

**A TEXT BOOK OF ENVIRONMENT AND POLLUTION
ECOLOGY**

***Editor
Dr. Mandaloju Venkateshwarlu**

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Dr. Mandalaju Venkateshwarlu

M.Sc., Ph.D., (Botany) M.Sc (Bio-tech), FSAB, FHAS, FCS (LLB).

**Department of Botany, Kakatiya University,
Warangal – 506 009, (TS) India.**

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UNIT II**POLLUTION ECOLOGY****CHAPTER 1****KINDS AND SOURCES OF POLLUTION: AIR, WATER AND SOIL.
QUALITY PARAMETERS****AIR POLLUTION**

The air that constitutes the atmosphere has a mixture of gases dominated by nitrogen (N₂), oxygen (O₂), argon (Ar) and variable amounts of water vapor. Traces of other types of gases and particulates from different sources also constitute the atmosphere. Some of the atmospheric pollutants occur naturally such as carbon dioxide or methane. Burning of fossil fuels leads to release of carbon dioxide along with the carbon dioxide generated during respiration and oxidative decay of organic matter.

1. Sources Of Air Pollution

Many of the pollutants in our atmosphere have natural as well as human related origins. Natural emissions of air pollutants include the release of gases such as sulfur dioxide from volcanic eruptions. The releases of hydrogen sulfide from geyser and hot spring activities and by biological decay contribute to air pollution. Air pollutants and their sources are listed in Table 2.1.

Table 2.1: Sources of air pollutants.

Air Pollutant	Major Sources
Particulates Sulfur oxides Carbon monoxide Nitrogen dioxide	Industrial processes, Combustion of fuels Combustion of fuels (mostly coal). Industrial processes Transportation, Agricultural burning Transportation (mostly automobiles), Combustion of fuels (mostly natural gas and coal)
Ozone	Concentration present depends on reaction in lower atmosphere involving hydrocarbons (automobile exhaust)
Hydrocarbons	Transportation (mostly automobiles), Industrial processes. Evaporation of organic solvents. Agricultural burning

Some of the atmospheric pollutants that are not manmade are called anthropogenic and some are newly synthesized called as xenobiotic. Atmospheric pollutants are either known as primary or secondary pollutants. The primary pollutants arise as a result of either man-made or natural processes. These pollutants undergo chemical

change and the products of such reactions are called as secondary pollutants. Pollutants are continuously being added to the atmosphere. The residence time of the pollutant in the atmosphere is calculated by the total amount of the pollutant in the atmosphere divided by the rate at which it is either removed from or added to the air.

Two major kinds of air pollution sources are: i) stationary sources and ii) mobile sources.

Stationary Sources

- i. Point sources: Air pollutants from one or more controllable sites such as smokestacks of power plants at industrial sites.
- ii. Fugitive sources: These include the pollution through wind processes, such as dirt roads, construction sites, farmlands, storage piles, surface mines etc.
- iii. Area sources: These include air pollutants emitted from well-defined area within which there are several sources such as in small urban communities or areas of intense industrialization within urban complexes or agricultural areas sprayed with herbicides and pesticides.

Mobile Sources

This includes vehicular emissions such as from automobiles, trucks, buses, aircraft, ships and trains.

2. Air Pollutants

Pollutants which have short residence times are not uniformly mixed throughout the lower atmosphere. Table 2.2 presents the residence times of some pollutants.

Table 2.2: Approximate residence times for some atmospheric pollutants.

Species	Residence Time (Years)
N ₂ O	20
CO ₂ , CH ₄	3
CO	0.4
SO ₂	0.02
NO, NO ₂	0.01
NH ₃ , H ₂ S	0.005

a. Sulphur Dioxide (SO₂)

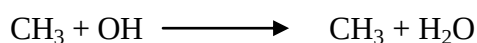
Sulphur dioxide is known for its unpleasant odour and in the range of 1 ppb to 2 ppm in remote and industrial locations respectively.

b. Hydrocarbons

Hydrocarbons are compounds containing only carbon and hydrogen. The simplest among them is methane (CH₄).

c. Methane

Methane is generated by natural sources in the range of 8.5×10^{12} and 2.9×10^{13} mol. through microbial activity under anaerobic conditions. Human activity also produces between 1.5×10^{13} and 3.6×10^{13} mol from the rice fields, burning of biomass, waste disposal and fossil fuel extraction activities. There are three sinks for the methane produced, namely some amount is absorbed by the soil, some is transferred to the stratosphere and the remainder is destroyed in the troposphere by a chain of reactions. Hydroxyl radicals attack methane.



Methane has a long atmospheric residence time, approximately three years, to be fairly evenly distributed throughout the troposphere. Methane is also a greenhouse gas and hence contributes to global warming.

d. Non-methane Hydrocarbons

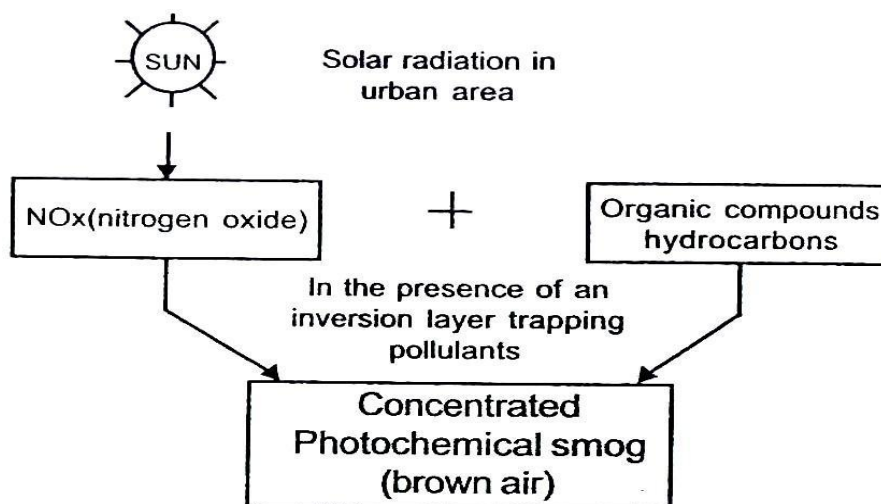


Figure 2.1: Formation of photochemical smog.

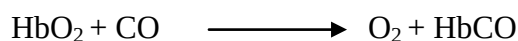
As per the research studies, more than 650 different airborne hydrocarbons have been identified. Human activities involving transport contribute a significant amount of air pollutants. Anthropogenic compounds released are benzene, ethane, ethyne, hexanes, pentanes, propane and toluene. Most of the non-methane hydrocarbons are oxidized similar to methane within the troposphere producing a large number of secondary

pollutants. Photochemical smog is produced during the partial oxidation of organics. These non methane hydrocarbons are said to cause global warming. Solar radiation is important in the formation of photochemical smog (Fig. 2.1). The reactions that occur in the development of photochemical smog are complex and involve both hydrocarbons and nitrogen oxides. The development is directly related to automobile use.

e. Oxides of Carbon

Oxides of carbon exist as carbon dioxide (CO₂) and carbon monoxide (CO). Carbon dioxide is present in the troposphere at a concentration of about 360 ppm. This is considered as a major greenhouse gas and hence known for causing global warming. The main sources of atmospheric carbon dioxide are respiration, oxidative decay, combustion and release from oceans. The main sinks for carbon dioxide are photosynthesis and dissolution in sea water. Approximately 70 % of hydroxyl radicals react with CO and CH₄.

Carbon monoxide is generated biologically on land and within the oceans, besides during the oxidation of hydrocarbons and during the incomplete combustion of fossil fuels and biomass. The residence time of carbon monoxide in the atmosphere is short and hence does not allow for spatial and temporal variation in its concentration. Northern hemisphere is considerably more contaminated with carbon monoxide than the southern hemisphere. The level of CO may rise to exceptional levels in areas like tunnels which could bring about changes in blood. It can combine with haemoglobin to form carboxyhaemoglobin. This may reduce the oxygen supply to vital organs causing decrease in behavioral effectiveness.



Oxygenated	Carboxy
Haemoglobin	haemoglobin

Elevated release of carbon monoxide is likely to reduce tropospheric concentrations of hydroxyl radical; this in turn will reduce the removal rates of many other pollutants as the reaction with hydroxyl radical serves as a major sink for these contaminants.

f. Halogenated Hydrocarbons

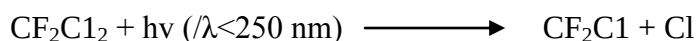
Halogenated hydrocarbons are produced when one or more hydrogen atoms of a hydrocarbon are replaced by atoms of a halogen (F, Cl, Br, I).

g. Chlorinated Hydrocarbons

Chlorinated hydrocarbons which do not contain fluorine undergo photolysis in the stratosphere liberating chlorine atoms. Anthropogenic emissions of brominated CFC analogues and brominated hydrocarbons are of importance. Brominated hydrocarbons are used as fire extinguishers.

h. Chlorofluorocarbons

Chlorofluorocarbons contain carbon, chlorine and fluorine and sometimes contain hydrogen. There is no natural source for CFCs. Two most abundant compounds are CFC-11 and CFC-12. They are inert, nontoxic, non-flammable and odourless. They are used as refrigerants and used as solvents in the manufacture of foamed plastics and as propellants in aerosol sprays. Most of the CFCs are not chemically altered during use and are eventually released into the atmosphere. They are not destroyed even in the troposphere and have long atmospheric lifetimes. They also get distributed throughout the troposphere and also stratosphere, where they are slowly degraded by a process called as photolysis. This is represented by the reaction.



The chlorine atoms thus released tend to destroy some of the ozone that shields the biosphere from harmful ultraviolet light.

i. Nitrogen Oxides

Nitrogen oxides (NO_x) are emitted in two forms: nitric oxide (NO) and nitrogen dioxide (NO_2). The most important of these is NO_2 which is visible as yellow brown to reddish brown gas. Nitrogen dioxide may be converted by complex reactions in the atmosphere to the ion (NO_3^{2-}) within small water particulates, impairing visibility. Nitrogen dioxide is one of the main pollutants that contribute to the development of smog and is a major contributor to acid rain. NO is emitted from automobiles and power plants that burn fossil fuels. The environmental effects of nitrogen oxides on humans include irritation of eyes, nose, throat, and lungs and increased susceptibility to viral infections, including influenza. Nitrogen oxides are known to suppress plant growth and damage leaf tissue. When the oxides are converted to their nitrate form and deposited on the soil, it can promote plant growth as nitrogenous fertilizers.

j. Particulate Matter

Particulate matter refers to the varying mixtures of particles suspended in the air. A particle of high concentration and or specific types of particles seems to present a serious danger to human health. All industrial processes, as well as burning of fossil fuels release particulates into the atmosphere. Particulate matter mostly is visible as smoke, soot or dust. Particulates include materials such as airborne asbestos particles and small particles of heavy metals such as arsenic, copper, lead, and zinc which are usually emitted from industrial facilities such as smelters. Fine particle pollutants less than $2.5\text{ }\mu\text{m}$ in diameter is of importance which can be inhaled easily into the lungs where they can be absorbed by the bloodstream or remain embedded for a long period of time. Eg. Sulfates and Nitrates. These are mostly secondary pollutants produced in the atmosphere through chemical reaction between normal atmospheric constituents and sulfur dioxide and nitrogen oxides.

These particulates affect human health, ecosystems, and the biosphere. Particulates enter lungs, may lodge there and have chronic effects on respiration. Dust raised by road building may get deposited on the surface of green plants and interfere with absorption of carbon dioxide and oxygen and release of water. Minute particles of dust, known as PM_{105} cause lung damage. Modern industrial processes have greatly increased the total suspended particulates in Earth's atmosphere. Particulates block sunlight and may cause changes in climate.

k. Carbon Monoxide

Carbon monoxide (CO) is a colourless and odourless gas and is extremely toxic to humans and other animals at very low concentrations. At high toxicity condition, hemoglobin in our blood will take up carbon monoxide nearly 250 times more rapidly than oxygen. Combustion of fuels can emit carbon monoxide as a result of incomplete combustion and may cause dizziness and headache to death. Carbon monoxide is particularly hazardous to people with known heart disease, anaemia or respiratory disease. It may cause birth defects, including mental retardation and impairment of growth of the foetus. Approximately, 90 % of the carbon monoxide in the atmosphere comes from natural sources, and the balance 10 % comes from fires, automobiles, and other sources of incomplete burning of organic compounds.

l. Photochemical Oxidants

Photochemical oxidants result from atmospheric interactions of nitrogen dioxide and sunlight. The common photochemical oxidant is ozone (O_3) which is a colourless gas with slightly sweet odour. Besides ozone, other photochemical oxidants such as PANs (peroxyacyl nitrates) also occur with photochemical smog. Ozone is very active chemically and it has a short average lifetime in the air. Because of the effect of sunlight on normal oxygen, ozone forms a natural layer high in the atmosphere (stratosphere). It protects us from harmful ultraviolet radiation from the sun. The adverse environmental effects of ozone and other oxidants depend on the dose or concentration of exposure and include damage to plants and animals as well as to materials such as rubber, paint and textiles. Effects of ozone on plants can be subtle. It can reduce growth rates; at higher concentrations it kills the leaf tissue or even the whole plant.

m. Hydrogen Sulphide

Hydrogen sulphide (H_2S) is highly toxic and corrosive gas produced from natural sources such as geysers, swamps and bogs as well as from petroleum processing, refining and metal smelting. It can cause functional damage to plants and health problems ranging from toxicity to death of humans and other animals.

n. Hydrogen Fluoride

Hydrogen fluoride (HF) is a gaseous pollutant that is released primarily by aluminium production, coal gasification and burning of coal in power plants. It is extremely toxic and even at low concentration (1 ppb) and may cause problems for plants and animals.

o. Asbestos

Asbestos is used in building and electrical insulation, roofing material and brake pads for vehicles. Some types of asbestos particles are believed to be carcinogenic or carry carcinogenic materials.

p. Lead

Lead is an important constituent of automobile batteries and other industrial products. When lead is added to petrol, it helps to protect the engine and promotes more even fuel consumption. Lead in petrol/ gasoline is emitted into the environment in the

exhaust. Once released, lead can be transported through the air as particulates to be taken up by plants through the soil or deposited directly on plant leaves. Thus, it enters terrestrial food chains. When lead is carried by streams and rivers, gets deposited in quiet waters or transported to oceans or lakes and taken up by aquatic organisms and thus enters aquatic food chain.

3. Air Pollution and Climate Change

It is well understood that human activities are contributing to climate change. Studies of Barnett et al. (2001), Levitus et al. (2001) have shown that human influence contributes to rise in global ocean temperatures. Four important features which contribute to the change are:

- Increasing concentration of 'greenhouse gases' in the atmosphere, especially carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and tropospheric ozone leads to
- Increasing global mean temperature through radiative forcing and
- An increased frequency of extreme weather events and
- The depletion of stratospheric ozone caused by the release of man-made ozone-depleting substances.

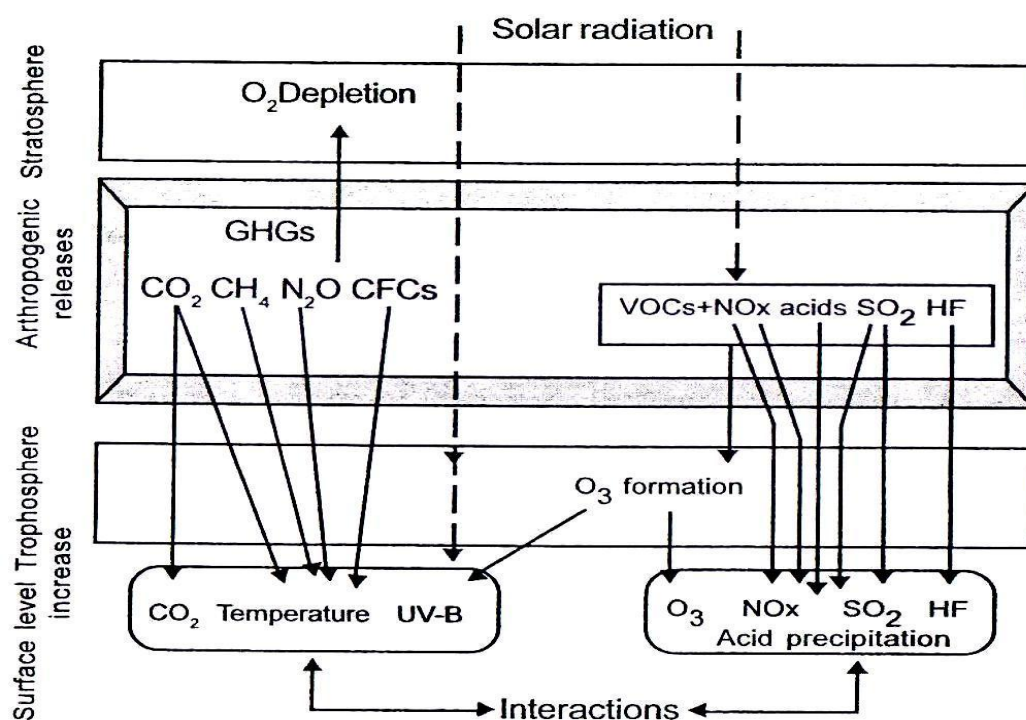


Figure 2.2: Major components of climate change and their interactions with major air pollutants.

Atmospheric carbon dioxide is essential to present day plant and animal life on earth because it provides the carbon input to photosynthesis, and it is released significantly into the atmosphere resulting from activities such as the combustion of fossil fuels and changes in land-use pattern. Figure 2.2 presents a diagrammatic summary of the interactions of ozone, sulphur dioxide, nitrogen oxides and hydrogen fluoride. Crawford and Wolfe (1999) and Luo et al. (1999) have reported that changes in CO_2 and surface temperature operate interactively with each other and also with other environmental factors. Carbon dioxide at increased concentrations produces main effects on plants (Table 2.3). Most plant species have the C_3 pathway of CO_2 assimilation and exhibit significant photorespiration (loss of CO_2 during illumination). These plants show large increases in assimilation rate with increasing CO_2 concentration.

Species with C_4 assimilation pathway possess foliar CO_2 concentrating mechanisms that result in photosynthetic carboxylation functioning close to CO_2 saturation, and exhibit little photorespiration. C_4 plants contribute nearly 20 % of global primary productivity, eg. Plants such as maize, sugarcane and sorghum.

Table 2.3: Effect of increased atmospheric carbon dioxide on terrestrial species.

Plant Response	Effect
Stomatal conductance	Decrease
Transpiration	Decrease
Photosynthesis	Increase ($\text{C}_3 > \text{C}_4$) Species
Growth rates (biomass and elongation)	Increase ($\text{C}_3 > \text{C}_4$) Species
Biomass and crop yield	Increase ($\text{C}_3 > \text{C}_4$) Species
Water use efficiency	Increase ($\text{C}_3 > \text{C}_4$) Species
Leaf area index	Increase
Specific leaf area	Decrease
Root/Shoot ratio	Increase
Branching and tillering	Increase
Fruit size, number and seed/plant	Increase

4. Control Of Air Pollution

Air Pollution problems vary in different regions of the world. The reasonable strategies include reduction, collection, and capture or retain the pollutants before they enter the atmosphere. Air pollutants are mainly in the form of (i) particulate matter, (ii) gaseous emission and (iii) automobile exhaust. The most effective means

of dealing with the problem of air pollution is to prevent emission at the source itself. Control of particulates can be accomplished by several ways. They include.

- i. **Gravity Settling Chamber:** This is the simplest method for the control of particulate matter. The coarse particulate matter is separated due to gravitational force with a settling velocity greater than 0.12 m/s. A variety of settling chambers or collectors are used to control emissions of coarse particulates from power plants and industrial sites.
- ii. **Cyclone Separator:** Cyclone separators are very useful for the removal of air streams of particles above 10 μm in diameter. The particle laden air spirals through the cylinder to create centrifugal forces which throw the particles to the outside walls (Learle 1966). Cyclone separator (Fig. 2.3) operates by the centrifugal force which is several times greater than the gravitational force. Cyclone separators are classified according to either their geometrical configuration or their efficiency.

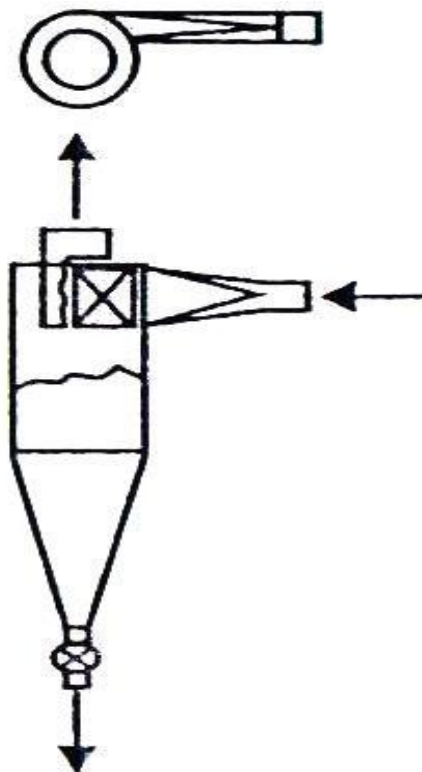


Figure 2.3: Cyclone separator.

- iii. Fabric Filter:** This is operated by means of filtration for separation of particulates from a carrier gas. A filter may be granular or fibrous material which retain the particulate and allows the gas to pass through the voids of the filter small articles are initially retained on the fabric by direct interception, inertial impaction, diffusion and gravitational settling. Fibrous and deep-bed filters have large void spaces and are tubular bags or cloth envelopes suitable for dust loading at 1 g/m^3 . Fabric filters are capable of removing dust as small as 0.5 microns. The hopper bottom serves as a collector of dust particles.
- iv. Electrostatic Precipitator:** The main purpose of electrostatic precipitator is to remove the fine particles contained in exhaust gas by electrostatic principles. By the use of static electricity, they attract particles in much the same way that static electricity in clothing, picks up small bits of dust and lint. Electrostatic precipitators are effective to the extent of 98-99 % and are used instead of baghouses when the particles are suspended in very hot gases, such as in emissions from power plants, steel and paper mills, smelters and cement plants.
- v. Scrubber:** In this method the gases are treated with a slurry (a watery mixture) of lime (calcium oxide) or limestone (calcium carbonate). Both wet and dry scrubbers are being used in industries. A compact packed tower venturi scrubber system for the capture and destruction of acid gases or other compounds is shown in Figure 2.4. Sulphur oxide emissions from stationary sources such as power plants can be reduced by removing the oxides from the gases in the stack before they reach the atmosphere. The sulphur oxides react with the calcium to form insoluble calcium sulphides and sulphates, which are collected and then disposed of. The calcium sulphate sludge formed during the scrubbing process is used to produce building materials.

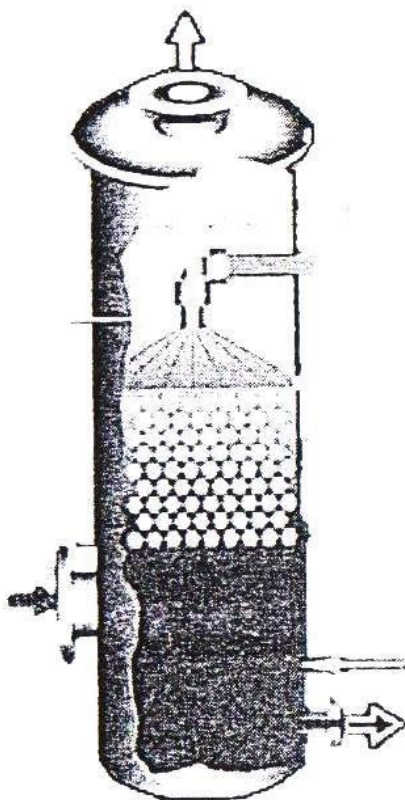


Figure 2.4: Venturi scrubber used for air pollution control in industry.

Alternatively the smoke from combustion is cooled then treated with liquid ammonia (NH_3) which reacts with the sulfur to produce ammonium sulfate. The sulphur contaminated smoke from burning the coal is cooled in a heat exchange process by outgoing clean smoke to a temperature that favors the reaction with ammonia. The cooled and cleaned outgoing smoke is then heated by dirty smoke to force it out of the vent.

5. Air Quality Standards

Central Pollution Control Board (CPCB) has introduced national air quality standards which are listed in Table 2.4. Non industrial sources of noise can be from domestic, loud speaker, traffic, crowded market, theatre, circus and carnivals, religious and cultural festival, trains, aircraft and atomic explosions.

Table 2.4: National ambient air quality standards (India).

Pollutant	Time	Concentration in ambient air ($\mu\text{g}/\text{m}^3$)		
		Industrial area	Residential Rural & Other areas	Sensitive areas
Sulphur dioxide (SO_2)	Annual Average	80	60	15
	24 hours	120	80	30
Oxides of Nitrogen (NO_x)	Annual Average	80	60	15
	24 hours	120	80	30
Suspended Particulate Matter (SPM)	Annual Average	360	140	70
	24 hours	500	200	100
Respirable Particulate Matter (size less than 10 μm) (RPM)	Annual Average	120	60	50
	24 hours	150	100	75
Lead (Pb)	Annual Average	.0	0.75	0.50
	24 hours	1.5	1.00	0.75
Carbon Monoxide (CO)	8 hours	5.0	2	1.0
	1 hours	10.0	4.0	2.0

- Annual Arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval.
- 24 hourly/8 hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days.

