium (Cd), Arsenic (As).
  - Most metals including, Al, Cu, Mn, As, Hg etc., are toxic.
  - They are different from other toxic substances as they are totally non-degradable (indestructible).
  - Some metals such as chromium and iron are essential, but in higher doses they might cause damages to nervous system, creation of mutations and kidney damages.

• **Pesticides**
  - A range of chemicals that kill organisms that are considered undesirable by humans.
  - Examples: insecticides, herbicides, rodenticides, fungicides
  - 3 main groups of synthetic organic insecticides: organochlorides (Ex. DDT), organophosphates, carbamates.

• **Volatile Organic Compounds (VOCs)** are found in industrial effluents (carcinogenic)
Water and wastewater systems.

When storm and sanitary sewers are combined, like in old cities, the wastewater could be discharged untreated in rainy seasons.

Source: Masters, 2008
Water Treatment Systems

A typical water treatment plant for surface water. Softening may be required as an additional step for groundwater. (Source: Masters, 2008)

**Screening:** remove large floating and suspended debris.

**Mixing:** with chemicals to coagulate suspended solids into large particles (which can settle).

**Flocculation:** gently mixing water and coagulant, allowing formation of large particles of floc.

**Sedimentation:** the flow is slowed enough so that gravity will cause the floc to settle.

**Filtration:** Effluent is cleaned.

**Sludge Processing:** Mixture of solids and liquids collected from settling tank is dewatered and disposed of.

**Disinfection:** of the liquid effluent to ensure it is free of harmful pathogens

*Hardness removal* can be added if needed.
Desalination

The two most widely used desalination technologies
a. Multi-stage distillation (one stage shown)
b. Reverse osmosis
(Source: Masters, 2008)

Worldwide desalination technologies
a. Percentage by number of facilities
b. Percentage by treatment capacity
(Source: Masters, 2008)
An example of wastewater treatment facility providing primary and secondary treatment using the activated sludge process. 
*Source: Masters, 2008*
Drinking water

• “Drinking water is water intended for human consumption for drinking and cooking purposes from any source. It includes water supplied by pipes or any other means for human consumption by any supplier.”
  
  BIS (2013)

• “The most effective means of consistently ensuring the safety of a drinking-water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer.”

  WHO (2011)
Drinking water purification

Three broad categories of impurities

(Murcott, 2006)

“Infectious diseases caused by pathogenic bacteria, viruses, protozoa and helminths [worms] are the most common and widespread health risk associated with drinking water” (WHO, 2004)

Point-of-use water treatment (household water treatment, HWT) has been advocated as a means to substantially decrease the global burden of diarrhoea and to contribute to the Millennium Development Goals. (Schmidt, and Cairncross, 2008)
### Effect of excess parameters on health (States of India affected by them)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Maximum permissible limit</th>
<th>Health impact</th>
<th>Affected states</th>
</tr>
</thead>
</table>
| **Fluoride** | 1.5 mg/l | • Immediate symptoms include digestive disorders, skin diseases, dental fluorosis  
• Fluoride in larger quantities (20-80 mg/day) taken over a period of 10-20 years results in crippling and skeletal fluorosis which is severe bone damage | Andhra Pradesh, Assam, Bihar, Chattisgarh, Gujarat, Haryana, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Tripura, Uttar Pradesh, West Bengal |
| **Arsenic** | 0.05 mg/l | • Immediate symptoms of acute poisoning typically include vomiting, oesophageal and abdominal pain, and bloody ‘rice water’ diarrhoea.  
• Long-term exposure to arsenic causes cancer of the skin, lungs, urinary bladder, and kidney. There can also be skin changes such as lesions, pigmentation changes and thickening (hyperkeratosis) | Assam, Bihar, Chattisgarh, Jharkhand, Tripura, West Bengal, Uttar Pradesh |
| **Iron** | 1 mg/l | • A dose of 1500 mg/l has a poisoning effect on a child as it can damage blood tissues  
• Digestive disorders, skin diseases and dental problems | Arunachal Pradesh, Assam, Bihar, Chattisgarh, Jharkhand, Jammu and Kashmir, Karnataka, Kerala, Manipur, Meghalaya, Mizoram, Madhya Pradesh, Maharashtra, Nagaland, Orissa, Punjab, Rajasthan, Sikkim, Tripura, Tamil Nadu, Uttar Pradesh, West Bengal, A&N Islands, Pondicherry |
| **Nitrate** | 100 mg/l | • Causes Methamoglobinemia (Blue Baby disease) where the skin of infants becomes blue due to decreased efficiency of haemoglobin to combine with oxygen.  
It may also increase risk of cancer | Bihar, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh |
| **Salinity** | 2000 mg/l | Objectionable taste to water. May affect osmotic flow and movement of fluids | Andhra Pradesh, Chattisgarh, Gujarat, Haryana, Kerala, Madhya Pradesh, Maharashtra, |
| **Heavy Metals** |  | Damage to nervous system, kidney, and other metabolic disruptions | Gujarat, Andhra Pradesh, Delhi, Haryana, Kerala |
| **Persistent Organic Pollutants** | None | High blood pressure, hormonal dysfunction, and growth retardation. | Delhi, Himachal Pradesh, Jharkhand, West Bengal, |
## Choice of Water treatment