WATER POLLUTION

Water pollution is defined as any chemical or physical change in water detrimental to living organisms. Water bodies are major recipient of variety of wastes produced by man. These may be discharged directly into watercourses by sewers or from industries or from agricultural or urban areas particularly after heavy rains (Table 2.5). The sources of pollution may be domestic, agricultural or industrial. The level of pollution tends to rise with the increasing human population. Hence the effectiveness of treating wastes prior to their release into the environment determines the balance between potential and actual pollution.

Table 2.5: Major types of pollutants and their sources.

Pollutant	Sources
Oxygen demanding wastes	Domestic wastewater, agricultural runoff, wastewater from food processing, paper mills, animal wastewater etc.
Plant nutrients	Domestic wastewater, agricultural runoff, low quality detergents etc.
Heavy metals	Mining activities, fly ash, petroleum oil spills
Oil	Drilling operations, petroleum oil spills
Pesticides	Applications on land, agricultural runoff
Radiation	From natural sources, nuclear power based stations, nuclear weapons based testing etc
Heat	Power plants
Acids	Acid rain, drainage from mine spoils

1. Major Pollutants

I. Organic Oxygen Demanding Wastes

The releases of large quantities of oxygen demanding organic wastes i.e. sewage effluent into watercourses have serious "effect on the flora and fauna. Some of the industries such as textile mills, brewing, food processing, paper, etc discharge the untreated wastes into flowing rivers, lakes or offshore directly into the sea. This provides a rich substrate for bacteria which can multiply thereby depleting the dissolved oxygen in the water. This increases the biological oxygen demand thereby depleting the available oxygen and cause death of aquatic fauna. Oxygen depletion sets-in anaerobic condition giving way to anaerobic bacteria which produce toxic products such as hydrogen sulphide and ammonia. When dissolved oxygen content of river water is measured downstream from the point of effluent discharge, a characteristic curve known as the 'oxygen sag curve' is produced (Fig. 2.5).

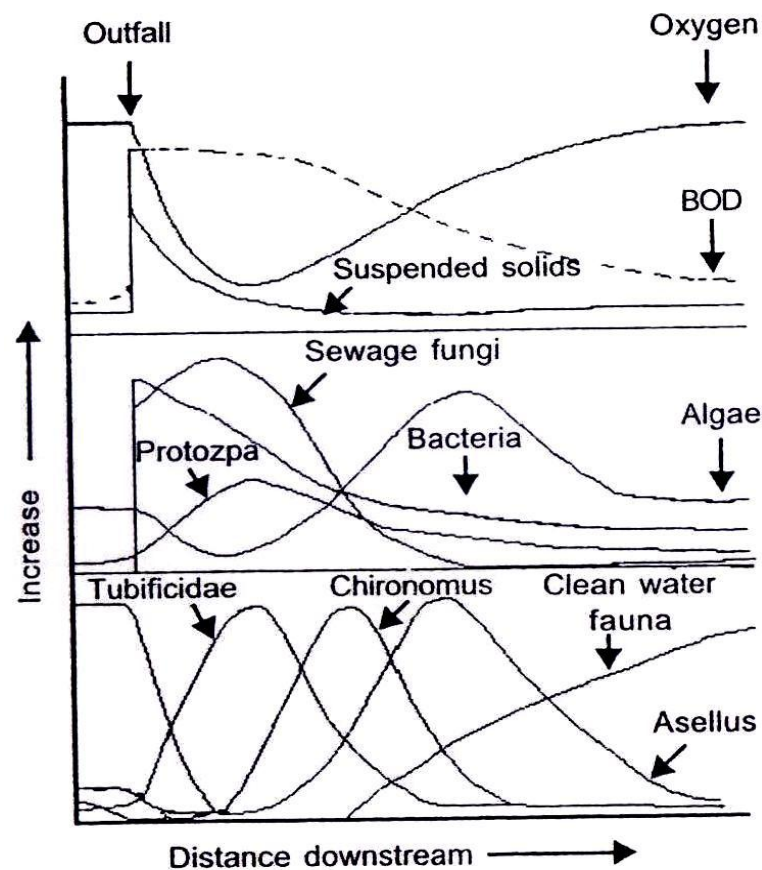


Figure 2.5: Changes in water quality and the population of organisms in a river below a discharge of an organic effluent.

This shows clearly that the input of organic waste severely depresses the amount of dissolved oxygen available. It also increases the turbidity of water, thus reducing the amount of light available for photosynthesis. At the point of sewage discharge, bacteria and predatory protozoan's proliferate. Due to gradual depletion of oxygen, tubificid worm which tolerate extremely low oxygen concentrations are able to thrive and fishes are unable to survive. Down the stream, the colonies of sewage fungi disappear and algae, followed by higher plants, will reestablish themselves. The tubificid worms are replaced by *Chironomus* larvae which in turn are replaced by *Asellus*.

Fishes may gradually reappear as the dissolved oxygen increases and the amount of organic sediment decreases. Other flora and fauna of clean water will reestablish themselves as the oxygen level increases. This process of decomposition of organic effluent by bacteria and eventual recovery of the river is known as self purification. This process depends on a number of parameters. The rate of water-flow is slower and

the volume of water carried is less leading to an increased concentration of organic pollutants. Higher water temperatures decrease the solubility of oxygen and favor bacterial growth, thus accelerating the problem of oxygen depletion.

II. Plant Nutrients and Eutrophication

The availability of inorganic plant nutrients are directly linked to the primary productivity in aquatic ecosystem. In freshwater lakes and rivers the limiting element is normally phosphorus whereas in marine waters nitrogen is often the limiting element. In water bodies, enrichment of nutrients through excess input leads to pollution. The process of nutrient enrichment in water bodies is known as eutrophication. Anthropogenic phosphate in the environment is largely due to domestic sewage effluent and also from agricultural activities and through detergents. The largest source of nitrate comes from the use of nitrogen containing fertilizers. Nutrient pollution stimulates excessive growth of surface algae forming algal blooms comprising of blue-green algae (Fig. 2.6). A large quantity of dead organic matter from submerged phytoplankton stimulates bacterial growth and causes oxygen depletion.

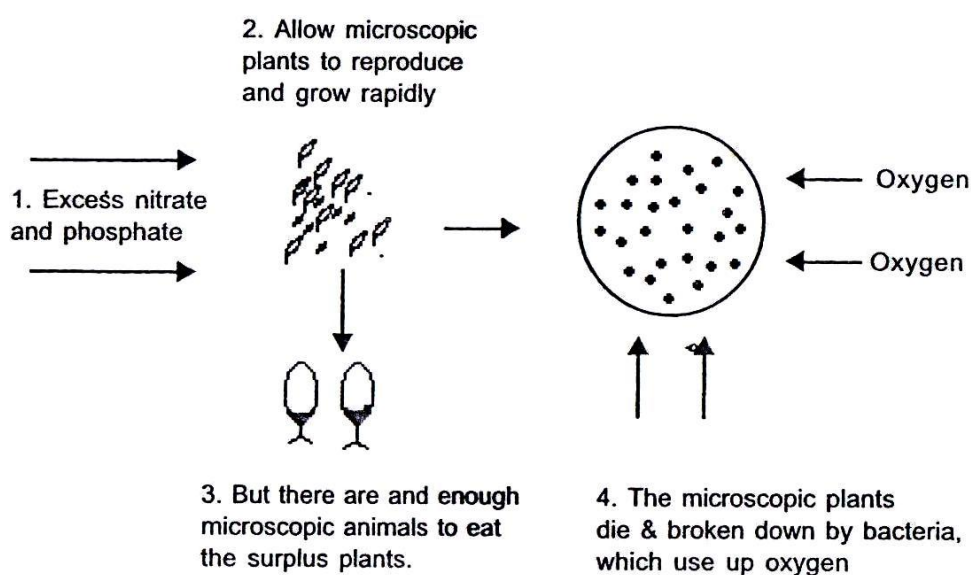


Figure 2.6: Effects of eutrophication.

III. Acidification

Acidification of water bodies is generally the result of acid rain and acid mine drainage. Acid rain is generated through sulphur dioxide and the oxides of nitrogen (NO_x) and their oxidation products. Sulphurous acid, sulphuric acid and nitric acid through wet deposition results in acid rain. Sulphur oxides are usually the main pollutants produced

through industrial activities and coal burning. Oxides of nitrogen originate from power stations and from vehicle emissions. Acidifications of water bodies cause an increase in the aqueous concentration of toxic metal ions e.g. Aluminium, mercury etc. cause toxicity to aquatic fauna. The acid effluents from mines contribute to acid pollution. This causes dissolution of toxic metals. This results in the depletion of fauna and characteristically dominated by chironomid larvae.

IV. Toxic Metals

Toxic metals originate from a variety of anthropogenic sources and from industries. They are mercury, lead, cadmium, zinc, tin and copper (Fig. 2.7). Certain chemical form of metals can be taken up by aquatic organisms directly and become concentrated in each level of food chain which is called as bio magnification. Mercury as such is not very toxic; however, methyl-mercury which is caused as a result of bacterial action is readily soluble in water and toxic when absorbed by fish. Food chain may lead to their accumulation in human beings. Methyl-mercury could disrupt the blood-brain barrier, acting as a neurotoxin and causes severe behavioral disturbances in affected individuals.

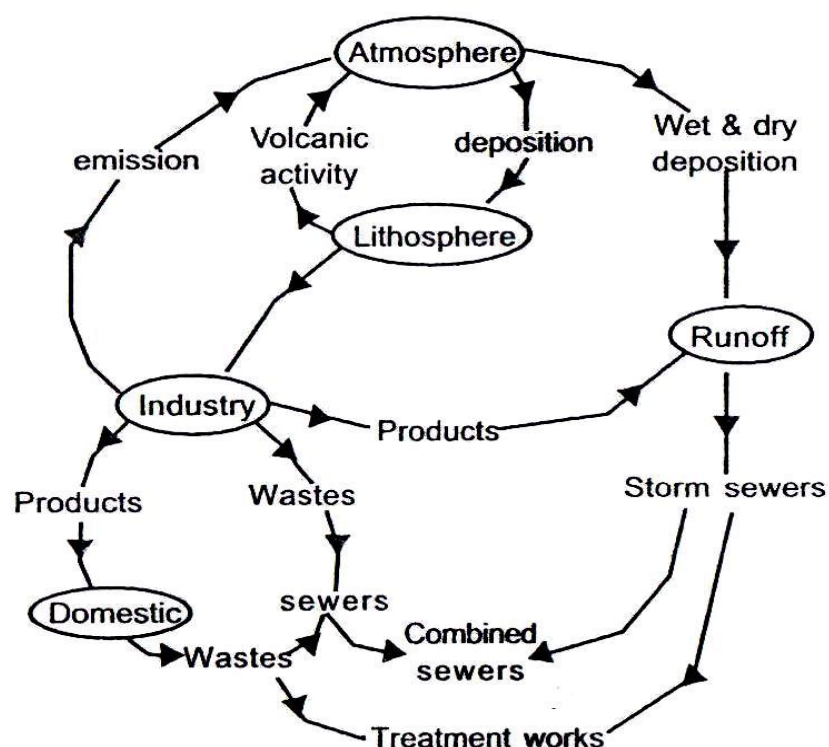


Figure 2.7: Sources and pathways of heavy metals entering waste water treatment processes.

The source for lead is through tetra alkyl lead compounds in petrol used as fuel. This accounts for nearly 75 % of the lead in the atmosphere. Water bodies may become polluted from industries through their effluents. The risk to human beings is generally cumulative effect which builds up in the body over time. In children, it can cause hyperactivity, a lowered IQ and even brain damage.

V. Oil

Crude oil is a complex mixture of several different organic molecules comprising of hydrocarbons such as aromatics, alkanes and cyclohexanes. Enormous amount of oil is produced in the world each year and marine oil pollution is considered as one of the important pollution. Accidents due to tanker operations cause 13 % of the total oil pollution in the marine environment. Other sources of marine oil pollution include municipal and industrial wastes, atmospheric fallout and urban and river runoff. Oil pollution in rivers is mostly due to illegal dumping of used engine oil and surface runoff from contaminated roads. Oil spill causes immediate death of many aquatic organisms. The oil globules on the feathers of marine birds cause them to lose their natural buoyancy and drown or lose their natural insulation and die of exposure.

VI. Organochlorines

Organochlorines are those organic compounds which contain chlorine. Some of the manufactured organochlorines include a number of pesticides, and polychlorinated biphenyls or PCBs. The first organochlorine pesticide, DDT (dichlorodiphenyl-trichloroethane) was cheap to manufacture, persistent in the environment and had unprecedented success against a number of insect borne diseases. Aquatic ecosystems become contaminated by organochlorines from direct application and also from industrial effluents and agricultural run-off. In addition, aerial crop-spraying creates an aerosol which is widely dispersed through the atmosphere and may settle in waters some distance from the target area of application.

Carnivorous birds which are at the top of the food chain are at risk from DDT application as it interferes with their calcium metabolism and results in thin-shelled eggs which are prone to premature breakage. DDT has been detected in human breast milk in a number of studies in various countries. The average concentration of DDT was in excess of the maximum allowable concentration in human foodstuffs (0.74 mg/kg in fat). DDT and many other organochlorines have been banned in many

developing countries. Presently, the focus is on the use of less persistent and more selective insecticides in agriculture.

VII. Polychlorinated Biphenyls (PCBs)

Polychlorinated biphenyls are a family of 209 congeners. Contamination of the aquatic environment by PCBs can originate from sewage effluent, waste incinerators, toxic dumps or landfill sites. PCBs are volatile and can escape into the atmosphere and disperse. They also could contaminate ground water directly, finding their way into rivers and finally the sea. PCBs are also persistent in the environment and they are lipophilic and therefore subject to biomagnification. PCBs accumulating in fish at high concentrations with little adverse effect, whereas the top carnivores are supposed to be at greater risk.

VIII. Radioisotopes

Radioactivity of a radionuclide depends on the length of its half-life, i.e. the amount of time it takes for half of the isotope to decay. The half-life of uranium-238 is 4.5×10 years. More than 80 % of the radiation is known from the naturally occurring radionuclide such as radium present in soils and rocks. The remaining 20% of radiation occur from anthropogenic sources and weapons testing. Contamination of water bodies can occur through nuclear reactors engaged in the production of nuclear energy. Long half-life of some radio-nuclides means that it will be thousands of years before they are considered harmless. At present, disposal of radioactive wastes in deep mines in geologically stable areas is adopted.

Severe environmental contamination by radiation had occurred on several occasions, the best being the dropping of nuclear bombs on Hiroshima and Nagasaki in Japan at the end of the Second World War. The testing of nuclear weapons, accidental leak from nuclear power plants, accidents from nuclear reactors at Chernobyl in Ukraine in 1986 were witnessed in recent years. Most of the radiation damage to body tissues is caused by the ionization of atoms of water and other molecules called as the ionizing radiation. E.g., Iodine-131 concentrate in the human thyroid gland, where it produces tumors; Strontium-90 which is deposited in bones, like calcium has a half-life of 28 years and can cause bone cancer and leukemia by irradiating the bone.

IX. Thermal Pollution

Water is able to absorb large quantities of heat without increasing its own temperature or changing from its liquid state. The principal user of water as coolant is the electricity generating industry. The coolant water required by industry is drawn directly from river or other water bodies. After use, the water now warm is often directly discharged back into the original water body constituting thermal water pollution. Thermal pollution affects aquatic ecosystems changing the species composition as species tolerant to warmer waters replace those unable to adapt. This results in overall decrease in species richness. Eg. Attached algae in heated effluents show an increase in biomass but decrease in the number of species.

Fish can be susceptible to thermal pollution since their body temperature fluctuates with that of the surrounding water. This increase in water temperature causes an increase in the metabolic rate of fish which in turn dependent on more oxygen. However, the amount of dissolved oxygen present in water is inversely related to its temperature and this lead to suffocation in fish adapted to cold water. Thermal pollution can also interfere with natural reproductive cycles in fish causing production of premature hatching of eggs by artificially raised temperatures which may lead to mass mortality of the young ones through starvation. Mass kills of fish and other aquatic organisms can occur when there is a rapid change in water temperature which is known as thermal shock in situations where power plants are operated.

2. Sources Of Pollution

Most of the sources result from runoff and leaks or seepage of pollutants into surface water or groundwater. Pollutants are also transported by air and deposited in water bodies. Some of the sources of water pollution of surface water and groundwater are listed in Table 2.6.

Table 2.6: Sources of water pollution.

Surface water	Ground water
• Urban runoff (oil runoff chemicals, organic matter etc.) • Agricultural runoff (oil, metals, fertilizers, Pesticides etc.) • Radioactive materials • Runoff (solvents, chemicals) from industrial sites • Leakes from surface storage tanks or pipelines (oil etc.) • Sediment from variety of sources including agricultural lands and construction sites • Air fallout (particulates, pesticides, metals) into rivers, lakes and oceans	• Leaks from waste disposal sites (chemicals, radioactive materials) • Leaks from buried tanks and pipes (oil) • Seepage from agricultural activities (nitrates, heavy metals, pesticides, herbicides etc.) • Saltwater intrusion into coastal aquifers • Seepage of acid rich water from mines • Seepage from mine waste piles • Seepage of pesticides, herbicide nutrients from urban areas&Seepage from accidental spills • Inadvertent seepage of solvents and other chemicals including radioactive materials from industrial sites or small enterprises

3. Surface Water Pollution

Pollution of surface waters occurs from point sources or nonpoint sources. Point sources are distinct and from industrial or municipal sites that empty into streams or rivers. Point source pollutants from industries are controlled through on-site treatment or disposal. Nonpoint sources such as runoff are diffused and intermittent and are influenced by factors such as land use, climate, hydrology, topography, vegetation and geology. Urban nonpoint sources include urban runoff from streets or fields (Fig. 2.8). Rural nonpoint sources are associated with agriculture, mining or forestry.

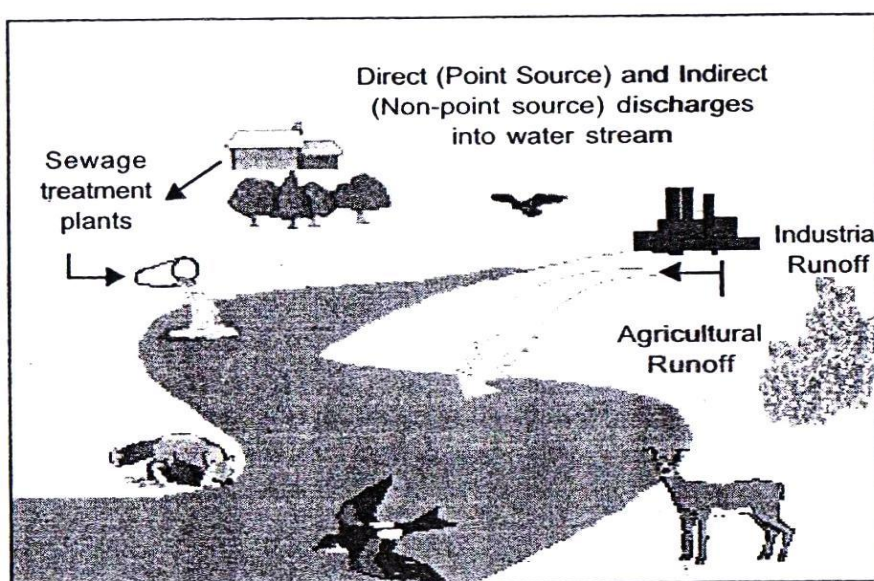


Table 2.8: Point and non point sources of water pollution.

4. Groundwater Pollution

Groundwater pollution differs in several ways from surface water pollution. Groundwater often lacks oxygen and may provide an ideal home for anaerobic microorganisms.

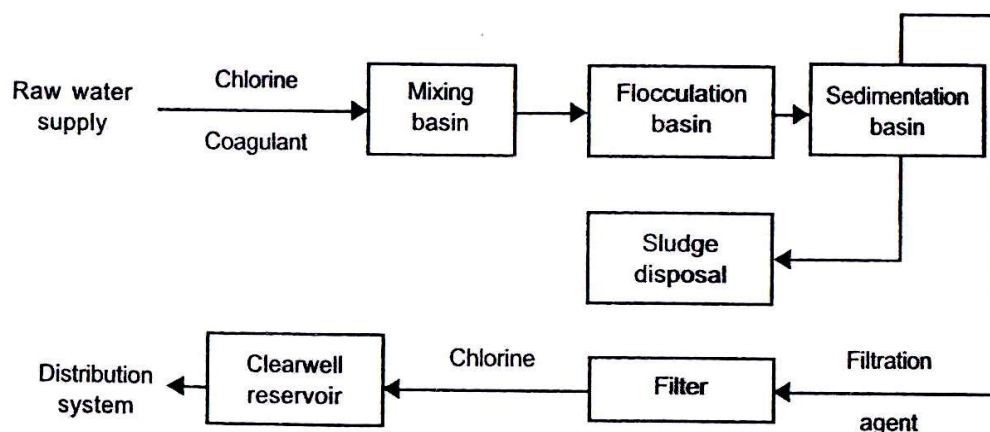


Figure 2.9: Typical unit operations in water treatment.

5. Treatment of Water

The type of treatment required depends on the application of water. Water treatment may include mechanical, physical, biological and chemical methods (Fig. 2.9). There are two filtration alternatives; (i) Slow sand filters which has only sand media, (ii) Rapid filters are sand filters or multimedia filters that have anthracite, sand and if necessary other media in them. The loading rates of rapid filters are much higher than slow sand filters. Slow filters treat water at a rate of about $0.1 \text{ m}^3 \text{ m}^{-2} \text{ h}^{-1}$ (approximately 0.029 mm s^{-1}) and rely to a great extent on the formation of a surface biological layer for their cleansing action. In rapid filters the rate of treatment is typically in the range of $5\text{-}6 \text{ m}^3 \text{ m}^{-2} \text{ h}^{-1}$ and the full depth contributes to purification and consequently requires frequent cleaning. Rapid filters are cleaned by backwashing and pumping at a rate sufficient to expand the media. Sometimes, the two systems are combined, a rapid filter being used as a 'roughing' filter to supplement a slow sand plant.

A typical slow sand filter unit is composed of 0.15 - 3.0 mm effective size sand and a uniformity coefficient < 3 , with a bed thickness in the range 0.6 - 1 m (Fig. 2.10). The sand bed is unstratified and is supported on a graded gravel layer; to prevent the ingress of sand into the underdrain system. The underdrain is designed to convey the

filtrate to a central collector channel or collector channel. Rapid filters are most frequently used in water treatment following pretreatment by chemical coagulation and clarification. Rapid filters contain about 0.6 - 1 m of sand overlying an under drain system. The depth of water overlying the sand surface in rapid gravity filters is generally not less than 1.0 m.

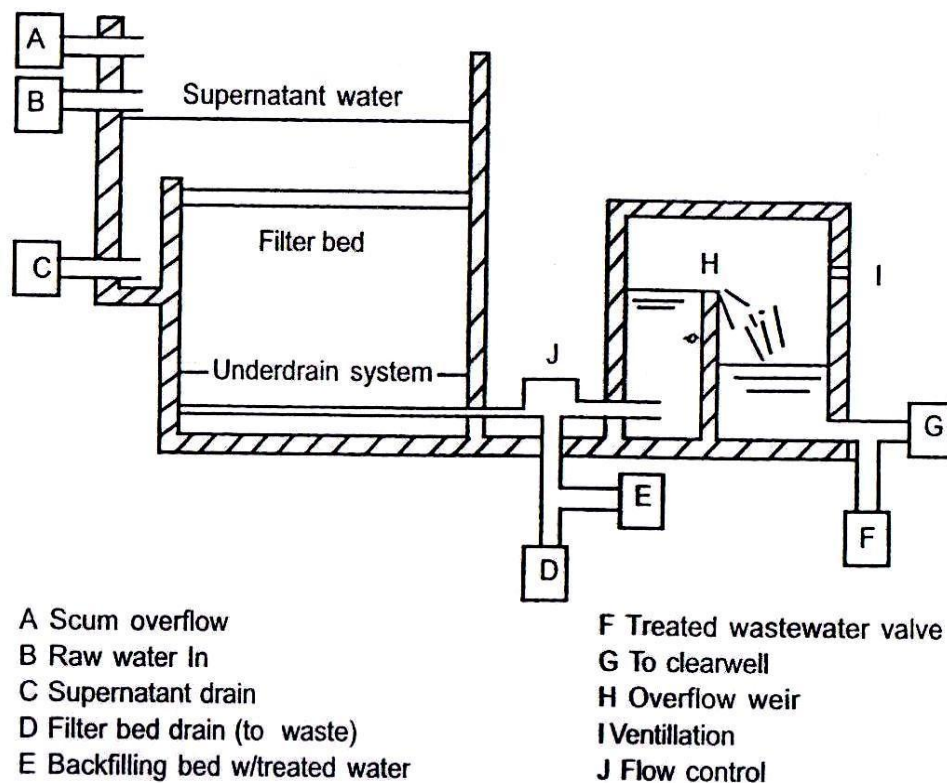


Figure 2.10: Typical cross section of slow sand filter.

The most commonly used system consist of a set of perforated pipe laterals surrounded by graded silica gravel layers having a four layer under drain system with the grain size ranging from 2 mm in the uppermost layer to 50 mm in the bottom layer. The main function of the gravel layers is to distribute the backwash up flow evenly over the bed area and prevent the penetration of the sand into the pipe lateral system. If air is used for filter cleaning, a air manifold and lateral system is provided. Table 2.7 shows the standards for drinking water as per BIS specifications.

6. Wastewater

The water used for municipal and industrial purposes is often degraded by the addition of suspended solids, salts, nutrients, bacteria and oxygen demanding matter.

I. Production of Municipal Wastewater

The wastewater from toilets, kitchen, bath, laundry and floor drain are collected in a public sewerage system and channeled to treatment facilities for safe disposal. The quantities of municipal wastewater are between 70 to 90 % which reach the sewers. The water consumed is a function of the population and in cities in India the per capita water consumption is around 140 liters PE per day.

Table 2.7: Environmental Standards for drinking water quality.

Sl. No.	Substance or Characteristics	Requirement/ Desirable limits
1	Color, Hazen units, Max.	10
2	Odor	Unobjectionable
3	Taste	Agreeable
4	Turbidity, NTU, Max.	10
5	pH value	6.5 to 8.5
6	Total Hardness (as CaCO_3) mg/l	300
7	Calcium (as Ca) mg/l, Max.	75
8	Magnesium (as Mg) mg/l, Max.	30
9	Copper (as Cu) mg/l, Max.	0.05
10	Iron (as Fe) mg/l, Max.	0.3
11	Manganese (as Mn) mg/l, Max.	0.1
12	Chlorides (as Cl) mg/l, Max.	250
13	Sulphate (as SO_4) mg/l, Max.	150
14	Nitrate (as NO_3) mg/l, Max.	45
15	Fluoride (as F) mg/l, Max.	0.6 – 1.2
16	Phenolics (as $\text{C}_6\text{H}_5\text{OH}$) mg/l, Max.	0.001
17	Mercury (as Hg) mg/l, Max.	0.001
18	Cadmium (as Cd) mg/l, Max.	0.01
19	Selenium (as Se) mg/l, Max.	0.01
20	Arsenic (as As) mg/l, Max.	0.05
21	Cyanide (as CN) mg/l, Max.	0.05
22	Lead (as Pb) mg/l, Max.	0.1
23	Zinc (as Zn) mg/l, Max.	5.0
24	Anionic Detergents (as MBAS) mg/l, Max.	0.2
25	Chromium (as Cr^{6+}) mg/l, Max.	0.05
26	Polynuclear aromatic hydrocarbons (as PAH) mg/l, Max.	-

II. Constituents of Sewage

Municipal wastewater consists of 99.9 percent water and a variety of different constituents for the other 0.01 percent (Fig. 2.11). The primary components of concern are biochemical oxygen demand (BOD), chemical oxygen demand, total dissolved solids, suspended solids, nitrogen and phosphorus.

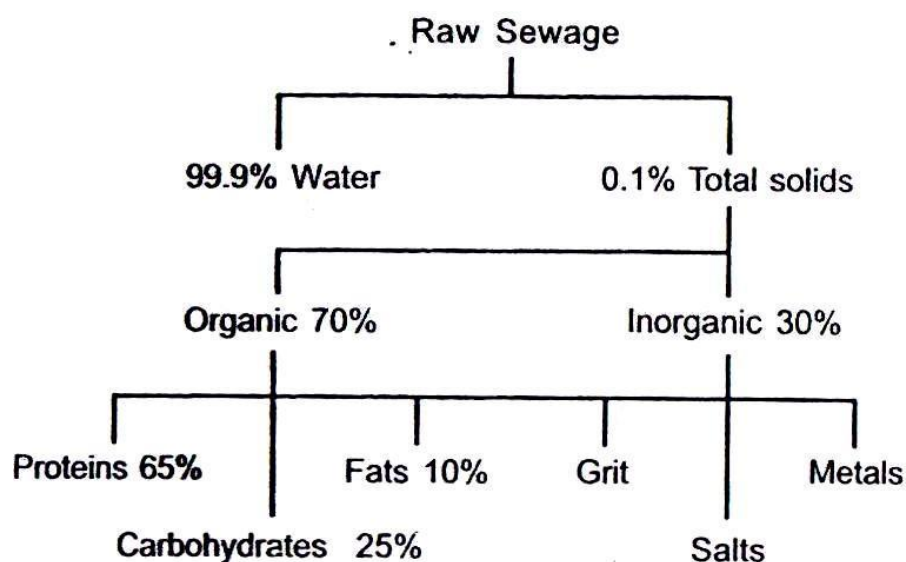


Figure 2.11: Composition of typical raw sewage.

Sewage provides an ideal environment for variety of microorganisms, mainly bacteria, fungi, viruses and protozoa to thrive. Most of these microorganisms are harmless; however, some pathogens carried through the excreta of people with infectious diseases can also be present. A variety of water borne bacterial diseases is known to occur such as cholera, typhoid and tuberculosis, viral diseases such as infectious hepatitis and protozoan caused dysentery. Standard tests could be performed for the detection of these organisms.

i. Solids

Total solids can be distinguished as dissolved solids and undissolved solids and this may be organic and inorganic in nature. Suspended solids and volatile suspended solids are of importance as an indicator of microbial population.

Organic Matter: This generally consists of proteins and carbohydrates constituting 90 % of organic matter in the municipal sewage. The main sources for these biodegradable contaminants are the excreta and urine from humans, food wastes, dirt from bathing, soaps, detergents and laundering. One of the parameters used as a measure of the organic strength of wastewater is the organic carbon which is generally realized when the organic carbon in the sample is oxidized by a strong oxidizer and comparing it with the amount in a standard of known total organic carbon. The other methods used are based on the amount of oxygen required to convert the oxidizable material to stable end products. They are COD and BOD. The

chemical oxygen demand of wastewater is measured as the amount of oxygen needed to chemically oxidize the organic present and the biochemical oxygen demand is measured as the amount of oxygen required by acclimated microorganisms to biologically degrade the organic matter in the wastewater.

Measurement of BOD: The amount of organic matter in water or wastewater can be measured directly as TOC or indirectly by measuring the amount of oxygen used by the growing microbial population to convert organic matter to CO₂ and H₂O in a closed system. The oxygen consumed or BOD is proportional to the organic matter converted and therefore BOD is a relative measure of the biologically degradable organic matter present in the system. For determination of BOD, a known quantity of wastewater is diluted to 300ml in a BOD bottle and the DO is determined. The diluted wastewater is incubated at 20°C for 5 days and at the end of 5 days, the DO is determined again. The BOD of the wastewater can be determined by the following formula.

BOD of wastewater = Depletion in DO x Dilution factor

Depletion in DO = DO before incubation - DO after incubation

$$\text{Dilution Factor} = \frac{\text{Volume of Sample}}{\text{Volume of BOD bottle}}$$

The value of BOD of the wastewater is an essential parameter for designing the treatment units. Similarly, chemical oxygen demand (COD) of wastewater is determined with the use of a strong oxidizing agent such as potassium dichromate under acidic conditions. COD of the wastewater is generally higher than its BOD because, more organic compounds can be chemically oxidized than by biochemical means. Inorganic Constituents: The common inorganic constituents of wastewater include the chlorides and sulfates, nitrogen, phosphorus, carbonates and bicarbonates and toxic substances such as heavy metals.

7. Industrial Wastewater

The wastewater from industries include the toilet wastes, process wastes from manufacturing, wash waters and water from heating and cooling operations. In contrast to consistent characteristics of the domestic sewage, industrial wastewaters often have quite different characteristics. Wastes are specific for each industry and can have high BOD through wastes which may be inorganic and toxic in nature.

I. Effluent Requirements

The primary objective of wastewater treatment is to remove or modify those contaminants that are detrimental to human health or the water, land and air environment.

II. Treatment Processes

The suspended, colloidal and dissolved contaminants in the wastewater may be removed physically, converted biologically or changed chemically. The typical scheme for the treatment of domestic wastewater and industrial wastewater is shown in Figure 2.12 and 2.13. The contaminants are generally removed from wastewater. This includes rags, sticks and miscellaneous objects which are retained on coarse screens. Most of the small solids are still in suspension and the settle able portion of these can be removed and concentrated in the primary gravity settling tanks. The concentrated solids, called raw sludge, are pumped to an anaerobic digester for biological decomposition and the clarified primary tank effluent flows to the secondary treatment units. These consist of.

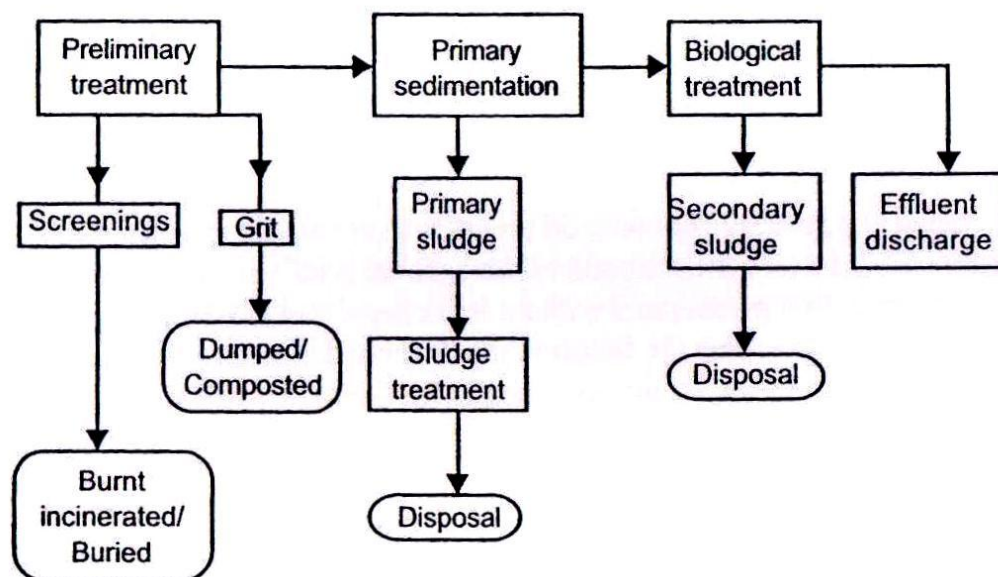


Figure 2.12: Flow diagram of conventional sewage treatment.

- a. A biological oxidation where the dissolved and colloidal matter in the wastewater provides food for microorganisms, which convert the organics to CO_2 and H_2O . The secondary biological unit operations remove BOD beyond what is achieved by sedimentation. These operations include activated sludge, trickling filters, lagoons etc. which aid in the breakdown of organics and

- b. A final gravity settling tank where the microorganisms are settled out. The last stage in treatment of wastewater is disinfection of the plant effluent before discharge to the receiving water body. Many of the processes used in water treatment are also used in wastewater treatment, but modified for the removal of greater amounts of pollutants.

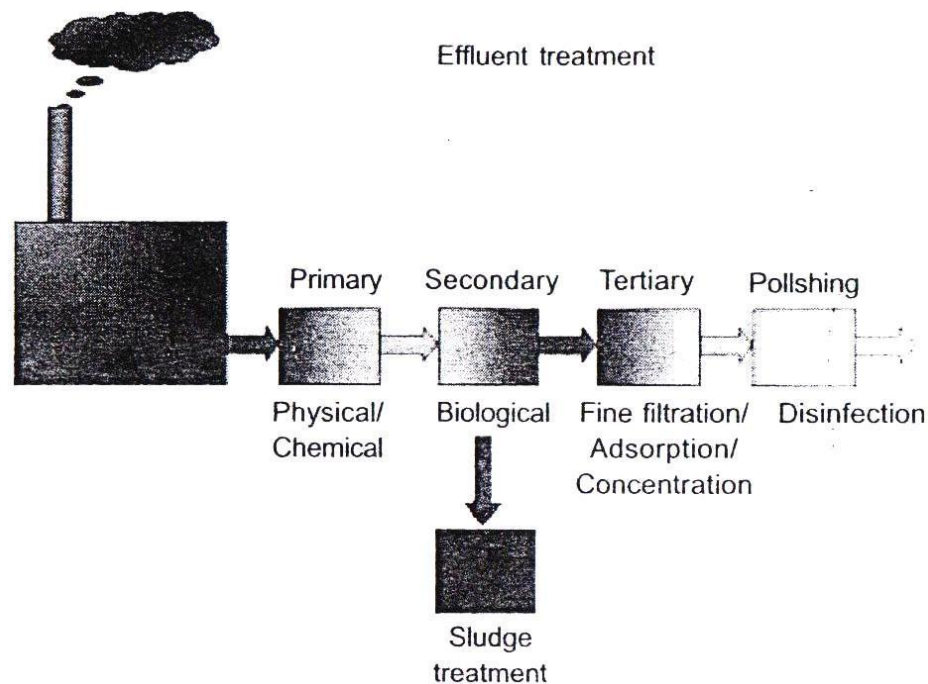


Figure 2.13: Industrial waste water treatment scheme.

III. Physical and Chemical Treatment Processes

i. Gravity Settling

Gravity settling is the most common physical process for removing suspended solids from wastewater. During this process, the removal of grit, clarification of raw sewage and concentration of settled solids, clarification of biological suspension, and concentration of settled floc and gravity thickening of primary or secondary sludge's will take place.

ii. Screening

Screening is the first operation to be performed in water and wastewater treatment plants for the removal of larger floating matter such as rags, wood pieces etc. The objective of screening is the protection of mechanical equipments such as pumps from damage due to large floating and suspended matter. Bar racks or screens of inclined disk or drum type are used. The spacing between the bars may be coarse, with 50-150 mm, medium with 20-50 mm or fine screens with 10 mm or less.

iii. Sedimentation

Sedimentation is the separation of water by gravitational settling of suspended and colloidal particles denser than water in water treatment and in almost all wastewater treatment plants. Sedimentation is used for grit removal, particular matter removal in the primary settling basin, biological floc removal in the activated sludge basin and chemical floc removal when the chemical coagulation process is used. Sedimentation tanks are made either in circular or rectangular shapes. There are four general types of classes of particle settling based on the concentration of the particles to interact. They are.

- a. Type I sedimentation (Discrete settling): Discrete settling requires the lowest suspended solids concentration. In discrete settling, individual particles settle independently and do not interfere with the settling of other particles present. This increases the average particle mass causing particle to sink faster.
- b. Type II sedimentation (Flocculent settling): Flocculation settling is used in primary clarifiers and the upper zones of secondary clarifiers.
- c. Type III sedimentation (Zone settling): In hindered or zone settling, particle concentration is sufficient enough so that particle interfere with the secondary clarifiers.

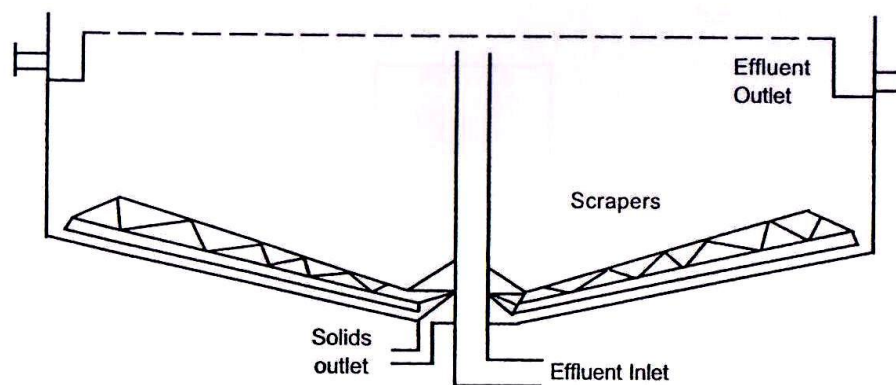


Figure 2.14: A schematic view of rectangular sedimentation tank.

- d. Type IV sedimentation (Compression settling): In compression settling, highest concentrations of suspended solids are involved and it occurs in the lower reaches of clarifiers. The particles settle by compressing the mass of the particles below, Compression occurs not only in the lower zone of secondary clarifiers but also in sludge thickening tanks.

Circular tanks fitted with rotary bridge scrapers are commonly used in wastewater treatment systems. The scraper blades move the sludge towards a central hopper, from which it is withdrawn. Tanks up to 60 m in diameter with a floor slope of about 1:10 are constructed. Rectangular tanks are also used for sedimentation, but generally for primary sedimentation in large treatment works (Fig. 2.14). The primary sludge is withdrawn continuously from sedimentation tanks so as to avoid septicity and generation of biogas which reduces the effective density of the settled solids.

iv. Grit Chamber

Grit chambers are also sedimentation basins in wastewater treatment plants to remove sand, egg shells, and other nonputrescible materials that clog channels or damage to pumps. Grit is generally sand, gravel, other nonputrescible matter with a diameter of 0.15 to 0.20 mm or more.

v. Aeration

Aeration is an important phenomenon in water treatment in the removal of certain substances that pose a threat to health or cause excessive consumption of chemicals. The application of aeration in wastewater is to supply oxygen to aerobic biological treatment processes. It causes turbulence and mixing besides providing enough oxygen.

Types of aeration systems: Gravity aerators: These systems also called as cascade aerators used in water treatment plant. Water falls down a series of steps, splashing creating a turbulence and water droplets. Spray aerators: These require very large land area to collect water. Diffused aerators: These are submerged aerators which can be used for transferring oxygen in biological treatment systems and for air stripping volatile organic compounds from contaminated waters. Different methods of aeration are being followed. They are,

- Diffused aeration where air bubbles through water.
- Spray aeration where water is sprayed through air.
- Multiple tray aeration where water flows through several trays to mix with air.
- Cascade aeration where water flows downwards over many steps in the form of thin waterfalls.

- Air stripping, where a combination of multiple tray and cascade technique plus random packed blocks cause water to mix thoroughly with air.

vi. Flotation

Flotation is an operation that removes not only oil and grease but also suspended solids. One of the most effective systems for suspensions which contain oil and grease is the use of dissolved air flotation (DAF) in which the waste stream is first pressurized with air in a closed tank. After passing through a pressure-reduction valve, the wastewater enters the flotation tank where due to the sudden reduction in pressure, minute air bubbles of 50-100 microns are formed. As the bubbles rise to the surface, the suspended solids and oil or grease particles adhere to them and are carried upwards. Figure 2.15 shows a dissolved air flotation system with recycle of treated water.

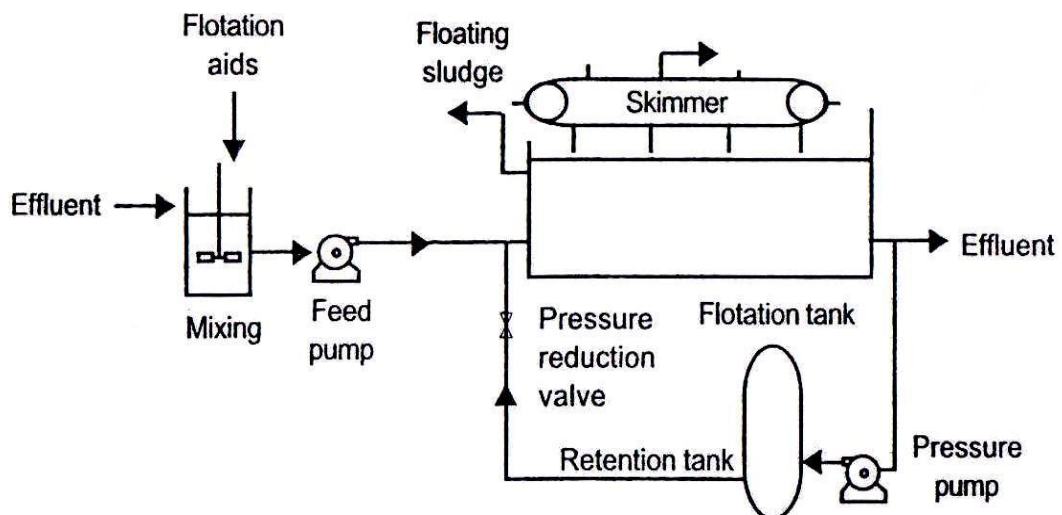


Figure 2.15: A view of DAF system with recycle.

vii. Chlorination

Chlorine is used as an oxidant in water and wastewater treatment and also important for colour removal whenever organic dyes are present.

viii. Ozonation

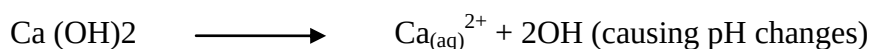
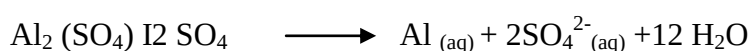
Ozone is a powerful oxidant and used for disinfection and wastewater treatment. Ozone decomposes in water at high pH to produce free radicals.

ix. Neutralization

Many industrial wastes are generally acidic or alkaline and require neutralization before discharge to receiving waters or prior to chemical or biological treatment. Generally, lime stone (CaSO_4) are used for neutralization of acidic wastes apart from caustic soda, magnesium hydroxide, sodium carbonate and sodium bicarbonate whereas for alkaline wastes sulphuric acid and carbon dioxide is used.

x. Coagulation

Coagulation is used in both water and wastewater treatment processes. It is used for the removal of waste materials in suspended or colloidal form. Colloids present in water and wastewater can be hydrophobic or hydrophilic. Hydrophobic colloids do not possess any affinity for liquid medium whereas hydrophilic colloids possess affinity for water. Coagulation and flocculation are used in both water and wastewater treatment processes. The colloidal particles which carry same charges and the phenomenon of repulsion prevent them from combining into larger particulates to settle. Thus, some chemical and physical techniques are applied to help them settle. This phenomenon is called as coagulation. Another method is to use high molecular weight material to attract or trap the particulates and settle down together. Such process is called flocculation. eg., Starch. The most popular coagulant is aluminum sulphate or alum ($\text{Al}_2 (\text{SO}_4)_3 \cdot 12\text{H}_2\text{O}$). Historically, dirty water is cleaned by treating with alum and lime ($\text{Ca} (\text{OH})_2$). These electrolytes cause the pH of the water to change due to the following reactions:



Slightly basic pH of water causes $\text{Al} (\text{OH})_3$ and $\text{Fe} (\text{OH})_3$ to precipitate bringing the small particulates with them and the water becomes clear. Other salts such as iron sulphates ($\text{Fe}_2 (\text{SO}_4)_3$ and FeSO_4 , chromium sulphate ($\text{Cr} (\text{SO}_4)_3$ and some special polymers are also useful. Ions such as sodium, chloride, calcium, magnesium and potassium and pH, temperature and concentration of ions also affect the coagulation process.

xi. Adsorption

Refractory organics which are difficult or impossible to remove by conventional biological treatment processes can be removed by adsorption on an active solid surface, eg., activated carbon. In general, the substances of highest molecular weight are most easily adsorbed. The application of activated charcoal for the removal of undesirable odour and taste in drinking water has been recognized at the dawn of civilization. Bone char and charred vegetation, gravel, and sand were used for the filtration of water for domestic application for thousands of years. Charcoal absorbs many substances, ranging from coloured organic particulates to inorganic metal ions. Charcoal consists of microcrystallites of graphite. The particles are small and amorphous. Particle size, surface area, pore structure, acidity, temperature and the nature of the material to be adsorbed are some of the important factors considered in this process.

xii. Ion-exchange

Ion exchange can be used for the removal of undesirable anions and cations from wastewater. Cations may be exchanged for Na^+ or H^+ and anions are exchanged for OH^- . Synthetic resins such as greensand zeolites (analcite, clinoptolite, montmorillonite etc. are used in water and wastewater treatment. Ion-exchange resins are called cationic if they exchange positive ions and anionic if they exchange negative ions. Some resins can exchange both cations and anions and are called as amphoteric ion exchangers. There are different types of ion-exchange resins such as: Strong-acid cationic resins.

- (i) Weak acid cation resins
- (ii) Strong base anion resins
- (iii) Weak base anion resin
- (iv) Heavy metal selective chelating resins.

Depending on bead structure and size, resins may be categorized as gel resins, macroporous resins, isoporous resins and microresins. Gel resins have a homogeneous non-porous structure and imbibe water which results in a swelling of the resin. Porous resins are also similar to gel resins, however pores in the media allow ready access of water into the beads and reduces the resistance to diffusion and increases high rate of ion exchange. Micro resins are in powder form and require separation by a filtration

process. Ions diffuse through the imbibed water and are exchanged for the mobile ions attached to the polystyrene chains. Each type of ion-exchange resin has affinity for counter-ions. For example.

Sulphonic acid resin: $\text{Fe}^{3+} > \text{Al}^{3+} > \text{Ca}^{2+}$

Carboxylic acid resin: $\text{H}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$

Quaternary ammonium resin: $\text{NO}_3^- > \text{CrO}_4^{2-} > \text{Br}^- > \text{Cl}^-$

Polyamine resin: $\text{OH}^- > \text{SO}_4^{2-} > \text{CrO}_4^{2-} > \text{NO}_3^- > \text{PO}_4^{3-} > \text{HCO}_3^- > \text{Br}^- > \text{Cl}^- > \text{F}^-$

The capacity of an ion-exchange medium is measured by the number of charges it can replace per unit volume of medium (eq l^{-1}). The exchange capacity of a given material is determined by measuring the total quantity of ions exchanged, when the exchange reaction is run to completion in a volume containing a known volume of the medium.

xiii. Filtration Processes

A variety of filters are used in water and wastewater treatment processes. They are categorized into two groups: a) Deep bed filters and b) Surface filters. Deep bed filter consists of a permeable granular medium especially silica sand through which water to be filtered flows and within the pores of which particulate material is retained. Hence it is called 'deep-bed'. Surface filters separate particles by a sieving mechanism, usually through a membrane or fabric which permits water flow in response to pressure difference or gradient. The choice of filters depends on the required filtering speed and the cleanness required.