- Water treatment method
  - based on kind of use
  - Kind of input water

<table>
<thead>
<tr>
<th>Area</th>
<th>Purification technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle filtration</td>
<td>coagulation/flocculation/clarification, multi-media filtration (anthracite, sand, garnet), continuous micro-filtration</td>
</tr>
<tr>
<td>Organics removal</td>
<td>Carbon filtration, UV, ozone</td>
</tr>
<tr>
<td>Water softening</td>
<td>ion exchange, chemical precipitation</td>
</tr>
<tr>
<td>De-ionization</td>
<td>reverse osmosis, ion exchange, electro de-ionization</td>
</tr>
<tr>
<td>Particle removal</td>
<td>ultrafiltration, nanofiltration</td>
</tr>
</tbody>
</table>

(Source: Kostoff et al., 2008)
### Water treatment technologies

<table>
<thead>
<tr>
<th>Thermal (heat based technologies)</th>
<th>Solar disinfection</th>
<th>UV light technologies using lamps, including UV emitting diodes</th>
<th>Coagulation-flocculation and/or sedimentation</th>
<th>Chemical disinfection</th>
<th>Ion Exchange</th>
<th>Filtration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling</td>
<td></td>
<td></td>
<td></td>
<td>Chlorination</td>
<td></td>
<td>Cloth filters</td>
</tr>
<tr>
<td>Heating to pasteurization</td>
<td></td>
<td></td>
<td></td>
<td>Disinfection with Iodine</td>
<td></td>
<td>Filtration through porous ceramic material</td>
</tr>
<tr>
<td>temperatures (&gt; 63 °C for 30 minutes)</td>
<td></td>
<td></td>
<td></td>
<td>Ozone disinfection</td>
<td></td>
<td>Granular media filters</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Disinfection by strong acids or bases</td>
<td></td>
<td>Carbon Adsorption</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Silver and Copper based disinfectants</td>
<td></td>
<td>Ultrafiltration (UF)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nanofiltration (NF)</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Reverse Osmosis (RO)</td>
</tr>
</tbody>
</table>
Particles removed by various filtration technologies based on their pore sizes

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Causes of its presence in water</th>
<th>Possible Purification methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pollutants/contaminants causing health hazards</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arsenic</td>
<td>Naturally occurring in water in some areas</td>
<td>Reverse osmosis; ion exchange</td>
</tr>
<tr>
<td>Bacteria/viruses</td>
<td>Well not sealed; sewage, manure or surface runoff</td>
<td>chlorination; ozonation; UV disinfection</td>
</tr>
<tr>
<td>Lead</td>
<td>Corrosive water, lead pipes or lead solder</td>
<td>Reverse osmosis; distillation</td>
</tr>
<tr>
<td>Nitrate</td>
<td>Well not sealed; faulty septic system; animal waste; fertilizers</td>
<td>Distillation; reverse osmosis; anion exchange (water softener)</td>
</tr>
<tr>
<td>Pesticides &amp; Organic chemicals</td>
<td>Use of pesticides, chemicals near water source</td>
<td>Activated carbon filter; reverse osmosis; distillation</td>
</tr>
<tr>
<td><strong>Contaminants that do not cause health hazards; may be treated for their aesthetic value</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bad odor, color, taste</td>
<td>Variety of sources</td>
<td>Ion exchange; activated carbon filter; chlorination</td>
</tr>
<tr>
<td>Cloudy or dirty water</td>
<td>Fine sand, clay, or other particles</td>
<td>Mechanical filter</td>
</tr>
<tr>
<td>Hardness</td>
<td>Naturally occurring minerals in water</td>
<td>Ion exchange (water softener)</td>
</tr>
<tr>
<td>Rotten egg odor</td>
<td>Hydrogen sulfide gas</td>
<td>Chlorination and activated carbon filter</td>
</tr>
<tr>
<td>Staining of sink and/or laundry (iron or manganese)</td>
<td>Naturally occurring in water, especially deep wells</td>
<td>Ion exchange, chlorination and filtration</td>
</tr>
</tbody>
</table>

Source: Daniels and Mesner (2010)
Water Quality Standards

• The prescribed safe limits called “water quality standards” differ according to use.
• International Standard Organisation (ISO) has technical committees in different aspects of water and related issues:
  – TC 147: standards for water quality
  – TC 224: service activities relating to drinking water supply systems and wastewater systems
  – TC 282: water reuse
  – TC 38/SC2: cleansing, finishing and water resistance tests
• India has accepted World Health Organisation (WHO) guidelines as its baseline
  – IS 14543: Indian standard – Packaged drinking water (other than packaged natural mineral water)
• There is an International standard ANSI/NSF 61*, which is applicable for the certification of water treatment components

Rao, and Bhattacharya, (2015)