Membrane Filtration: Membrane is an alternative to the conventional potable water treatment processes such as coagulation, sand filtration and disinfection steps. Membrane processes can be classified in two groups on the basis of the nature of driving force employed: (i) Pressure gradient filtration process and (ii) Electrical potential gradient based filtration process. Pressure driven membrane is performed based on the molecular weight or particle size cut-off of the membrane. A classification of different membranes is listed in Table 2.8.

Table 2.8: Classification of different membrane separation processes.

Membrane process	Size cut off range (μm)	Examples of materials separated
Microfiltration (MF)	0.05 – 1.5	Microbial cells, large colloids, small particles
Ultrafiltration (UF)	0.002 – 0.05	Macromolecules, viruses, colloids
Nanofiltration (NF)	0.005 – 0.007	Viruses, humic acids, organic molecules. Ca^{2+} , Mg^{2+}
Reverse osmosis (RO)	0.0001 – 0.003	Aqueous salts, metal ions

Membranes are sold in module or cartridge housings which can be fitted with feed, permeate and concentrate connections. Membrane modules are available as tubular, capillary, hollow fiber, spirally wound sheets (Fig. 2.16) and plate and frame configurations. In general, membrane filters are operated in either 'dead-end' or 'cross-flow' modes (Fig. 2.17). In dead-end mode of operation, the permeate is the only outflow from the module during a filter run and hence the removed particulate and solute species accumulate within the module. Cross-flow filtration operates in a recirculation mode with the feed introduced tangentially to the membrane surface.

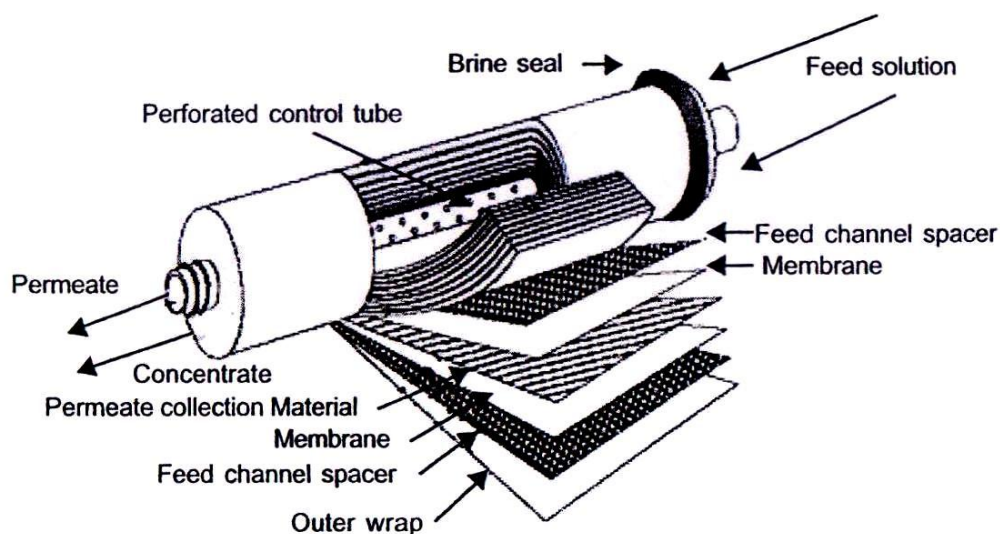


Figure 2.16: Reverse osmosis: Spirally wound membrane unit.

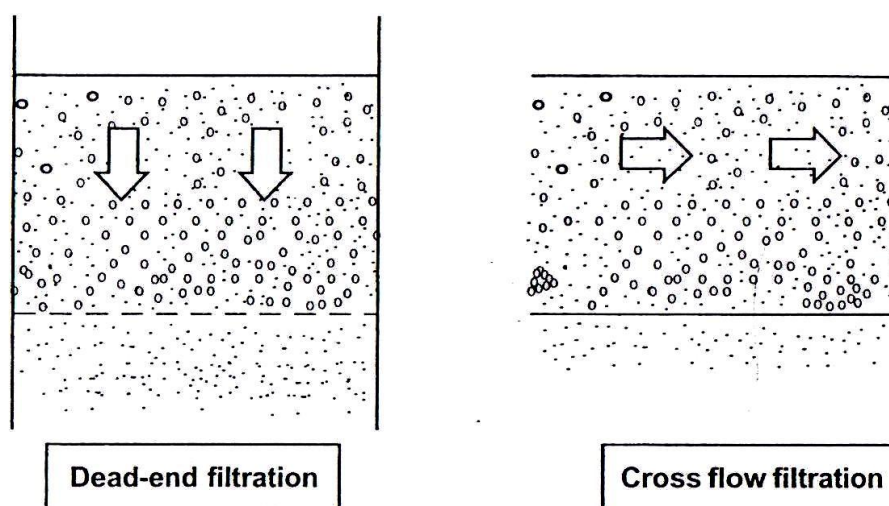


Figure 2.17: Dead end cross flow filtration.

Microfiltration is used to remove turbidity and chlorine resistant pathogens such as *Cryptosporidium* and *Giardia* and also bacteria depending on the cut-off range. They are usually operated at a differential pressure of less than 1 bar and at flux rates up to $150 \text{ L m}^{-2}\text{h}^{-1}$. Ultrafiltration is used in food and process industries as well as in water and wastewater treatment. UF membranes with lower end cut-off can be used to remove viruses, humic substances, including colour from waters.

Nano filtration and RO membranes have lower cut-off limits than UF membranes and are capable of rejecting inorganics as well as organic species. RO membranes can remove the dissolved organics completely and remove most of the inorganic salts. Typical contaminant rejection rates range from 85% to 95%, in some of the highest quality reverse osmosis membranes. A schematic flow diagram showing membrane filtration is shown in Figure 2.18. Feed is normally drawn from a tank, passed through a membrane module where some fluid will pass through the membrane as clean filtrate. The vast majority of the feed fluid, that creates shear across the membrane surface, returns to the feed tank. In this process, a suspension is continuously fed into the retentate tank with a recycle and mixing it into the feed. The liquid in the retentate tank flows through the membrane into the permeate tank and is collected in the permeate tank.

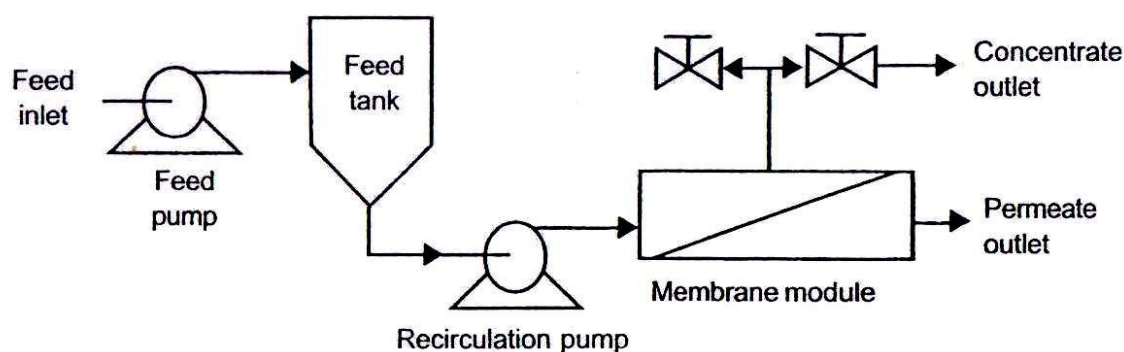


Figure 2.18: Cross flow membrane filtration.

xiv. Electrodialysis

Electrodialysis (ED) is a membrane filtration process in which ionic species are removed under the driving force of an electric field. The water to be treated is pumped through a membrane stack which consists of alternatively placed anion-permeable and cation-permeable membranes. Under the electric field, the anions migrate towards anode and the cations migrate towards the cathode thereby stripping of ions from alternate chambers and their concentration in the remaining chambers.

IV. Disinfection

Disinfection of water or wastewater is to kill or remove pathogenic organisms. Organisms such as viruses, bacteria, protozoa and helminthes could be removed by this process. Three different categories of water and wastewater disinfection processes can be recognized.

(i) Chemical disinfectants, eg. chlorine and ozone, iodine, phenolic compounds and silver nitrate (ii) Physical disinfectants such as heat and high frequency electromagnetic radiation, (iii) Physical separation processes such as centrifugation and membrane filtration.

Traditionally disinfection is done using either chlorine gas or a hypochlorite solution depending on the capacity of the treatment facility. Ozone (O_3) is a powerful oxidizing agent. It is used for disinfection of drinking water and for deodourization of air in wastewater pumping stations and in sludge handling facilities. Ultraviolet rays (254 nm) kill the vegetative and spores of microorganisms. Microorganisms from fluids can be removed by filtration using fine filters.

V. Biological Treatment Processes

The organic constituents in wastewater can serve as food to provide energy for microbial growth. The microorganisms may be aerobic, anaerobic or facultative. The microbial population may be maintained in the liquid as suspended growth, referred as mixed liquor suspended solids or volatile suspended solids (MLSS or MLVSS) or it may be attached to some medium in a fixed-film process. The rate of microbial growth varies directly with the amount of available substrate. In a batch culture when food is not limiting, the microbial population, after an initial lag period, grows rapidly at a logarithmic rate. As food decreases, growth slows and stops and the number of new cells produced is balanced by the number of old cells that are dying. When the substrate is exhausted, the number of microorganisms declines as old cells decompose releasing their nutrients for use by new microorganisms. These four phases are referred to as the lag, log growth, declining growth and endogenous (auto-oxidation) phase.

i. Important Microorganisms and Microbial Processes

The microbiological processes in wastewater treatment are fundamentally similar to other naturally occurring processes. Microorganisms use specific pollutants as source of energy and for the formation of cell mass. The main products of aerobic treatment processes are carbon dioxide, water, biomass and nitrogen compounds such as ammonium and nitrate. Many nutritional types of microorganisms are encountered.

Lithotrophic Organisms: Bacterial species using inorganic compounds eg. ammonium and hydrogen sulphide as their source of energy grow autotrophically with carbon dioxide as a carbon source along with the heterotrophic organisms.

Facultatively Autotrophic and Mixotrophic Organisms: Some species of algae and mixotrophic bacteria are known to occur. Eg. *Beggiatoa*.

Phototrophic Organisms: General algae and cyanobacteria belong to this group. These may be absent inside the filter bed and the activated sludge tank but present on the surface and fix inorganic nutrients into biomass by their autotrophic growth.

Protozoans are also found in large numbers in aerobic treatment process but they will account for a small percentage of the biomass. There are some primary feeders which

are present in the influent. The presence of ciliated protozoans is usually indicative of good treatment. These protozoans occur in the presence of higher amounts of DO and lower amounts of dissolved organic matter. Rotifers and crustaceans may also be present and indicate a healthy treatment process. Yeasts and fungi are not common in wastewater treatment processes. They if present interfere with the settling and make it difficult to separate them from the wastewater. Viruses are present in a biological treatment process but they have no significance in the removal of organic compounds.

The diversity of microorganisms ensures a complex ecosystem in the secondary and tertiary treatment processes. Bacteria represent the most abundant form of microorganisms in wastewater treatment processes to the extent of 10^{12} /L. In the primary treatment, a total of 30 - 40 % BOD is removed by heterotrophic bacteria. During the secondary treatment, due to the contribution of bacterial species 85 - 90 % of BOD will be removed. *Zoogloea* spp. which secretes a polysaccharide with mucus like consistency brings about both attachment of the bacteria to the surface of the bed and adhesion of other fungi, algae, insect larvae and nematodes. The degradation of organic nutrients increases their population. Settling characteristics offices are important in wastewater treatment. Proliferation of specific filamentous bacteria such as *Sphaerotilus*, *Beggiatoa*, etc. and fungi such as *Geolrichum*, *Cephalosporium* cause problems such as "bulking".

Other bacteria such as *Sarcina*, *Pseudomonas*, *Escherichia*, *Aerobacter*, *Vibrio*, *Shigella*, *Salmonella* etc. are also known to occur in wastewater treatment and participate in the removal of carbohydrate, protein and fat.

ii. Activated Sludge Treatment Process

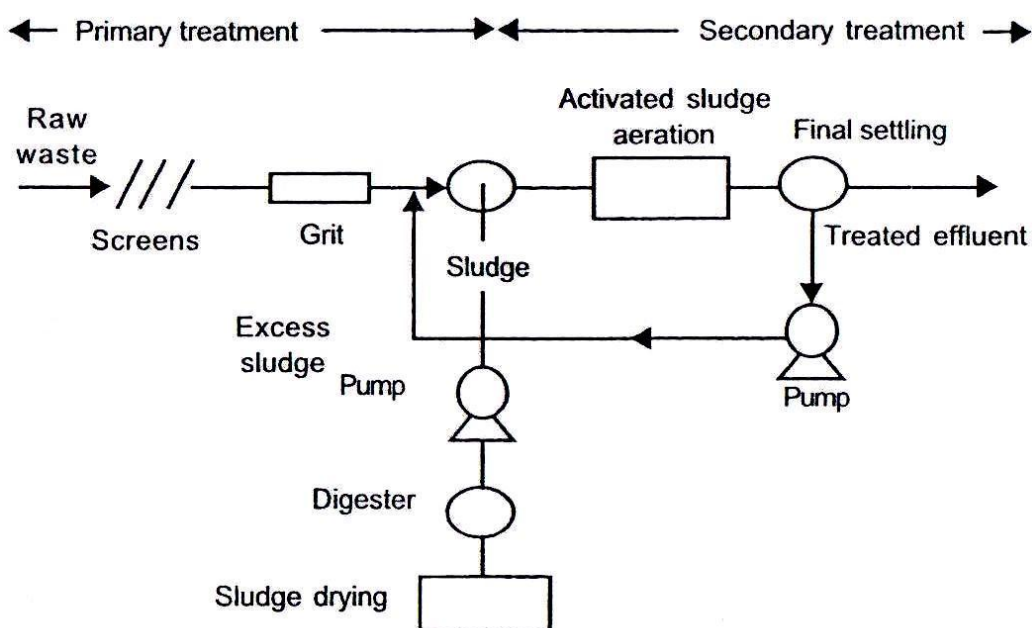


Figure 2.19: A schematic view of activated sludge treatment process.

The term activated sludge refers to the sludge in the aeration tank of an activated sludge treatment process (Fig. 2.19). The process was developed in the early 1900s by Arden and Lockett (1914) and Ardem (1917) as fill and draw reactors. It consists of flocs of bacteria, which consume the biodegradable organic substances in the wastewater. Usually in an activated sludge treatment plant, the wastewater is passed through a bar screen to remove gross materials such as rags, napkins and other materials that may damage the mechanical equipment further down the treatment plant. The bar screen consists of vertical bars and the screened solids are continually scrapped off the bars. The screenings can be landfilled or incinerated. Sand and similar heavier particles are removed next in a grit chamber. This chamber may be aerated to separate these particles from other suspended solids and the wastewater passes through grit chamber in a short period. Finer solids are removed in a settling or sedimentation tank where the wastewater is retained more than an hour to allow the solids to settle or float.

The mechanical removal of solids is called 'primary treatment' from which the overflow from the sedimentation tank is tailed the primary treated wastewater and the sludge as primary sludge. The wastewater passes to an aeration chamber where air supply is provided to the activated sludge and inturn it thoroughly mixes the sludge

and the wastewater. Aeration is usually provided by bubbling through diffusers at the bottom of the aeration tank or by mechanically agitating the surface of the water. In the aeration tank, the bacteria consume the organic substances in the wastewater. The wastewater flows through the aeration tank in few hours before entering the secondary sedimentation tank to separate the activated sludge from the treated wastewater. The activated sludge is returned to the aeration tank. Excess sludge is wasted to maintain a desired amount of sludge in the system. This process is called as 'secondary treatment'. The overflow from the secondary sedimentation tank is called as secondary treated wastewater (secondary effluent) and excess activated sludge as secondary sludge.

This system is widely used, where the microorganisms are kept in suspension for 4 to 8 h in an aeration tank by mechanical mixers or diffused air and their concentration in the tank is maintained by the continuous return of the settled biological floc from a secondary settling tank to the aeration tank. The flocculent suspension which is settled and returned to "reseed" the aeration tank was named as activated sludge by Arden and Lockett (1914). The content of the aeration tank is referred to as mixed liquor and the solids are called mixed liquor suspended solids (MLSS). The determination of living or active proportion is not easy and it is usual to assume that the volatile portion of the solids (MLVSS) which accounts for about 80 % of the MLSS represents the active mass. Of the biological floc that settles in the final tanks (secondary clarifiers), about 25 to 40 % is returned to the aeration tank. The rest, called as waste activated sludge, which must be further treated. In small plants, the waste activated sludge is returned to the primary tanks to settle with the primary sludge whereas in larger plants, the waste activated sludge from the final tanks is thickened by gravity settling or dissolved air flotation before digestion with the primary sludge.

iii. Other Variations in Activated Sludge Process

Extended Aeration Process: This system is similar to that of conventional activated sludge (CAS) but without primary tanks. This system provides 24 h aeration which results in process stability but costly for operation. Detention time in the final tanks is about twice that of a conventional plant.

Contact Stabilization Process: This process also called as biosorption, the biological sludge rather than mixed liquor, undergoes long aeration. The process is suitable for

wastes having a high proportion of organic contaminants in a particular form, since it depends on the adsorption of these particulates by the stabilized sludge during the contact period. Assimilation of the adsorbed organics takes place in the stabilization tank over a 4 h period. Since there are no primary tanks, no primary sludge is produced and stabilization of aerobic waste sludge is carried out by aerobic digestion.

Plug Flow Activated Sludge Process: Plug flow process has long and narrow aeration tanks to provide a mixing regime in order to achieve plug flow. The wastewater is mixed with the biological sludge and the biomass is separated from the liquid stream in the secondary clarifier (Fig. 2.20). A portion of the biological sludge is wasted and the remainder returned to the aeration tank with additional incoming wastewater.

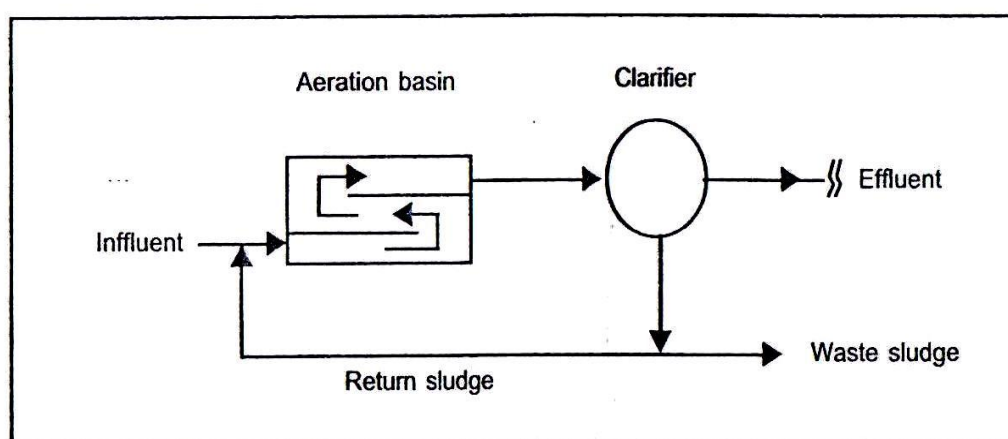


Figure 2.20: A schematic view of plug flow activated sludge process.

Completely Mixed Activated Sludge Process: This is another variant of the activated sludge process in which complete mixing is ensured in the aeration tank with proper tank geometry, feeding arrangement and aeration equipment. Through the use of either diffused or mechanical aeration, a uniform mixed liquor suspended solids (MLSS) concentration is maintained throughout the basin volume. The system is very resistant to shock load. The influent wastewater and recycled sludge are introduced to the aeration basin at different points.

iv. Oxidation Ditch System

A typical system appears like a loop-reactor where the basin geometry and aerator performance is matched to yield adequate channel velocity for mixed liquor solids

conveyance. This is particularly suitable in cases where both BOD and nitrogen removal are required.

v. Pure Oxygen Activated Sludge Process

Pure oxygen activated sludge process is a conventional activated sludge with the supply of pure oxygen to the aeration basin. The aeration basins are covered to minimize the escape of oxygen rich gas above the basin with a limited gas exhaust to remove carbon dioxide produced in the process. Higher DO is maintained in the aeration basin compared to the air fed activated sludge process.

vi. Sequencing Batch Reactor (SBR)

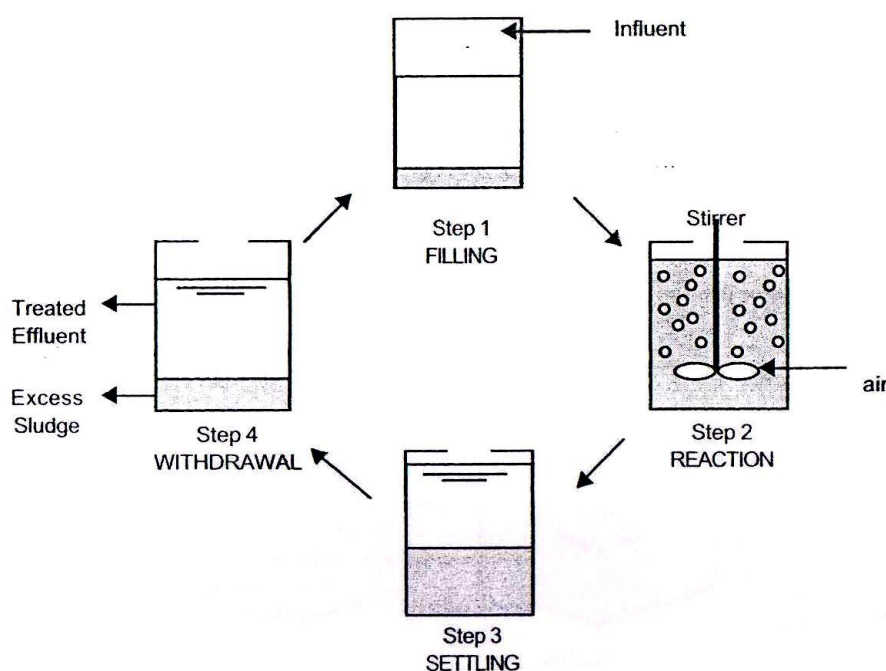


Figure 2.21: A schematic view of SBR cycle.

In sequencing batch reactor, the aeration and clarification are performed sequentially in the same tank. The operation cycle of an SBR process takes place in five steps: fill, react (with mixing and aeration), settle, decant, and idle (Fig. 2.21). Sludge is wasted from the reactor during the decant or idle phases when the settled sludge volume reaches a certain level. Construction and operation cost of SBR is 20 % less than the conventional activated sludge plants. Large fluctuations in hydraulic and organic loading are easily accommodated by varying the reactor volume, dissolved oxygen level and MLSS concentrations. Microbial growth rates are faster and hence faster oxidation of organic matter.

vii. Fixed Film Processes

In this type of process, the wastewater is brought into contact with the microorganisms attached to a solid medium such as rock, plastic or sand. Trickling filters and rotating biological contactors are the common processes.

Trickling Filter: The concept of trickling filter grew from the use of contact filters, which were watertight basins filled with broken stones. The contact bed was filled with wastewater from the top, and the wastewater was allowed to contact the media for a short time. The bed was then drained and allowed to rest before the cycle was repeated. The first used Trickling filter in England in 1893 acted as contact beds where settled sewage was spread by a rotary distributor over circular beds containing inert media with a high void ratio. While passing through the bed, colloidal and soluble organisms in the wastewater are adsorbed and assimilated by a layer of microbial slime on the media surface. Oxygen required for biochemical oxidation is supplied by natural or forced air circulation through the void spaces in the media. When the slime reaches a certain thickness, excess biomass in properly operating units is continuously sloughed off at a constant rate. A typical schematic view of unit operations in trickling filter treatment system is shown in Figure 2.22.

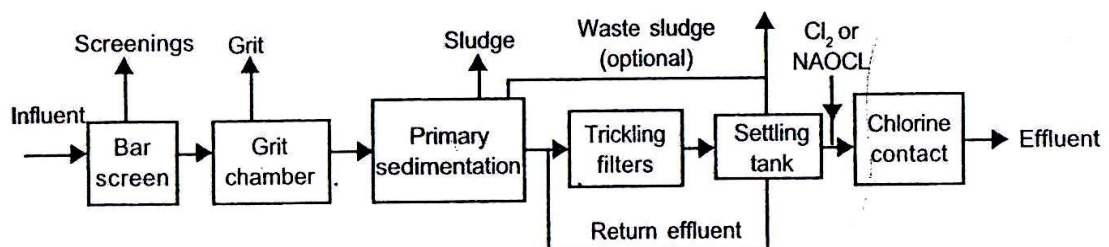


Figure 2.22: A schematic view of unit operations in trickling filter system.

Two common trickling filter configurations are being used; (i) Single stage and (ii) Two stage filters. The recirculated flow will either be filter effluent or clarified effluent from the intermediate and secondary clarifiers (Fig. 2.23). Excess biomass is usually wasted from the primary clarifier, which thickens combined primary and secondary sludge. Two stage filters are usually used for the treatment of high strength wastewater to improve the BOD removal and for nitrification. Early trickling filters were 1.5 to 2.0 m deep and consisted of 50 to 100 mm of stone or wood media however, now filters are constructed as stackable modules of plastic media. In these

types of biological tower trickling filters, plastic beds up to 12 m are used to treat large, high strength wastewaters. Earlier, trickling filters utilized the natural airflow through the filter caused by differences in the temperature and humidity between the ambient air and filter air. Forced ventilation systems with covers over the filter beds ensure adequate oxygen supply and better temperature control and therefore are common on newer designs. Trickling filters are better suited to handle shock due to organic and hydraulic loads, cheaper and simpler to operate and yield fewer biological solids.

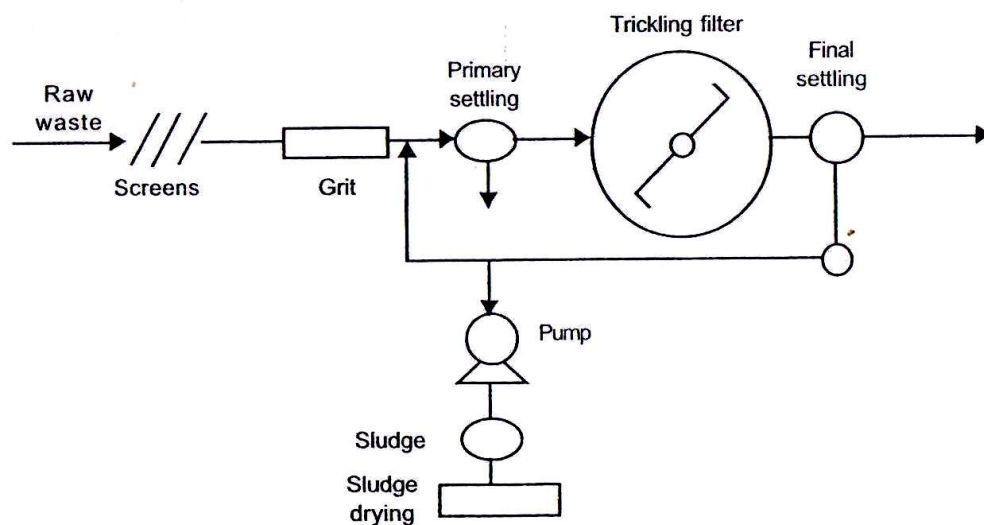


Figure 2.23: A schematic view of unit operations in trickling filter treatment process.

The energy requirement for operating a trickling filter is less than for an activated sludge process because oxygen supply to the bacteria is provided by natural diffusion of air. However, the area requirement is larger than an activated sludge process to achieve the same quality of treated wastewater.

Rotating Biological Contactor (RBC): This was first conceived in 1900 and became popular in Europe in 1960s. A modern RBC unit consists of a series of closely packed, large diameter, high density polyethylene disks on a horizontal shaft, with about 40 % of the media surface area submerged in wastewater in a concrete tank. The shaft is rotated, either mechanically or by air bubbles from an aeration unit, at a speed of 1 to 2 rpm. The biomass film attached to the media surface is alternately in contact with wastewater for adsorption of organic material and with the atmosphere for

oxygen supply. RBCs are also preceded by a primary clarifier and followed by a secondary clarifier which removes sloughed off biomass. Although each stage is completely mixed, the overall flow pattern is plug flow so that the first stage has the highest organic load and oxygen demand. RBCs are simple and stable systems and have the lowest power consumption.

VI. Anaerobic Wastewater Treatment Processes

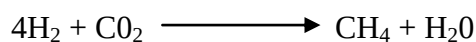
Microbiology and Metabolism of Anaerobic Treatment Process

In this process, the microorganisms do not have access to oxygen or other inorganic electron acceptors such as nitrate which may be used to oxidize organic materials. Instead, they derive energy from the rearrangement of the organic material in which some of the organic carbon is oxidized while the remainder is reduced. Anaerobic treatment processes involve a wide variety of organisms and complex interactions, loenen et al. (1970) suggested three categories of processes and microbial species. They are.

- (i) Hydrolysis:** Hydrolysis is the breakdown of large, complex soluble and insoluble molecules into smaller molecules that can be transported into the cells and metabolized. Extracellular enzymes associated with the primary fermentative microorganism which is responsible for the conversion.
- (ii) Acetogenesis and acid formation:** Hydrogen producing organisms which mainly utilize the products of catabolism of hydrolytic organisms produce acetic acid. Bacteria such as acetogenic bacteria produce a significant amount of hydrogen. Other acid forming bacteria form butyric and propionic acids. The acid formers have an optimal pH between 5-6.
- (iii) Methanogenesis:** The formation of methane is the ultimate product of anaerobic digestion and it occurs via two routes. The primary route is the fermentation of the major product of acid forming phase, acetic acid, to methane and carbon dioxide. The overall reaction is



The most common acetoclastic methanogens are from the genera *Methanosarcina* and *Methanosaeta*. Some methanogens are also able to use hydrogen to reduce carbon dioxide to methane (Hydrogenophilic methanogens).



There is a synergistic relationship between the hydrogen producers and the hydrogen scavengers.

VII. Anaerobic Suspended Growth Processes

Among the processes, the most common anaerobic suspended growth processes used for the treatment of wastewater is the completely mixed anaerobic digestion process.

i. Anaerobic Digestion

Escalating costs and the need for energy conservation have renewed the interest in the anaerobic process. Anaerobic digestion occurs in two phases. In the first stage, hydrolysis (liquefaction) of the organics and their biological conversion to organic acids proceeds rapidly (Fig. 2.24). In the second stage, slow-growing, environmentally sensitive methane bacteria utilize the organic acids to produce gas which has $2/3^{\text{rd}}$ methane and $1/3^{\text{rd}}$ CO_2 and traces of H_2S . Two types of anaerobic digesters are used, (i) The standard rate digestion process where the contents of the digester are usually unheated and unmixed with the detention time of 30 to 60 days, (ii) In high rate digestion process, the contents of the digester are heated and mixed completely with a detention time of 15 days or less. A combination of these two is known as two stage process where the primary function of the second stage is to separate the digested solids from the supernatant liquor and additional digestion and gas production may take place.

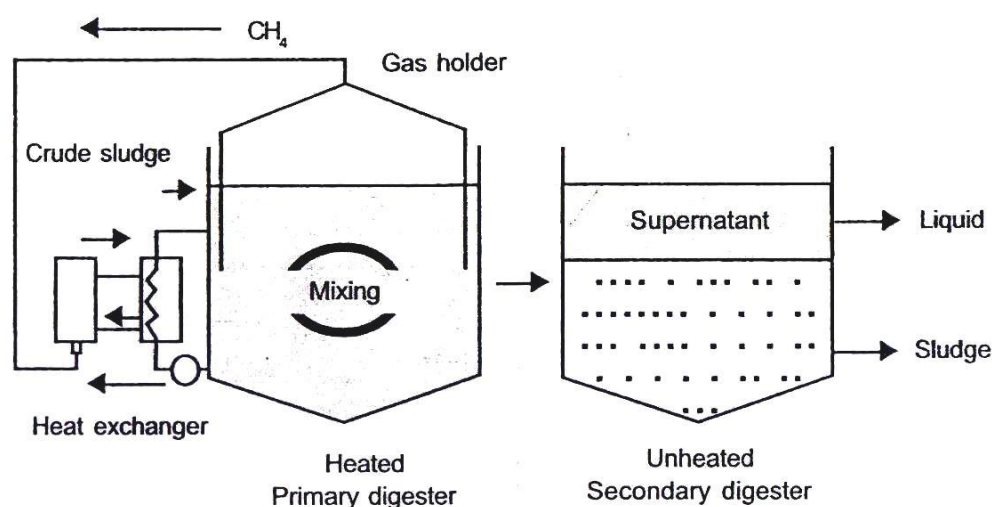


Figure 2.24: Simple anaerobic digester.

ii. Anaerobic Contact Process

In anaerobic contact process, the untreated wastes are mixed with recycled sludge solids and then digested in a reactor sealed off from entry of air. The digester contents are mixed completely and the mixture is separated in a clarifier or vacuum flotation unit and the supernatant is discharged as effluent. The settled anaerobic sludge is then recycled.

iii. Up flow Anaerobic Sludge Blanket Process

The up flow anaerobic sludge blanket (UASB) process is provided with an arrangement for the movement of wastewater upward through a sludge blanket composed of biologically formed granules or particles (Fig. 2.25) Treatment occurs when the wastewater comes in contact with the granules. The methane and carbon dioxide produced cause internal circulation which helps in the formation and maintenance of the biological granules. Some of the gas produced within the sludge blanket becomes attached to the biological granules. The free gas and the particles with the attached gas rise to the top of the reactor. The particles which rise to the surface strike the bottom of the degassing baffles which causes the attached gas bubbles to get released. The free gas and the gas released from granules are collected at the gas collector. The separated solids from the settling chamber fall back through the baffle system to the top of the sludge blanket. The sludge blanket is kept in suspension with an up flow velocity between 2 to 3 ft/h.

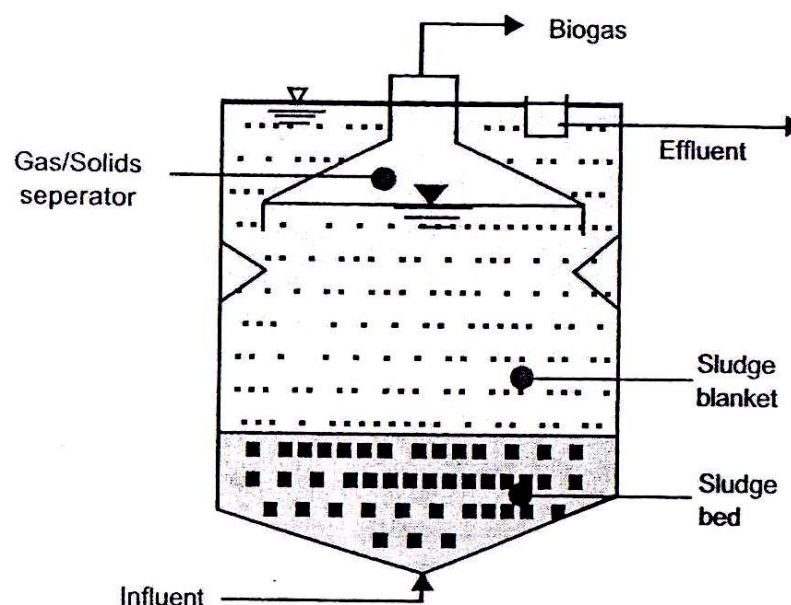


Figure 2.25: A schematic view of the anaerobic sludge blanket process.

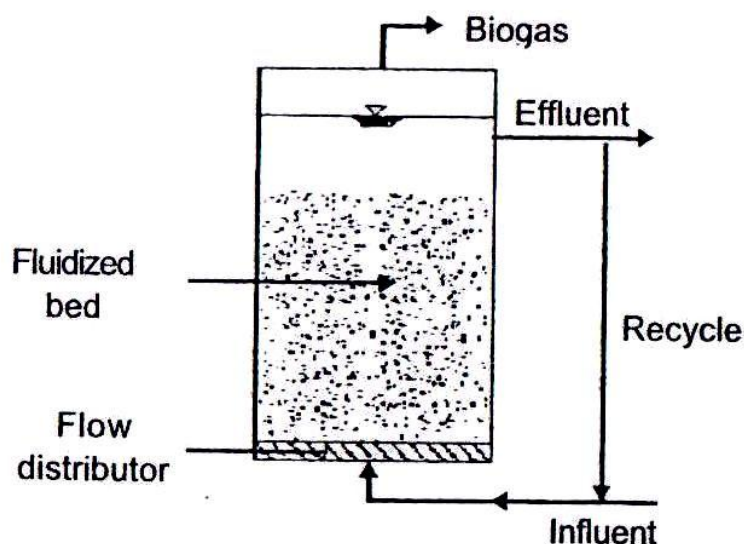


Figure 2.26: A schematic view of the anaerobic fluidized bed process.

iv. Anaerobic Fluidized Bed Process

Fluidized bed reactor is the most recent in anaerobic treatment processes (Fig. 2.26). The bacteria are grown on particles of medium such as sand and the liquid is pumped through the reactor at a high rate thereby suspending the medium particles and obtaining high rates of mass transfer. The fluid shear developed by high liquid velocities limits the growth of bacterial films and thus provides less diffusional resistance to mass transfer of substrate and nutrients than thicker films. The bacterial end products are removed at a faster rate.

VIII. Anaerobic Attached Growth Processes

The most common anaerobic growth processes are the anaerobic filter and the expanded bed process.

i. Anaerobic Filter

This is a column filled with solid media on which biofilm formation takes place (Fig. 2.27). The wastewater flows upward through the column and organic matter is degraded when the waste come in contact with the media. Anaerobic bacteria are retained on the media and this system can be used for low strength wastes.

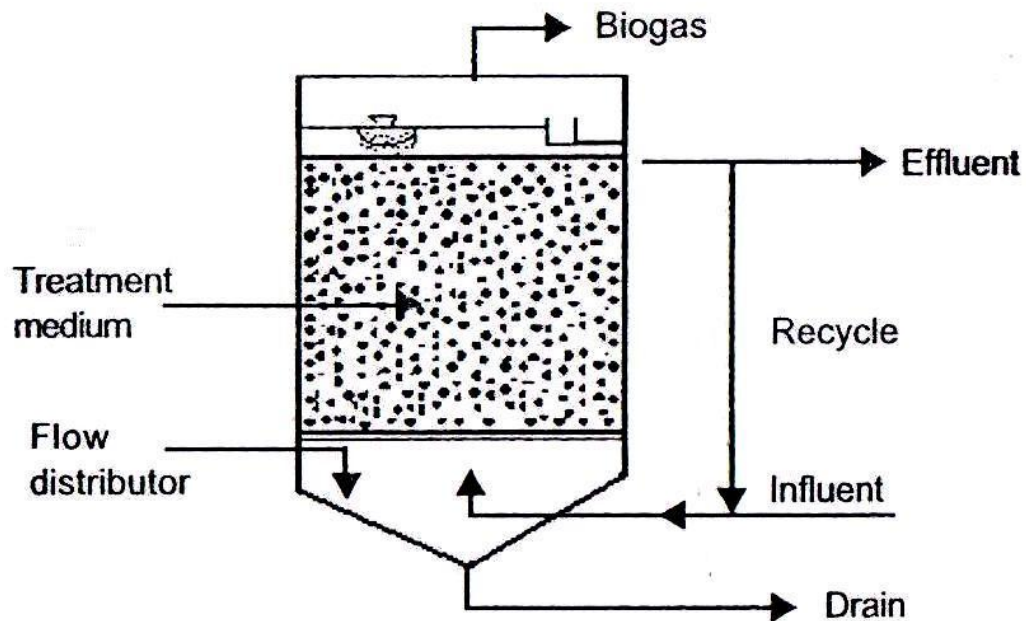


Figure 2.27: A schematic view of the anaerobic filter process.

ii. Expanded Bed Process

In this, the wastewater is pumped upward through a bed of an appropriate medium on which biological growth develops. Effluent is recycled to dilute the incoming waste and to provide an adequate flow to maintain the bed in an expanded condition. Expanded bed can be maintained to have a large biomass and can have very short hydraulic detention times. The quantity of sludge produced in expanded-bed process is considerably less than that produced in aerobic systems like activated sludge process.

Advantages of Anaerobic Technology

- Low production of stabilized sludge (0.04 to 0.14 kg sludge/kg COD removed, as compared to 0.3 to 0.5 kg sludge/kg COD removed in aerobic process).
- Recovery of 80 to 90 % of the energy present in the metabolized waste as methane gas.
- Low consumption of nutrients.
- Lower energy requirements than aerobic treatment.
- High degree of waste stabilization with high organic loading.
- Well acclimated anaerobic reactors can be preserved and unfed for 1 year without any appreciable deterioration in sludge properties.

- Anaerobiosis helps to inactivate pathogenic bacteria as well as some viruses and parasites.

Limitations of Anaerobic Technology

- Sensitivity to specific compounds such as CHCl_3 , CCl_4 , and CN^-
- Due to slow growth rate, the first start-up may take several months.
- High temperature may be necessary to reach high conversion rates.
- Anaerobic digestion is essentially a pretreatment method.
- Anaerobic digestion offers a potential tidal energy saving of about 2.3×10^4 kJ/kg.

IX. Land Based Treatment Methods

Land based wastewater treatment methods need large areas for the storage or treatment of wastewater, for the disposal of effluent when no suitable outlet is available. The hydraulic and organic loading rates are commonly based on land area requirements. A comparative list of advantages and disadvantages of different treatment methods are listed in Table 2.9. The physical, biological and chemical processes are combined. Sedimentation or filtration may remove particulates while the oxidation of organic matter by bacteria and assimilation of nitrogen and phosphorus by plant and microbial growth occur simultaneously. Reduction of pathogens takes place because of natural die-off and the effect of ultraviolet rays in sunlight.

Table 2.9: Advantages and disadvantages of conventional and non conventional waste water treatment technologies.

Type of treatment	Advantages	Disadvantages
Stabilization lagoon	Low capital cost, low operation and maintenance cost, low technical manpower equipment	Requires a large area of land and may produce undesirable odours
Aerated lagoon	Requires relatively little land area and produces few undesirable odours	Requires mechanical devices to aerate the basins, produces effluents with a high suspended solids concentration
Septic tank	Suitable for individual households, easy to operate and maintain and can be built in rural areas	Provides low treatment efficiency, requires periodic disposal of sludge
Constructed wetland	Removes up to 70 % solids	Remains largely experimental,

Filtration system	and bacteria, minimal capital cost, low operation and maintenance requirements Minimal land requirement, can be used at household level, relatively low cost, easy to operate	requires periodic removal of excess plant material, best suited for rural areas Requires mechanical devices
Vertical biological reactors	Highly efficient treatment method, requires little land area, applicable in small communities and to big cities	High cost, complex technology, requires technically skilled manpower for operation and maintenance, high energy requirement
Activated sludge	Highly efficient treatment method, requires little land area, applicable to small communities and to big cities	High cost, requires sludge disposal area, requires technically skilled manpower for operation and maintenance

i. Land Application of Wastewater

Application of sewage to agricultural land is well known. This method was not accepted because of concern about pathogens in the waste. However, the objective of this application was to reduce waste discharges to surface waters while utilizing the nutrient content for crops and encourage the use of effluent for irrigation and groundwater recharge. Over the years, this has improved due to the introduction of pre-application treatment which is required depending upon the type of system employed, the type of crop grown, the intended use of the crop, the degree of contact by the public with the applied wastewater, and the method of application.

ii. Slow-rate Infiltration System

Slow-rate infiltration systems by spray irrigation involve the intermittent application of secondary effluent on crops, vegetation or forest land. Filtering, biological conversion and adsorption take place to remove contaminants during percolation. This method can provide a high level of treatment because of the relatively low application rates and the presence of vegetation and an active soil ecosystem.

iii. Rapid Infiltration System

These require highly permeable soils to which wastewater is applied at high loading rates, to shallow, un vegetated basins. The percolate is either used for groundwater recharge or recovered by under drains or recovery wells for further treatment or

disposal. This type of system is most adaptable in temperate climates; however this does not offer the treatment efficiency of slow-rate application method.

iv. Overland Flow System

The pretreated wastewater is applied to fairly impervious land having a slope of 2 to 8 percent for substantial runoff. Vegetation plays an important role in overland flow systems. Sedimentation and biological conversion by a bacterial slime layer are the major treatment mechanisms. This method has also been used to treat high-strength food-processing wastewater and as a polishing step to remove nitrogen and trace metals from secondary effluents.

X. Impoundment Systems

In these systems, the wastewater can be retained or held through natural wetlands, oxidation ponds or through aerated lagoons.

i. Wetland

Natural or constructed wetlands such as marshes and swamps provide an ideal microenvironment for the sedimentation, filtration, adsorption and bacterial decomposition of wastewater constituents. Wetlands are intermittently flooded with water. They are important sink for nutrients or other substances and perform other ecological functions besides being aesthetic. Natural wetland treatment is to meet the regulatory requirements and hence limited to treating secondary or tertiary effluents. Constructed wetlands are employed to treat primary effluent, industrial wastewaters, acid mine drainage, landfill leachate, and urban runoff. A schematic view of constructed wetland system is shown in Figure 2.28. The wastewater flows in a wetland with impermeable bottom soil, emergent vegetation and water depths of 0.1 to 0.6 m. Wetlands are designed to remove conventional pollutants such as BOD, SS and nutrients. Wetlands can also be effective for heavy metal removal making them ideally suited for treatment.

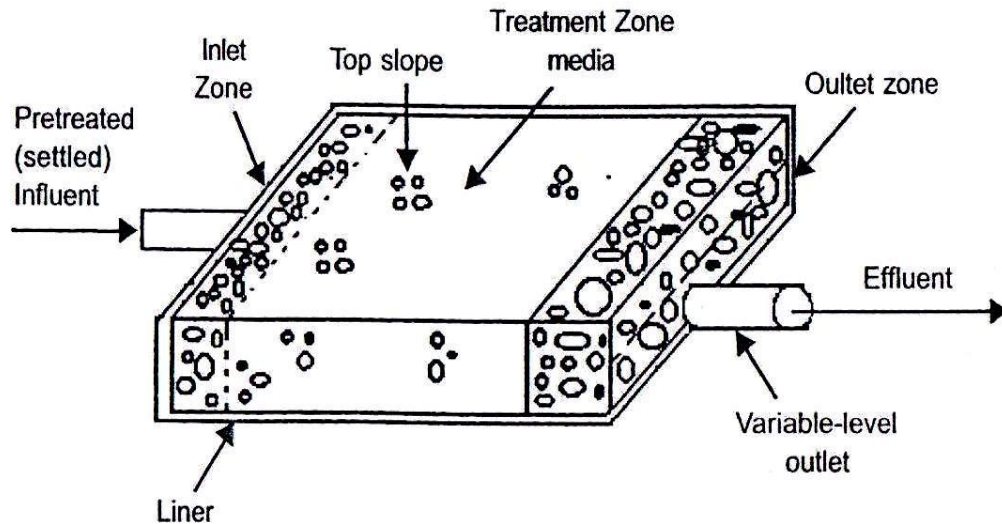


Figure 2.28: A schematic view of a constructed wetland system.

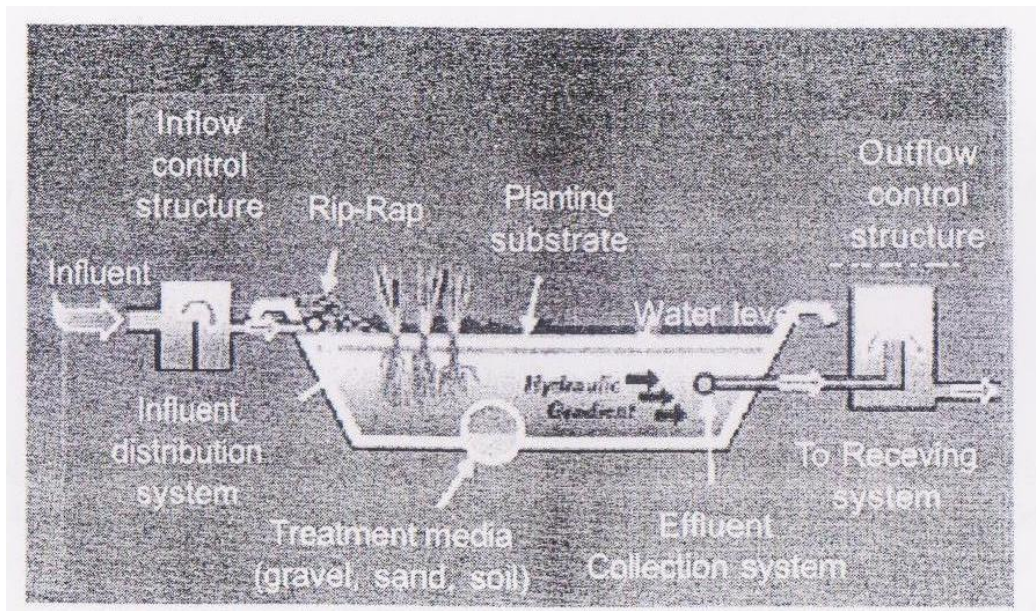


Figure 2.29: A view of subsurface wetland system.

Two types of wetlands systems exist. They are.

- (i) Surface flow systems and
- (ii) Subsurface flow systems. Figure 2.29 shows a view of subsurface flow wetland system.

The vegetation is generally represented by Cattail (*Typha* sp.), reed (*Phragmites* sp.), sedges (*Carex* sp.), bulrushes (*Scirpus* sp.), rushes (*Juncus* sp.), and grasses. The floating plants used in wetland treatment systems are *Eichhornia crassipes* and *Lemna*

sp. The accumulation of nutrients and organics in a wetland follow from the growth of vegetation, death or dieback, decay and soil accretion.

ii. Oxidation Ponds

Oxidation pond or lagoon is a shallow earthen basin of 1 to 2 m deep used to biologically treat a variety of municipal and industrial effluents. The system has aerobic through facultative to anaerobic condition depending on the aeration provided. Aerobic conditions are maintained through photosynthetic process when low strength and soluble organic wastewater is treated. In such facultative ponds, the detained settleable solids undergo anaerobic decomposition at the bottom of the pond while soluble organic wastes are converted to carbon dioxide and water by aerobic bacteria in the upper levels. Photosynthetic algae utilize the CO_2 and produce oxygen for the bacteria. These ponds are arranged in series mainly to reduce short circuiting, and when high BOD load is applied. Additional aeration may be provided whenever or wherever necessary.

Anaerobic lagoons are 2 to 3 times deeper than oxidation ponds and provide only partial stabilization of wastes and therefore are used in series with facultative ponds to provide complete treatment. Odour problem could be one of the factors encountered.

iii. Aerated Lagoon

Aerated lagoons have mechanical means of aeration as diffused aeration which supplies continuous air. Aerated lagoons have limited surface area and may be deeper than oxidation pond. Figure 2.30 shows the different unit operations in an aerated lagoon. In general, the treatment proceeds at a slow rate in land based systems and hence the applications are limited to small communities where the wastewater generation is less.

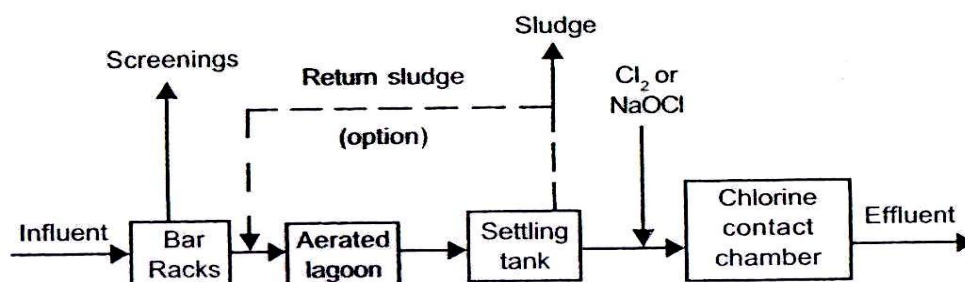


Figure 2.30: A schematic view of aerated lagoon treatment process.

XI. Sludge Generation and Treatment

Solids generated in water and wastewater treatment operations consist of all suspended solids. Sludges are derived from the processes of chemical coagulation and softening at water works and from preliminary, primary, secondary and tertiary stages of wastewater treatment. Most of these sludges are of an unstable organic nature and readily undergo active microbial decomposition. They have high water content, usually greater than 95 % by weight. Sludges derived from wastewaters containing domestic sewage or animal excreta may contain significant concentrations of pathogenic organisms.

i. Sludge Conditioning

The water characteristics of sludges can be improved by chemical and thermal conditioning processes as well as by elutriation. Chemical conditioners include the salts of trivalent iron and aluminium and organic polyelectrolytes. Thermal conditioning of sludge may be by heat treatment at 200° C for 20-30 min at 18 atm pressure or freezing. Elutriation is applied to the washing of sludge to remove fines and to lower its alkalinity, thereby improving its dewatering.

ii. Sludge Thickening

Sludge thickening is a concentrating process to separate water either by sedimentation or flotation. Thickening can effect a considerable volume reduction. Two methods of thickening are employed, (i) Gravity thickening and (ii) Flotation thickening.

iii. Sludge Dewatering

Dewatering is a means of removal of water so that the remaining sludge residue behaves like a solid. Dewatering can be accomplished by spreading on drying beds, vacuum filtration, pressure filtration and centrifugation. Open air sand beds may be used for dewatering of stabilized sludges. Sludge is discharged onto the sand to a depth of 150-300 mm and is left until it can be lifted as a semi-dry cake. Vacuum filtration is widely practiced and is carried out in a rotating drum covered by a filter cloth. As the drum rotates, suction draws water inwards leaving a sludge layer attached to the drum surface. Pressure filters are also employed in sludge dewatering. Dewatering is carried by: (i) plate press and (ii) belt press. Centrifugation is widely used in industrial solids-separation process and also extensively used for sludge thickening.

iv. Sludge Stabilization

Many sludges from wastewater treatment plants contain high concentrations of biodegradable materials amenable for decomposition. Such sludges can be stabilized by biological conversion of its organic fraction to stable end products by aerobic or anaerobic digestion processes or by chemically inhibiting microbial activity.

v. Anaerobic Digestion

It is widely used for sludge stabilization and treatment of high strength organic wastes. This can affect 40-60 % reduction in organic solids by improving dewaterability, reducing the odour potential and producing methane as a byproduct. Digestion is generally slow at lower temperatures and fast at higher temperatures. The quantity of gas produced varies in the range of 0.9 to 1.4 m³ per kg of volatile solids removed.

vi. Aerobic Digestion

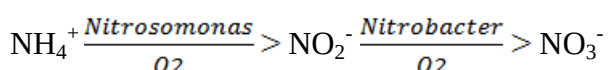
Aerobic stabilization means aeration of primary, secondary or mixed sewage sludges resulting in microbial oxidation of organic material. This is generally influenced by the concentration of microorganisms, biodegradable solids and inorganic nutrients, temperature, mixing intensity, etc. Chemical stabilization involves addition of lime to raise the pH of sludge to inhibit the microbial activity. However, due to long term storage in pits, pH may gradually drop for resumption of microbial activity.

8. Tertiary Treatment Processes

The main objective of tertiary treatment is the removal of dissolved nitrogen and phosphorus.

Nitrogen removal: Nitrogen is found in the form of ammonia and organic nitrogen in domestic wastewater. Its removal occurs by the following steps.

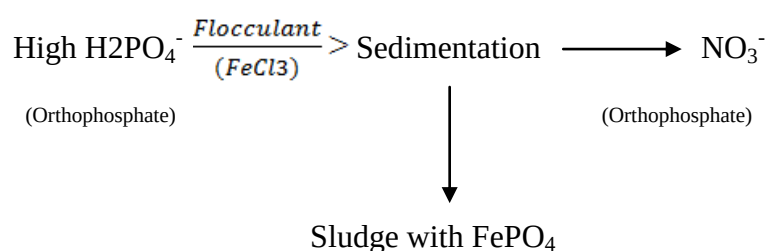
- (i) In the first step ammonia is oxidized to nitrate mediated by nitrifying bacteria. Eg. *Nitrosomonas* sp. This is an aerobic reaction.



- (ii) In the second step, nitrates are denitrified to molecular nitrogen by means of different set of bacteria such as *Pseudomonas*, *Bacillus*, etc. They use nitrates as the oxidizing compound instead of oxygen. This reaction occurs under anoxic

environment. In industrial wastewaters, nitrogen removal is carried out by alkaline air stripping, ion exchange and "breakpoint" chlorination.

Phosphorus removal: Phosphorus removal is most commonly carried out by chemical precipitation with iron or aluminium compounds such as ferric chloride or alum (aluminum sulphate). The solids which are produced can be settled along with other sludges. Phosphorus can also be removed by biological means, with alternate anaerobic condition and an aerobic one to induce a high phosphorus uptake by certain type of phosphorus accumulating bacteria.



Disinfection: Disinfection, usually the final process before discharge, is the destruction of harmful (pathogenic) microorganisms, i.e. disease-causing germs. The object is not to kill every living microorganism in the water but to reduce the number of harmful ones to levels appropriate for the intended use of the receiving water.

The most commonly used disinfectant is chlorine, which can be supplied in the form of a liquified gas which has to be dissolved in water, or in the form of an alkaline solution called sodium hypochlorite, which is the same compound as common household chlorine bleach. Chlorine is quite effective against most bacteria, but a rather high dose is needed to kill viruses, protozoa, and other forms of pathogen.

Limitations of Chlorine Usage: Chlorine has several problems in its use such as.

- (i) It reacts with organic matter to form toxic and carcinogenic chlorinated organics such as chloroform.
- (ii) Chlorine is very toxic to aquatic organisms in receiving water and it is hazardous to store to handle. Hypochlorite is safer, but it produces the first two problems, however, it can be dealt with by adding sulphur dioxide or sodium sulphite or hydrogen sulphite to neutralize the chlorine. The products of such reactions are harmless chloride and sulphate ions.

Ozone can also be used as a disinfectant. Ultraviolet disinfection is becoming more popular because of the increasing complications associated with the use of chlorine.

9. Decentralised Wastewater Treatment

Water pollution in general, is on the increase due to the discharge of untreated wastewater largely due to domestic wastewater followed by industrial wastewater. In the developing countries in general, most of the discharged wastewater is finally purified by nature, often not before reaching the ocean. Percolation, evaporation or treatment by oxidation in wild ponds takes place, but the polluting or toxic substances and pathogens is out of control and too often only realized after damage to nature or human life has been done. In India, only very negligible percentage of wastewater is being treated from all cities and towns while in villages and small towns there are no treatment facilities at all. There is hardly any developing country where more than 10 % of wastewater is treated. The sophisticated treatment technologies used in large scale industries are not often economical and feasible to maintain. Hence, decentralized wastewater, treatment option could solve the problems by utilizing decentralized funds directly from the polluters. Decentralised small and medium size wastewater treatment systems with low maintenance are suitable for organic wastewaters from households, industry and agriculture. This would be an ideal choice for easy maintenance, operation and providing a safer environment.

10. Onsite Treatment Systems

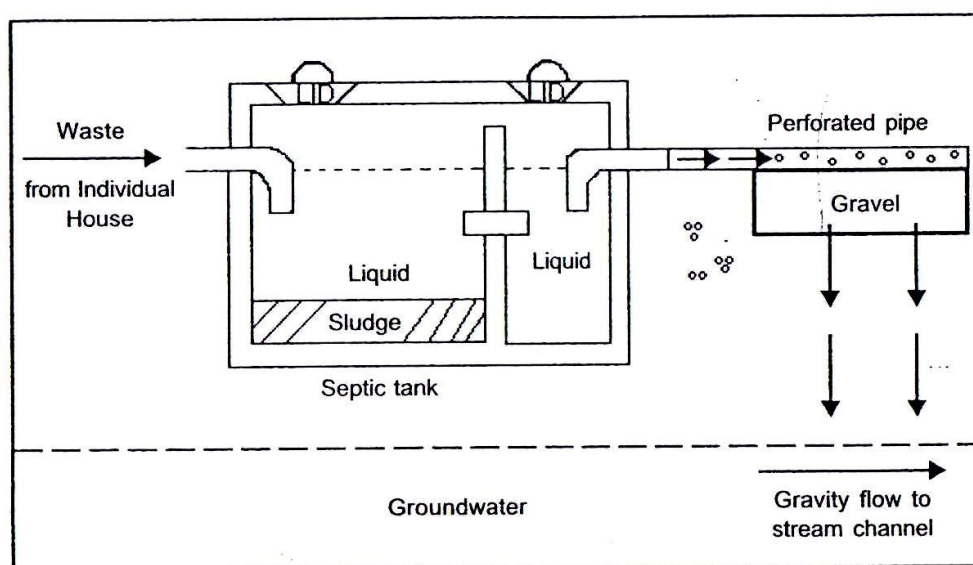


Figure 2.31: Septic tank.

On-site systems are preferable to a municipal facility in small communities due to the overall cost and pollution control. The preferred locations include resorts, service centers, camps and isolated institutions where no municipal sewers are available.

Septic tanks: Septic tank system is the most common method of on-site wastewater treatment and disposal can be designed for a small family and a large institution. This has a concrete, fiberglass, or coated steel tank located below and provides 24 h retention of the wastes in one or two compartments, allowing the heavy solids to settle and oil and grease to rise to the surface (Fig. 2.31).

These solids undergo slight compaction and anaerobic decomposition and the accumulate should be removed every three to five years to maintain tank storage capacity and effluent quantity. The liquid effluent with BOD and SS concentrations of about 175 and 75 mg/L is discharged through an intermittent dosing siphon to a subsurface disposal system. This system may consist of open tile drains laid in trenches filled with gravel or crushed stone and permit downward percolation and upward evaporation and transpiration. A septic tank can be constructed of bricks and mortar and or of concrete. Its shape can be rectangular or cylindrical. A septic tank can be partitioned into two chambers to reduce flow short-circuiting and improve solids removal. The overflow from a septic tank is directed to a leach pit or trench. The organic solids in a septic tank undergo anaerobic bacteria decomposition just as in the pit of a pit latrine. The sludge needs emptying, and the period between emptying is usually designed to be between 3 to 5 years. The sludge has to be further treated before reuse or disposal.

Waterless Systems: Wherever pressurized water is not available or soil conditions are not suitable for effluent disposal, the on-site treatment or waterless toilets could be an alternative. When the surface or groundwater contamination is not a problem, the arrangement over an earthen pit would be the simplest and cheapest solution. Compost toilets are a recent development in which wastes dried to critical moisture content by evaporation, are composted aerobically at a controlled temperature and forced ventilation. Chemical toilets stabilize organic matter and destroy bacteria with strong caustic solution which must be removed and replaced on a regular basis. Incinerator toilets use electricity, oil or gas to oxidize organics completely to a dry inert ash that must be periodically removed.

11. Ecosan Concept

Conventional forms of centralized and individual sanitation do not offer sustainable solutions to the massive worldwide sanitation problems. Despite the intensive efforts of many institutions at national and international level, many developing countries cannot afford to provide adequate water supply and sanitation services to their populations, as the initial cost and operation of conventional systems are often too expensive. Conventional flush and discharge and drop and store disposal systems cause worsening pollution, mainly of ground and surface water by organics, nutrients, pathogens, hazardous material and such other polluting substances as pharmaceutical residues, hormones etc. Moreover, conventional waterborne sewage systems add to the waste of precious drinking water by misusing it as a transport medium for faeces, urine and waste.

A possible solution to such problems is an alternative sanitation concept called "ecological sanitation" or "ecosan" in short which represents a more holistic approach towards ecologically and economically sound sanitation. The concept is spearheaded by the German Technical Cooperation, Germany. This approach is based on the systematic implementation of a material-flow-oriented recycling process of nutrients and water as a hygienically safe, circular and holistic alternative to conventional solutions. Ecological sanitation system enables the complete recovery of all nutrients from human faeces, urine and grey water to the benefit of agriculture, thus helping to restore soil fertility, to assure food security for future generations, and to minimize water pollution. There are two basic design features of ecological sanitation, (i) First is the urine-diversion, in which urine and faeces are never mixed and kept separate at all times. The toilet has a dividing wall, in which the urine exits from the front of the toilet and faeces drop below the toilet from the back of the bowl, (ii) The second is the composting, in which urine and faeces are combined and the product is composted. In each case it is possible to manage urine, faeces or excreta with little or no water and it is also possible to keep the end product out of ground and surface waters. The concept has been implemented in few villages in Kerala, India on a different idea to prevent pollution of high groundwater table.

12. Bacterial Pathogens in Wastewater

Many types of harmless bacteria colonize in the human intestinal tract and are routinely shed in the faeces. One such group of intestinal bacteria, the coliiform bacteria is being used historically as an indicator of sewage contamination. In addition, pathogenic bacteria such as *Salmonella*, and *Shigella* are present in the faeces of infected individuals.

Table 2.10: Potential waterborne microbial diseases.

Pathogen	Clinical syndrome
Bacterial diseases	
<i>Aeromonas hydrophila</i>	Acute diarrhea
<i>Leptospira</i>	Leptospirosis
<i>E. coli</i>	Gastroenteritis
<i>Pseudomonas aeruginosa</i>	Gastroenteritis
<i>Salmonella typhi</i>	Typhoid fever
<i>Shigella</i> spp.	Shigellosis
<i>Vibrio cholera</i>	Cholera dysentery
<i>Campylobacter</i> spp.	Acute enteritis
<i>Cyanobacterial disease</i>	
<i>Cylindrospermopsis</i> spp.	Heptoenteritis
Viral diseases	
<i>Poliovirus</i>	Paralysis, encephalitis
<i>Adenovirus</i>	Conjunctivitis
<i>Rotavirus</i>	Infantile gastroenteritis
<i>Coxsackie virus A</i>	Herpangina, paralysis
<i>Coxsackie virus B</i>	Myocarditis, pericarditis, encephalitis
<i>Echovirus</i>	Meningitis, enteritis
<i>Hepatitis A</i>	Infectious hepatitis type A
<i>Influenza A</i>	Influenza
<i>Norwalk and other parvovirus like agents</i>	Epidemic, acute nonbacterial gastroenteritis
<i>Rotavirus</i>	Nonbacterial, endemic, infantile gastroenteritis, diarrhoea
Protozoan diseases	
<i>Balantidium coli</i>	Balantidiasis
<i>Cryptosporidium</i>	Cryptosporidiosis (Diarrhoea)
<i>Entamoeba coli</i>	Diarrhoea
<i>Entamoeba histolytica</i>	Amoebiasis (amoebic dysentery)
<i>Giardia lamblia</i>	Giardiasis
Helminth diseases	
<i>Ascaris</i>	Ascariasis (roundworm infection)
<i>Ancylostoma</i>	Hookworm infection
<i>Clonorchis</i>	Clonorchiasis
<i>Dipyllobothrium</i>	Diphyllobothriasis (broadfish tapeworm infection)
<i>Dracunculus medienensis</i>	Dracontiasis (Guinea worm infection)
<i>Fasciola</i>	Facioliasis
<i>Taenia</i>	Taeniasis (tapeworm infection)
<i>Trichuris</i>	Trichuriasis (whipworm infection)

More than one hundred different enteric viruses may be excreted in human faecal material. These viruses and other parasitic pathogens such as protozoans are shed in the faecal material of individuals who are infected either purposely or inadvertently by consumption of contaminated food or water, swimming in contaminated water or person to person contact with an infected individual. There are several ways in which an individual can acquire disease from wastewater use during wastewater treatment. A list of microorganisms present in domestic wastewater is given in table 2.10.

Questions

1. While performing the BOD analysis, once the stopper is placed in a BOD bottle, does the total amount of organic matter (microorganisms and nonliving organic matter) remain constant? Explain.
2. Does a change in pH influence the COD content of a sample?
3. List any three pathogens and their associated diseases from bacteria, protozoa and virus groups.
4. What are the unit operations you would adopt for treating surface water?
5. Describe the general features of each unit operation in the treatment of drinking water.
6. Write the chemical equation for the reaction of alum with sodium carbonate.
7. What are the limitations in the usage of chlorine in disinfection?
8. Why rapid mixing is required for coagulant addition?
9. What is the purpose of increasing the number of media types in a rapid filter?
10. Draw a typical chlorine demand curve and explain each phase of the curve?
11. The nutrient requirement for nitrogen and phosphorus is 100:5:1 (mass basis) when the degradable organic matter is expressed on a COD basis. What is the ratio if BOD₅ is used to express degradable organic matter and BOD₅ is assumed to be two thirds of ultimate BOD?
12. Explain the activated sludge process with a flow diagram.
13. Explain the trickling process of treatment with a flow diagram.
14. What are the main steps of metabolism in anaerobic digestion?
15. Distinguish between acetogenic, acetoclastic and hydrogenophilic bacteria.
16. Discuss the nutrient removal in an aerobic process compared to an activated sludge process.

17. Why anaerobic organisms produce less sludge per unit of substrate metabolized compared to aerobes?
18. How do algae influence the oxygen budget of a stream?
19. How do you differentiate microfiltration and nanofiltration.

SOIL POLLUTION

Soils play an important role in the regulation of pollutants in ecosystems and acts as an important sink for pollutants through precipitation, sorption and immobilization reactions. Soil degradation causes decline in soil productivity through adverse changes in nutrient status, organic matter, structural stability and concentrations of solutes and agrochemicals. Soil degradation causes a number of environmental problems, including leaching, erosion, acidification etc.

The effects of soil degradation are not confined to soil alone, but have a number of off-site influences. For example, soil erosion is often associated with increased flooding, siltation of rivers, lakes and reservoir and deposition of material in low lying area. Salination and solidification of soils are often associated with poor quality of irrigation water. Soil acidification is commonly linked with acidification and aluminium contamination of surface waters. Agricultural run-off may carry a variety of pollutants which may lead to contamination of surface and groundwater. Contamination of soils by urban and industrial pollutants such as heavy metals, toxic organic chemicals and radionuclides which may accumulate in arable produce and grazing animals pose health effects in human beings through food chain.

1. Composition of Soil

Soil has following main components.

Mineral matter: A matrix of mineral particles derived by varying degrees of breakdown of the parental material rock.

Biological agents: consisting of distinctive flora and fauna of algae, bacteria, protozoa, nematodes and arthropods.

Organic matter: the plant and animal remains are decomposed by microorganisms and converted to humus by a process called as humification.

2. Sources of Pollutants

Rapid urbanization, with the consequent increase in population and building construction has resulted in decrease of lands for the wastes to be disposed. Soil pollution mainly results from the following sources such as

- i. Industrial wastes
- ii. Urban wastes
- iii. Radioactive pollutants
- iv. Agricultural practices
- v. Chemical and metallic pollutants and
- vi. Biological agents

Pollutants in soil remain in direct contact with the soil components for relatively longer periods and hence alter the chemical and biological properties of the soil (Fig. 2.32). Indiscriminate dumping of industrial wastes and municipal wastes leads to the leaching and/or seepage of toxic substances into the soil and pollution of ground water. Fly ash generated from thermal power plants, industrial wastes discharged into streams or dumped into the surrounding land, mining wastes, non-biodegradable organic pollutants, industrial sludges such as heavy metal sludges etc. cause serious water and soil pollution. Fig. 2.32 shows the sources of soil pollution.

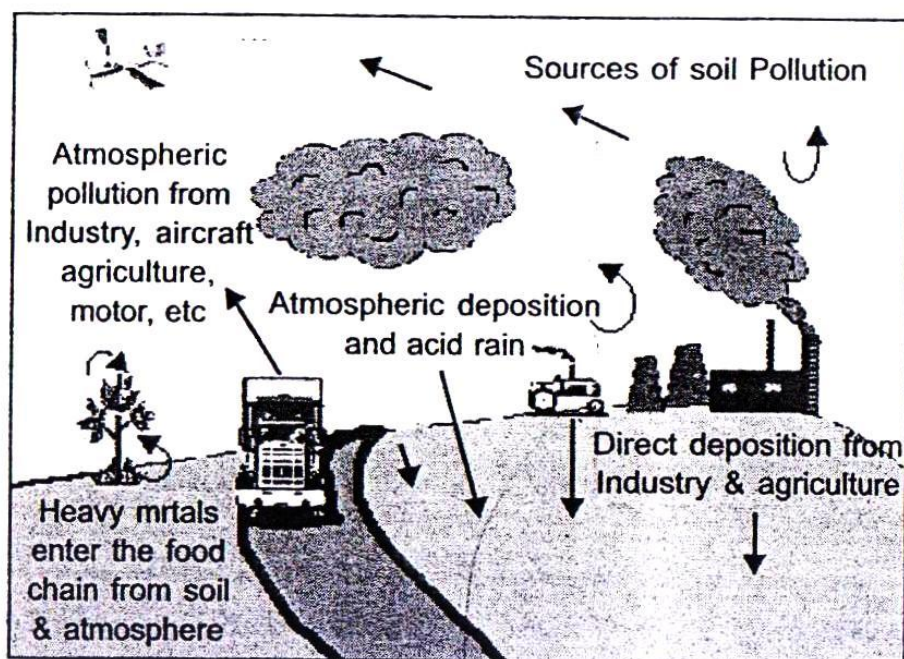


Figure 2.32: Sources of soil pollution.

Domestic urban wastes consisting of dried sewage sludge as well as garbage and rubbish materials such as plastics, metal cans, glasses, street sweepings, waste paper, fibres, rubber, etc. contribute to soil pollution (Fig.2.33). Heavy metals penetrate the soil as solid substances deposited, most often, by air. Lead is contributed through the vehicles that pollute the environment, while rains help lead enter the soil and vegetables. Sources of heavy metals to agricultural lands are generally through: (i) parent material (underlying geology) (ii) mine wastes, (iii) atmospheric deposition, (iv) farm manures, (v) sewage sludge, (v) fertilizers and lime, (vi) agrochemicals and (vii) industrial wastes.

I. Nature of Agrochemicals Contamination

A wide range of agrochemicals are being used by farmers to sustain food production (Table 2.11). They are fertilizers which contribute to phosphorus, nitrate, sulphur, calcium, potassium zinc, iron and manganese and pesticides to control both weeds and pests. In addition, a range of heavy metals such as cadmium and mercury are being indirectly added to soils through the use of fertilizers which influences the crop quality.

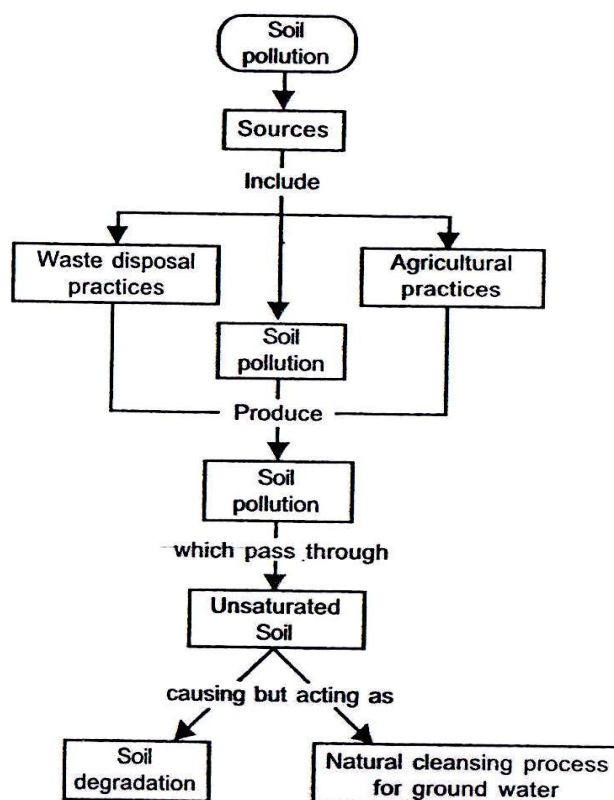


Figure 2.33: General scheme of soil pollution.

Table 2.11: Some of the commonly used agro chemicals in agriculture.

Pesticide group	Type of Pesticides
Quaternary N pesticides	Diquat, Paraquat
Basic pesticides	Amitrole, Atrazine, Benomyl, Cyanazin
Carboxylic acid herbicides	2,4-D, Dalapon, Dichlorprop, MCPA
Hydroxy acid pesticides	Bromacil, Dinoseb, Terbacil
Organic As and P acid pesticides	DSMA, Glyphosate
Organometallic fungicides	Mancozeb, Maneb, Zibeb, Ziram
Carbamate pesticide	Aldicarb, Carbaryl, Carbofuron, Chloropropham,
Chlorinated hydrocarbon pesticide	Chlorothalonil, Endosulfan. Lindane, Metoxychlor
s	Aldrin, Chlordane, DDT, Heptachlor
Organochlorine pesticides	Chlorphyrphos, Diazinon, Malathion,
Organophosphate pesticides	Monocrotonphos, Parathion, Phosmet
	Diuron, Linuron, Flumeturon
Phenylurea pesticides	Bifeenthrin, Cypermethrin, Fenvalerate,
Pyrethroid pesticides	Permethrin

With the modernization of agriculture, the use of fertilizers in agriculture has multiplied by several folds in recent years. Today, over 1,00,000 different chemicals including insecticides, fungicides, herbicides, acaricides and rodenticides are being used throughout the world for pest or weed control. India is one of the largest manufacturer as well as consumer of pesticides in Southern Asia. On an average, approximately 500g ha of pesticides being used in India.

II. Impact of Agrochemicals on Soil Quality

A number of adverse impacts are encountered due to the use of nitrogenous and phosphate based fertilizers. For example, in legume crops, nitrogen is derived mainly through the biological fixation of nitrogen through *Rhizobium* living in the root nodules of legumes. Addition of N fertilizers reduces nitrogen fixation. This stimulates the acidifying effects of N fertilizers added to soil. Similarly, additions of phosphorus in the form of super phosphate seem to cause soil acidification where the direct application of reactive phosphate rocks as a source of phosphorus decreases the rate of soil acidification.

Inorganic fertilizers such as nitrate and phosphate based fertilizers lead to extensive contamination of surface and ground waters. The fate of the fertilizers depends on the physical, chemical and biological factors in that environment. The main processes which affect the soil quality depend on the plant and animal uptake, adsorption and exchange in soil, leaching or infiltration, volatilization and gaseous losses to the

atmosphere. Loss of nutrients especially nitrogen due to leaching is most common in coarse soils and well drained soils whereas denitrification losses are greatest in fine textured, waterlogged and poorly aerated soils. Phosphate, sulphate, nitrate and chloride are the major nutrients causing contamination of groundwater and surface waters resulting in eutrophication of water bodies. The reactive anions such as phosphate and sulphate are considered to be important in their mobilization in soil.

3. Xenobiotics in Soil Contamination

The major sources of xenobiotics in soil arise from agricultural pesticides applied on crops, and those spilled at the production and distribution facilities, petroleum leaking tanks, spills in manufacturing and distribution and land disposal of xenobiotic wastes. The xenobiotics occur in soils in solid, dissolved and gaseous phases and undergo transformations. Xenobiotics can be toxic to soil biota, inhibit seed germination and suppress plant growth. They may contaminate crops and livestock and can enter the food chain through direct ingestion of contaminated soil. Livestock contamination can occur at contaminated sites when animals graze pastures by ingestion of soil either directly or indirectly on the vegetation. There is a concern on the persistence of pesticide residues in soil which contaminate subsequently the groundwater and surface water. Persistence of pesticide in soil depends on the extent of adsorption onto soil particles and the rate of mineralization or degradation. Adsorption of pesticide decreases the leaching of residues to groundwater.

4. Degradation of Organic Pollutants

Organic pollutants are degraded in soils either by.

- a. Non biological mechanisms or by
- b. Biological mechanisms

Microbial species on the surface of soil particles forming biofilms secrete various extracellular enzymes which degrade the pollutant. Partial degradation of pollutant may occur when it is absorbed into the microbial cell where intracellular enzymes may catalyse further decomposition for the release of energy and nutrients. Several species of bacteria, fungi, etc. play a role in the degradation of complex organic substances to simpler compounds. Although most of the organic molecules are biodegradable, the rate at which this takes place can vary greatly. The susceptibility of an organic molecule to biodegradation depends largely on its structure. Compounds

which are substituted, insoluble or of high molecular weight are often very resistant to enzyme attack. Many compounds are resistant to biodegradation due to the incorporation of halogens in the molecule. Cyclic structures, aromatic compounds, cycloalkanes and heterocyclic compounds are also more resistant to biodegradation than linear ones due to the chemical stability of their ring structures.

Recalcitrant nature of organic compounds may also be due to failure of the compound to induce the synthesis of degrading enzymes, even though it may be susceptible to their action, failure of the compound to enter the microbial cell, due to its molecular size, lack of permeases required for its transport across the membrane, insolubility in aqueous transport media, or adsorption to external matrices such as soil particles, or excessive toxicity of the compound or its metabolic products, to microbial cells.

5. Effects of Pollutants on Soil

Soil pollution has received greater attention due to its direct impact on general health of human beings.

I. Transfer of Pollutants to Plants

Transfer of pollutants from soil to plants takes place through the roots. This depends upon the extent of sorption of pollutants in soil. Heavy metals such as arsenic, cobalt, chromium, and lead have a transfer coefficient of 0.01 to 0.1 whereas cadmium, and zinc have a transfer coefficient of 1.0 to 10.0. Organic pollutants have lower transfer coefficients. Some of the pollutants are taken up by the plants with or without any detrimental effects on them, and enter into the food chain and impart damage or toxic effect on the consumers.

II. Ecotoxicological Aspects of Soil Pollution

It is understood that although soils are mildly polluted with metals from sewage sludge to levels within EC guidelines do not cause obvious symptoms of phytotoxicity in most crops; however, some effects can occur in the soil microbial biomass. Zinc levels at 300 ug/g can cause a marked decrease in the activity of nitrogen fixing bacteria such as *Rhizobium leguminosarum* which occur in root nodules of white clover plants. Greatest risk is posed by zinc received through sewage sludge. The order of toxicity to heavy metals to bacteria is $Cu > Cd > Ni > Zn$.

Table 2.12: Hazards caused by land contaminants.

Contaminant	Nature of Hazard
As, Cd, Pb, coal tars, phenols Toluene, benzene, xylene, various or ganic solvents, Hg etc. As, Cd, Pb. PAH	Direct ingestion of contaminated soil Inhalation of dusts and vapours from contaminated soil Uptake by plants and passage to human beings through food chain
SO ₄ ²⁻ , Cu, Ni, Zn SO ₄ ²⁻ , SO ₃ ²⁻ , Cl, Coal tar, phenol, organic solvents	Phytotoxicity Deterioration of building materials
CH ₄ , S, coal dust, oils, rubber, high calorific organic wastes	Fires, explosions
Phenol, soluble metals, solvents, pesticides	Contact of people with contaminants during demolition
CN ⁻ , SO ₄ ²⁻ , soluble metals, pesticides	Contamination of water

Heavy metals such as copper, zinc and molybdenum are essential trace elements for plants and animals but excessive concentrations can damage overall soil fertility. Metals, such as cadmium and lead can have adverse effects on human and animal health if they are allowed to accumulate in the food chain. The occurrence of high concentrations of heavy metals in agricultural top soils is generally very localized. The residence time of most heavy metals is long and they tend to be unavailable for plant uptake. Several adsorption reactions can occur between the surfaces of organic and mineral colloids and the contaminants. The extent to which the reactions occur will be determined by the composition of soil based on the presence of clay mineral, hydrous oxide and organic matter contents, soil pH and nature of contaminants. Some of the hazards caused by the contaminants are listed in Table 2.12.

6. Remediation of Soil Contamination

A schematic flow diagram giving the survey and remedial action undertaken for assessing the extent of pollution and decontamination of soil is given in Figure 8.3. Contamination of soil can be remediated by the following methods.

- Removal of contaminated soil from site: This involves stripping off the contaminated soil and disposing to landfill or cleaning it by thermal or chemical means.
- Covering contaminated land with barren soil: Contaminated land can be covered with clean soil for providing an uncontaminated rooting medium for plants.
- Insitu remediation of soil:** This involves irrigation of soil with chemical reagents to extract harmful contaminants or by the use of microbial cultures to decompose

persistent organic pollutants or in case of radioactive contamination, abandoning the site until radioactive contamination have decayed through one or more half-lives.

- iv. Remediation of soil by reducing bioavailability: Liming of soil thereby raising the pH of soil to 7.0 render metals less mobile. Additional supplement of organic matter can lock the heavy metals as stable complexes with organic colloids.

7. Control of Soil Pollution

Various approaches can be practiced for the control of soil pollution. They are:

- i. Implementation of deterrent measures against deforestation.
- ii. Formulation of stringent pollution control legislations and effective implementation.
- iii. Banning of use of highly toxic and resistant synthetic chemical compounds.
- iv. Use of biopesticides over chemical pesticides.
- v. Effective treatment of domestic sewage and adoption of modern methods of sludge disposal.
- vi. Segregation and treatment of industrial wastes by suitable methods.
- vii. Enforcement of environmental audit for industries and promotion of ecolabelled products.

Questions

1. What are the sources of soil pollution? What are the detrimental effects of soil pollutants?
2. Discuss the various sources of soil pollutants.
3. What are the measures to control soil pollution?
4. What are the methods in the remediation of soil contamination?
5. What are the elements recycled?

QUALITY PARAMETERS

MEASUREMENT OF AIR QUALITY

Air quality measurement is complicated by the lack of knowledge as to what is clean air and by the difficulty in defining quality. Pure air contains only the naturally occurring gases but pure air does not occur in nature. Pollen, dust, fog etc. are all natural contaminants. Air quality measurements are therefore designed to measure all

types of contaminants, natural as well as man-made. The measurements of air quality generally fall into three classes.

Measurement of emissions: This is called stack sampling when a stationary source is analyzed. A hole is punched into the stack and samples are drawn out for on-the-spot analyses. Sampling moving sources is more difficult.

Meteorological measurements: The measurement of meteorological factors is necessary if we are to know, how and why the pollutants travel from the source to the recipient.

Ambient air quality: This is indeed of major concern to us, since all evidence of health effects are based on these measurements. Monitoring air quality provides data on warning of episodes to public. There are a wide variety of methods to detect pollutants in air. Such devices are described below and some most commonly used methods for measuring particulate and gaseous pollutants of air have been described in the final chapter of the book dealing with Practical Exercises.

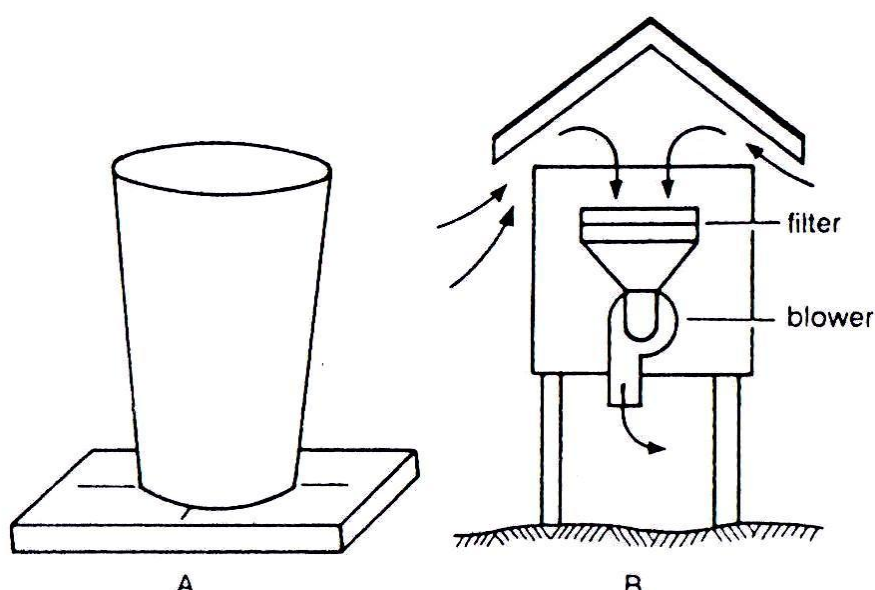


Figure 2.34: A. Dust fall jar; B. High volume sampler.

Measurement of Particles

1. Dust fall

Measurements of dust fall are the simplest means of evaluating air quality. The dust is collected either in open buckets (Fig. 2.34) or on sticky tape wrapped around jars. The

sampling period for the buckets is generally 30 days, and the sticky tapes are most often read in one week. The results are reported as dust settled/sq. mile/ 30 days.

2. High Volume Sampler

This is the workhorse of particulate sampling. The sampler (Fig. 2.34) operates like a vacuum cleaner by simply forcing a large quantity of air through a filter. Sampling time is generally 24 hrs, and over 70,000 cubic feet air is sucked through the filter during that time. The analysis is gravimetric; the filter is weighed before and after, and the difference is the particulates collected.

3. Tape samplers

These further reduce the sampling time, to as little as 10 min. per sample. These are shown in Fig 2.35. The particulates are caught on a paper tape, which is automatically reeled through the instrument, and form a black dot. The amount of particulate pollution (also called haze) is estimated by analysing the light transmissibility of the spot. This measurement is reported as COH/ 1000 feet. A COH is defined as $100 \log 100/\%T$, where % T is the percentage of light transmitted through the spot if a clean paper with 100% transmission is selected as control.

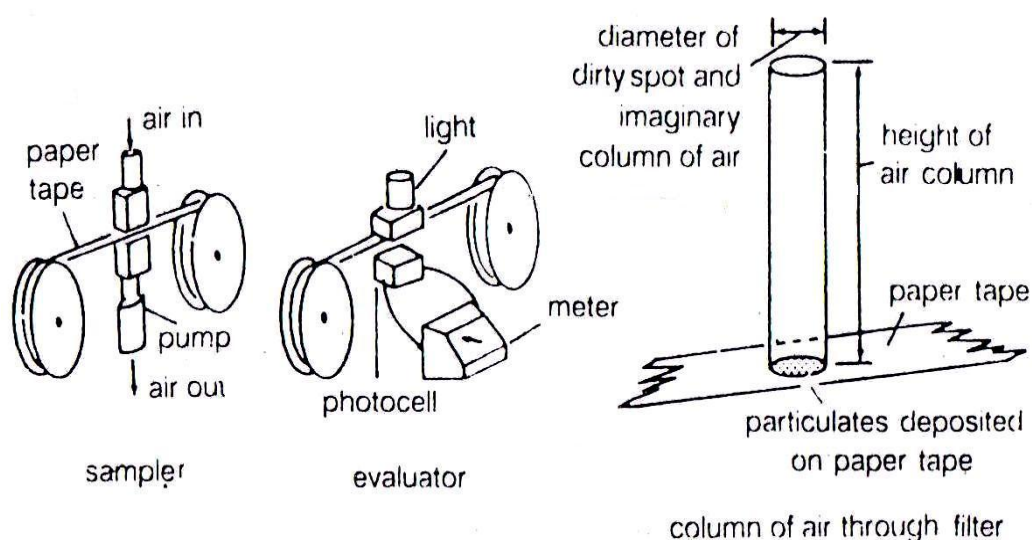


Figure 2.35: Tape sampler and evaluator.

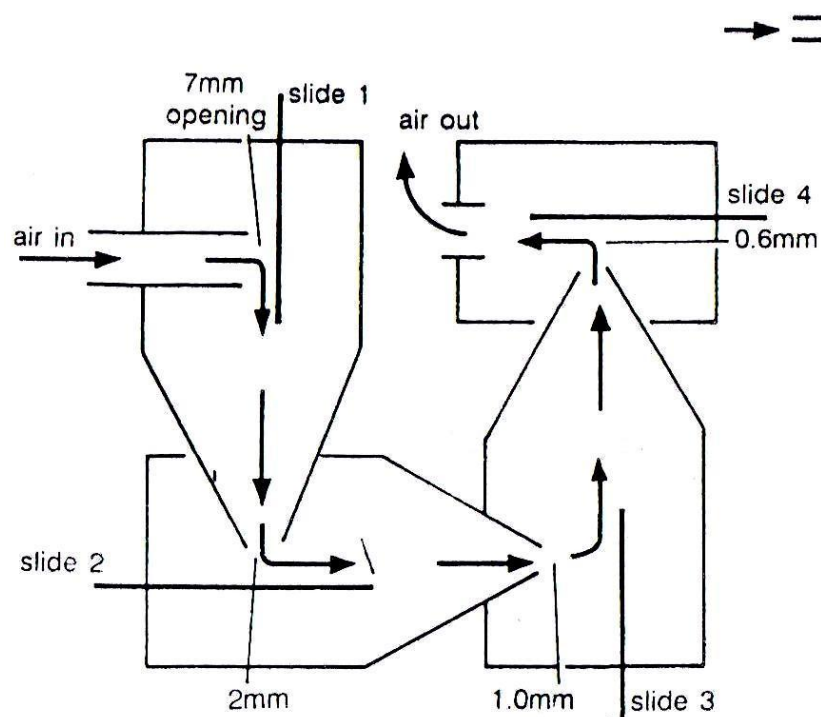


Figure 2.36: A cascade impactor.

4. Inertial collectors

These are used to collect samples and not for air quality monitoring. A cascade impactor (Fig. 2.36) consists of four tubes, each with a progressively smaller opening, thus forcing higher and higher velocities. A particle entering the device may be small enough to follow the streamline of flow without hitting the microscope slide. At the next nozzle, however, the velocity may be sufficiently high to prevent the particle from quite negotiating the turn, and thus impinging on the slide.

Measurement of Gases

Gas concentration in air is expressed as parts per million (by volume). Gases can be collected from atmosphere either by adsorption or absorption. Adsorption is a surface phenomenon and activated carbon is usually the adsorbent. The activated carbon is coated with a chemical which either collects the gas for future elution or undergoes a chemical and color change, thus providing a direct estimate of the gas concentration.

Absorption is the dissolving or otherwise chemically trapping the gas in a liquid. The equipment used is often called, a bubbler since the gases are bubbled through the collecting liquid (Fig. 2.37). Some gases (as SO₂) can be collected by dissolving them in the liquid and then analysing the liquid by chemical means. This may not be done

for N_2 and CO ? Which are only very slightly soluble in water? SO_2 may also be collected by bubbling it through H_2O_2 , and H_2SO_4 thus formed may be titrated with a base. Bubblers must be 100% efficient and no gas must escape.

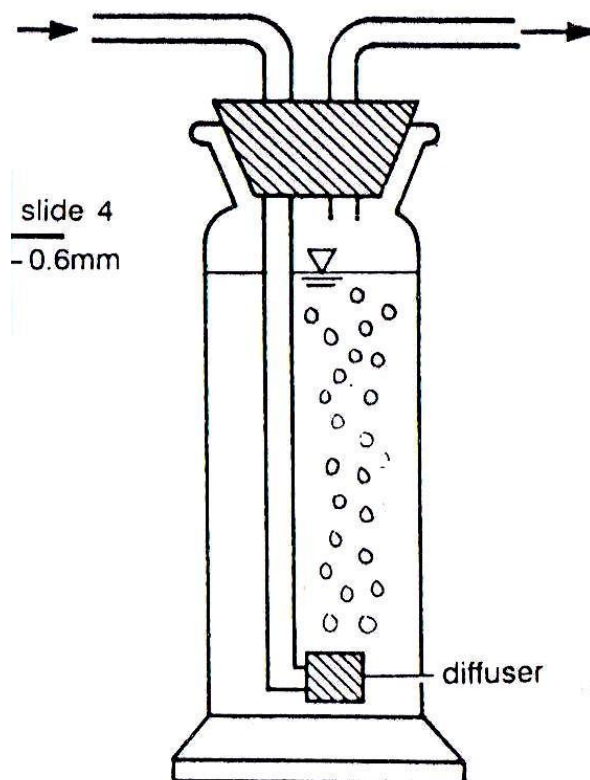


Figure 2.37: A gas bubbler collector.

Absorption techniques are also used for continuous analysis. The gas to be evaluated is mixed with reagents and then automatically and continuously passed through a measurement section which usually is a photometric device (Fig. 2.38). Almost all gaseous air pollutants can be measured with continuous monitors, though are more expensive than the bubblers.

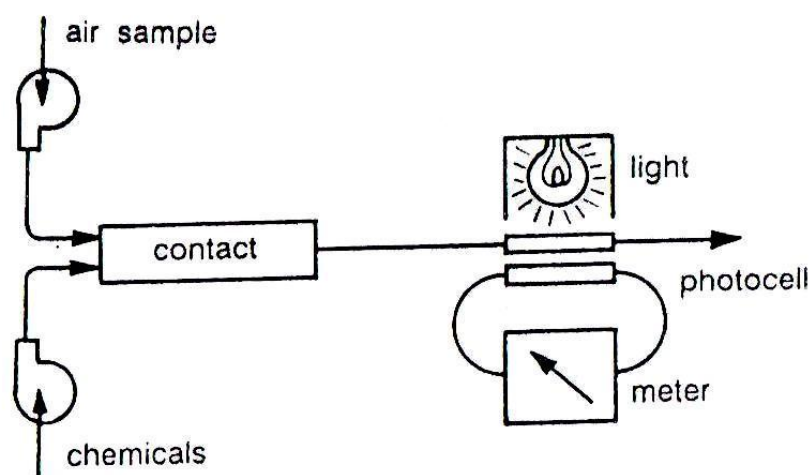


Figure 2.38: A photometric device of continuous air monitoring.

Grab samples of a gas are often taken for future analysis in the laboratory. In air quality measurements it is a real challenge, when compared to water pollution work. One method is the use of evacuated containers, drawing a vacuum in a glass jar and releasing it when the air is to be sampled. Bubbling gas into a container with water in it and displacing the water is an effective method only if the gases of interest are not all soluble in water. Plastic and aluminium bags have been used extensively. Usually the gas is pumped in and allowed to escape through a hole. By thus displacing two or three volumes of the bag, contamination may be avoided.

Stack sampling involves the sampling of gas from smokestack, and is necessary for evaluating compliance with emission standards and determining efficiencies of air pollution control equipment. A thorough survey of the flow, temperature and pollutant concentration in a stack is made to avoid the risk of obtaining an unrepresentative sample. Samples are obtained from a series of locations within a stack. A train of instruments (Fig. 2.39) is often utilised for slack sampling so that a number of measurements can be determined at each positioning of the intake nozzle.

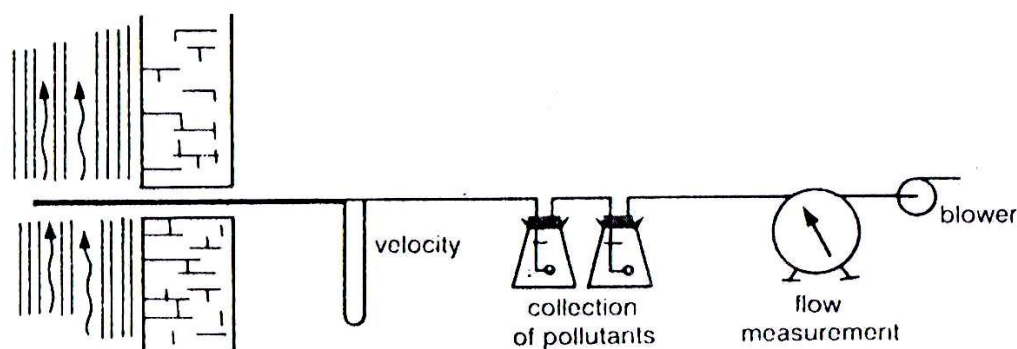


Figure 2.39: Stack sampling, involving a train of instruments.

Smoke

The density of smoke is measured on the Ringelmann scale, running from 0 for white or transparent smoke to 5 for totally black opaque smoke. The test is conducted by holding a card as shown in Fig. 2.40 and comparing the blackness of the card to the smoke. A fairly dark smoke is thus said to be "Ringelmann 4".

Prevention and Control of Air Pollution

For ages man has been dumping wastes into the atmosphere, and these pollutants have disappeared with the wind. We have seen that the main sources of air pollution are (i) motor vehicles, (ii) industries-particularly their chimney wastes, (iii) fossil-fuel (coal) based plants, as thermal power plants. Steps are to be taken to control pollution at source (prevention) as well as after the release of pollutants in the atmosphere. There is an urgent need to prevent the emissions from the above said major sources of air pollution.

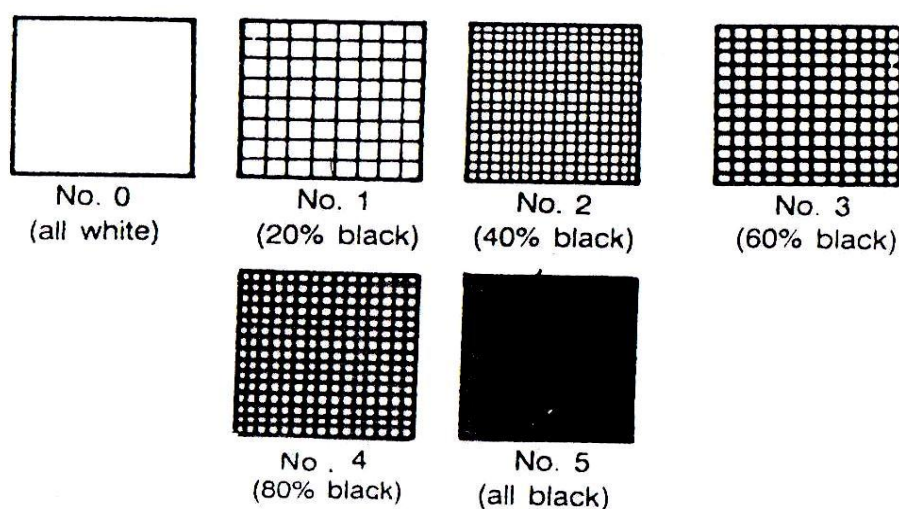


Figure 2.40: Ringelmann scale for measuring smoke blackness.

The control of emissions can be realised in number of ways. Five separate possibilities for control are shown in Fig. 2.41. These are briefly considered here as follows.

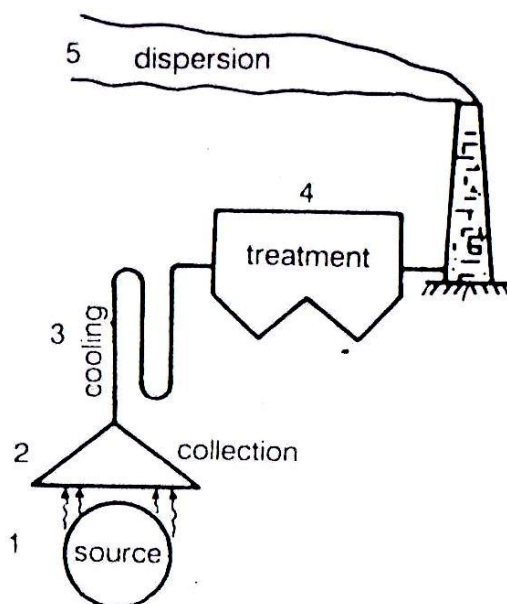


Figure 2.41: Five points of control of possible emission of air pollutants.

1. Source correction

This is the easiest solution to air pollution problem, where we stop the guilty process. Hence, it is also called prevention. The engineer must consider the possibility of controlling the emissions by changing the process. For instance, if automobiles are found to release high lead levels in air, the most reasonable solution is simply to eliminate the lead in the gasolines. The source has been corrected and the problem solved. In addition to a change of raw material, a modification of the process might also be used to achieve a desired result. For example, municipal refuse incinerators are known to stink.

The odors can often be readily controlled if the incinerators are operated at a high enough temperature to completely oxidise the organics which cause the odor. Strictly speaking, such measures as process change, raw material conversion or equipment modification to meet emission standards are known as controls. In contrast, abatement is the term used for all devices and methods for decreasing the quantity of pollutants reaching the atmosphere, once the stuff has already been emitted from the source. In a wider sense and for simplicity, it is better to refer to all of the procedures as controls.

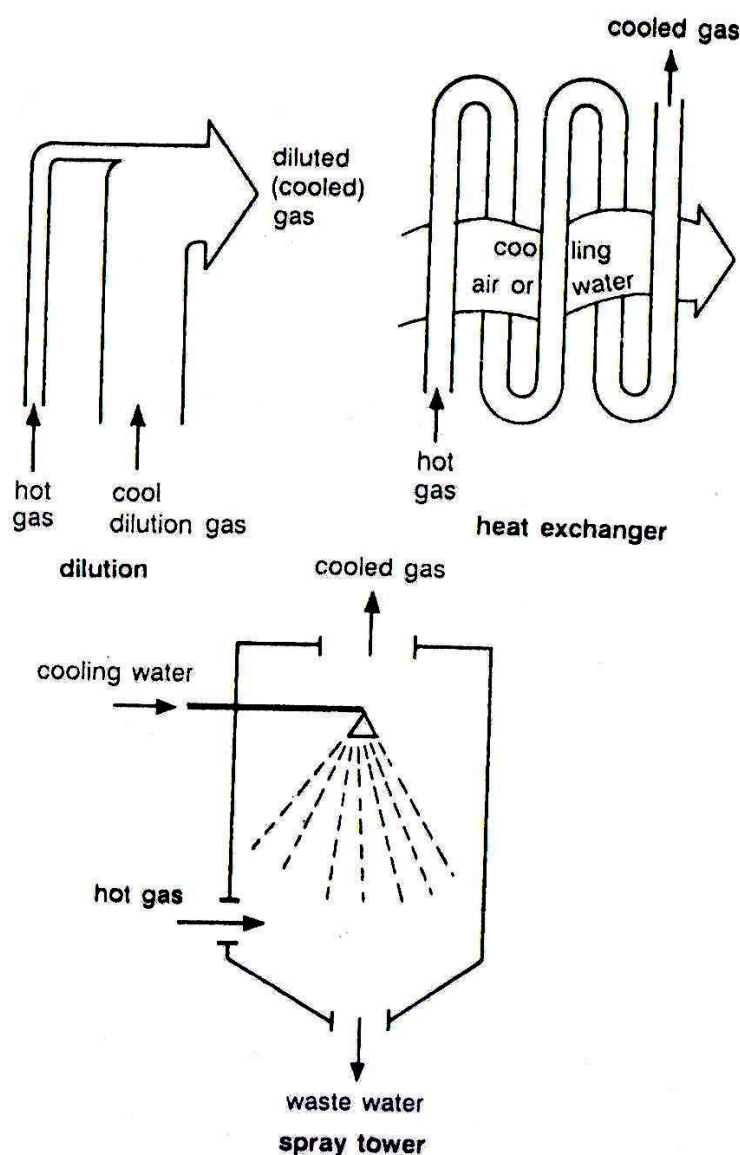


Figure 2.42: Device of cooling hot waste gases.

2. Collection of pollutants

Often the most serious problem in air pollution control is the collection of the pollutants so as to provide treatment. Automobiles are most dangerous, but only because the emissions cannot be readily collected. If we could channel the exhausts from automobiles to some central facilities, their treatment would be much more reasonable than controlling each individual car.

One success in collecting pollutants has been the recycling of blowby gases in the internal combustion engine. By reigniting these gases and emitting them through the car's exhaust system, the need of installing a separate treatment device for the car can be eliminated. Air pollution control engineers have their toughest time when the

pollutants from an industry are not collected but emitted from windows, doors and cracks-in-the-walls.

3. Cooling

The exhaust gases to be treated are sometimes too hot for the control equipment and the gases must first be cooled. This can be done in three general ways: dilution, quenching, or heat exchange coils (Fig. 2.42). Dilution is acceptable only if the total amount of hot exhaust is small. Quenching has the additional advantage of scrubbing out some of these gases and particulates. The cooling coils are perhaps the most widely used, and are especially appropriate when heat can be conserved.

4. Treatment

The selection of the correct treatment device requires the matching of the characteristics of the pollutant and the features of the control device. It is important to realise that the sizes of air pollutants range many orders of magnitude, and it is therefore not reasonable to expect one device to be effective for all pollutants. In addition, the types of chemicals in emissions will often dictate the use of some devices. For example, a gas containing a high concentration of SO₂ could be cleaned by water sprays, but the resulting H₂SO₄ might present serious corrosion problems.

Although, any new devices may appear any day in the market, the following are the most widely used

- a. *Setting chambers*- are nothing more than large places in the flues, similar to settling tanks in water treatment. These chambers remove only the large particulates.
- b. *Cyclones* are widely used for removing large particulates. The dirty air is blasted into a conical cylinder, but off the centerline. This creates a violent swirl within the cone, and the heavy solids migrate to the wall of the cylinder where they slow down due to friction and exit at the bottom of the cone. The clean air is in the middle of the cylinder and exits out the top. Cyclones are widely used as pre-cleaners, to remove the heavy material before further treatment.
- c. *Bag filters* operate like the common vacuum cleaner. Fabric bags are used to collect the dust which must be periodically shaken out of the bags. The fabric removes nearly all particulates. Bag filters are widely used in many industries, but are sensitive to high temperature and humidity.

- d. *Wet collectors* come in many shapes and styles. The simple spray tower (Fig. 2.43) is an effective method for removing large particulates. More efficient scrubbers promote the contact between air and water by violent action in a narrow throat section into which the water is introduced. Generally, the more violent the encounter, and hence the smaller the gas bubbles or water droplets, the more effective the scrubbing.

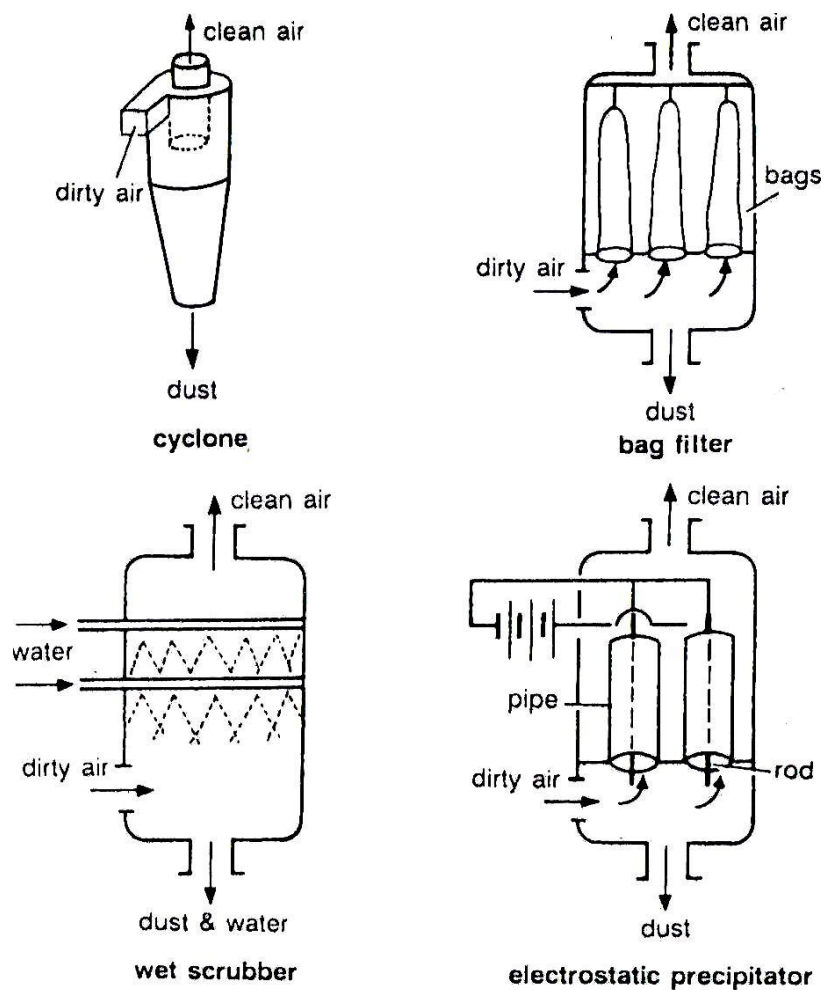


Figure 2.43: Wet collectors and electrostatic precipitators for control of particulate air pollution.

- e. *Electrostatic precipitators* are widely used in power plants. The particulate matter is removed by first being charged by electrons jumping from one high voltage electrode to the other, and then migrating to the positively charged electrode. One type as shown in Fig. 2.43 consists of a pipe with a wire hanging down the middle. The particulates will collect on the pipe and must be removed by banging the pipes with hammers. Electrostatic precipitators have

no moving parts, require electricity, and are extremely effective in removing submicron particulates. They are expensive.

- f. *Gases scrubbers* are simply wet collectors as described above but are used for dissolving the gases.
- g. *Absorption* is the use of a material such as activated carbon to capture pollutants. Such absorbers may be expensive to regenerate. Most of these work well for organics and have limited use for inorganic pollutants. Figure 2.44 shows the steps of an adsorption tower.

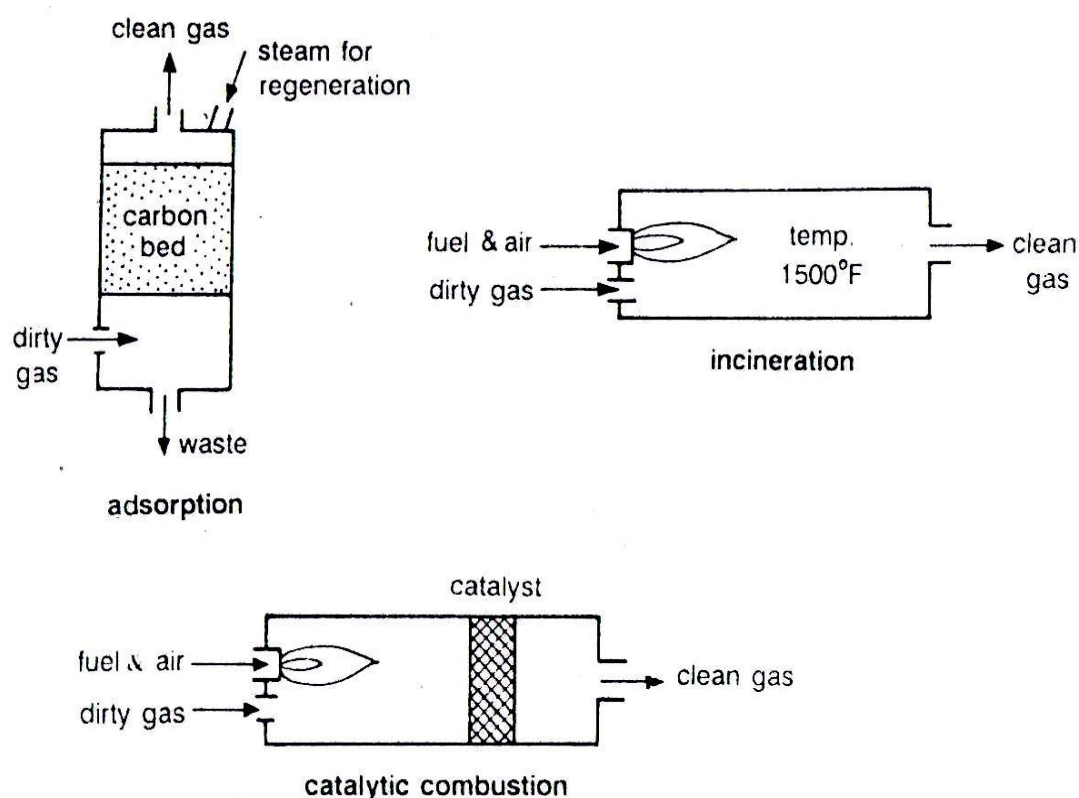


Figure 2.44: An adsorption tower used for control of gaseous pollutants of air.

- h. *Incineration* is a method for removing gaseous pollutants by burning them to CO₂, H₂O and inerts. This works only for combustible vapours.
- i. *Catalytic combustion* involves the use of a catalyst to adsorb or chemically change the pollutants.

It is again important to emphasize the dependence of effectiveness of a treatment device on particle size. Fig. 2.45 shows the approximate ranges of the adaptability for the various treatment methods discussed above.

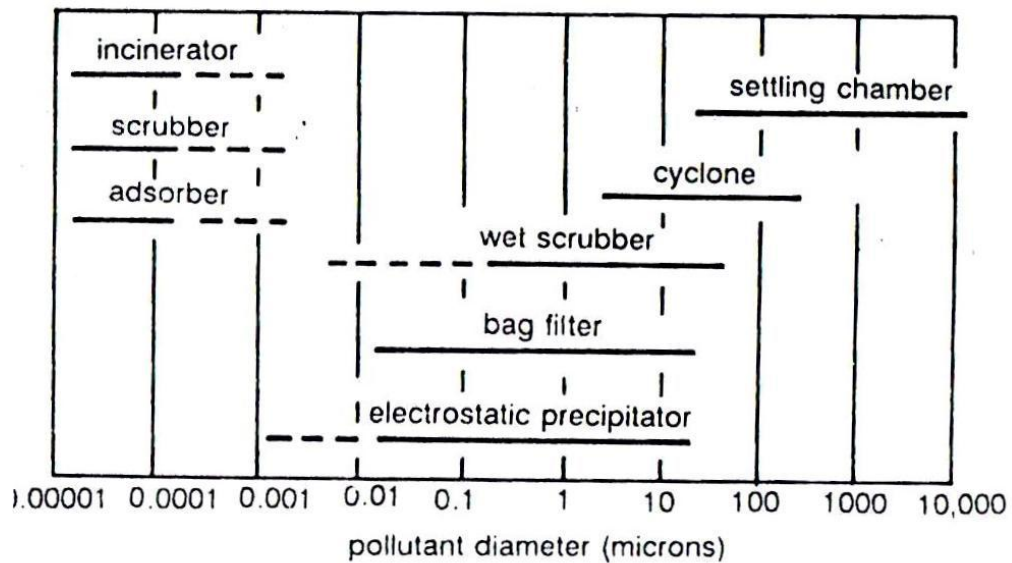


Figure 2.45: Selection of various treatment methods and equipment by particle size in air pollution.

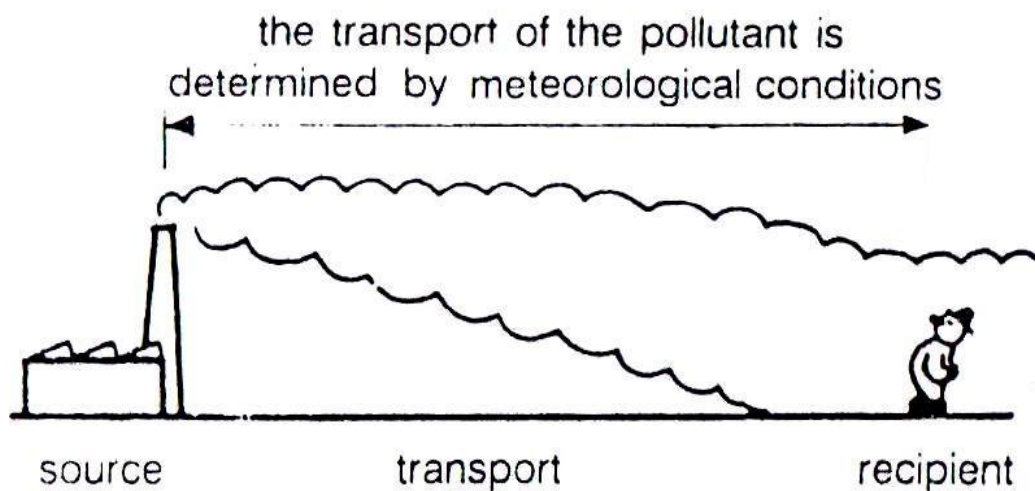


Figure 2.46: Meteorology and air pollution.

Dispersion

The science of meteorology has great bearing on air pollution. An air pollution problem involves three parts. The source, the movement of the pollutant, and the recipient (Fig. 2.46). The concentration of the pollutants at the recipient is affected by atmospheric dispersion, or how the pollutant is diluted with clean air. This dispersion takes place horizontally as well as vertically. Earth rotation presents new areas for the sun to shine upon and to warm air. Accordingly a pattern of winds is set up around the world, some seasonal (e.g. hurricanes) and some permanent. Air pollution engineers

often use a variation of the wind rose (a wind rose arc graphic pictures of wind velocity and direction data), called pollution rose to determine the source of a pollutant.

Diffusion is the process of spreading out the emission over a large area and thus reducing the concentration of the specific pollutants. The plume spread or dispersion as told above is horizontal as well as vertical. We assume that the maximum concentration of pollutants is in the plume centreline, i.e. in the direction of the prevailing wind. As we move further from the centreline, the concentration becomes lower. If we assume that the spread of a plume in both directions is approximated by a Gaussian probability curve, we can calculate the concentration of a pollutant at any distance X downwind from the source.

Episodes can be predicted on the basis of meteorological data, and early warning for impending episode conditions and emergency plans may be developed (as to close down industries).

Control of pollutants from moving sources

Though many of the above said control methods can also apply to moving sources as well, one very special moving source the automobile- deserves special mention. Engine operation has direct effect on the emissions. Amount of CO, HC and NO_x differs during idling, accelerating, cruising and decelerating.

Emission control techniques for the internal combustion automobile engine include tune-ups, catalytic reactors, and engine modifications. A tune-up may have a significant effect on emission components. For example, a high air/fuel ratio (a lean mixture) will reduce both CO and HC, but with increased NO_x. The second control strategy, now extensively used, is the catalytic reactor which oxidises the CO and HC to CO₂ and H₂O, The second reactor reduces NO_x to N₂. The most popular catalyst seems to be platinum which must be periodically regenerated. However, catalyst reactors have two serious drawbacks. First, they are easily fouled by lead. Infact the move to nonlead gasoline has been prompted by this reason and not by the concern for lead levels in the atmosphere. The second problem with the reactors is that the sulphur compounds in gasoline are oxidised to particulate SO₃, and thus increases the sulphur levels in environment.

In third control technique — engine modification, the stratified charge engine, is used without catalytic reactors. In these engines the cylinders have two compartments, with one compartment receiving a rich mixture, igniting, and then providing a broad flame for an efficient burn in the main cylinder compartment. Other modifications have also been developed. It is difficult to manufacture a totally clean internal combustion engine. Electric cars are clean but they can store only limited power and thus their range is limited.

General methods to control air pollution by automobiles and industries have been considered briefly above. Some specific measures to control vehicular and industrial pollutants in air are given below.

Vehicular pollution

1. To check pollutant emission from vehicular exhaust

This can be achieved by

- i. Using new proportion of gasoline and air,
- ii. More exact timing of fuel feeding,
- iii. Using gas additives to improve combustion,
- iv. By injecting air into the exhaust to convert exhaust compounds to less toxic materials, and by
- v. Updating of engine design and/or install abatement equipment (device) to improve combustion with the existing engine design.

Carbon monoxide results from low air content of the fuel mixture, whereas NO_x production is promoted by high combustion temperatures. Hydrocarbons follow more or less the pattern of CO. The complete elimination of these three pollutants may be achieved by either updating the present design of engines or by making appropriate changes in devices for improving combustion. Very recently, I.K. Bharati of Bombay has claimed to have devised a simple attachment —the patented name Thermo reactor, to curb air pollution by motor vehicle. The reactor is fitted to the exhaust tailpipe and it converts carbon monoxide into pure oxygen.

2. To control evaporation from fuel tank and carburetor

This can be done by

- i. Collection of vapours with activated charcoal when the engine is turned off and its ignition when the engine is started,
- ii. Subjecting the gasoline in the tank to slight pressure to prevent the gas from evaporation and
- iii. Developing low-volatile gasoline that does not evaporate easily.

3. Use of filters

Some gas vapours escape between walls and the pistons which enter the crankcase and then discharge into atmosphere. Hydrocarbons (about 25%) are released in this way. Thus use of filters that capture and recycle these escaped gases in the engine should control the emission of these hydrocarbons.

4. Control through Law

There are to be enforced some standards through Motor Vehicles Act and other Acts for design of engines etc. We shall refer to these later.

Industrial pollution

To check air pollution by industrial plant chimney wastes, we must devise measures for removal of the particulate matter and gaseous pollutants from the wastes. Removal of particulate matter involves their collection under the influence of different forces, thereby moving them continuously out of the gas stream. The equipment used for their removal is (i) cyclone collectors, and (ii) electrostatic precipitators (ESPs). Thus we have to generate the control technology. At present there are few power plants and industries that have installed the requisite ESPs.

1. Cyclone collectors

Here the waste gas containing particles is subjected to centrifugation. The suspended particles move towards the wall of cyclone body, and then to its bottom and finally discharged out. The cyclone collectors remove about 70% of the particles.

2. Electrostatic precipitators (ESPs)

To remove the particles from gas stream, the electrical forces are applied within the chamber in the precipitator. Suspended particles become charged or ionised, and they

are attracted to charged electrodes and removed. ESPs can remove 99% of the particulate pollutants from chimney exhaust. ESPs work very well in power plants, paper mills, cement mills, carbon block plants etc. High resistivity dust may make separation in a ESP difficult. To overcome this, fabric filters or begs fillers are employed. But fabric filters are unsuitable for wet or sticky particles, extreme corrosive conditions, and high gas temperatures.

Gaseous pollutants

These can be removed by the following three methods.

(a) Wet systems. There are used washing towers in which alkali fluid circulate continuously. This liquid reacts with SO_2 to produce a precipitate.

(b) Dry systems. Here the gas pollutants are allowed to react with an absorbent under a dry phase. Dolomite, lime (CaO) and limestone (CaOH) are placed in the way of the flowing gas (SO_2). The process is not very expensive and does not involve any spray of water. Water in contact with SO_2 produces corrosive H_2SO_4 .

(c) Wet dry systems. Here water in the absorbent reacts with the acid components. This offers an alternative to traditional wet process used for desulphurisation of fuel gases from coal-fired boilers. The absorbent calcium hydroxide slurry is spread into the hot gas stream in the form of small droplets. Calcium reacts with SO_2 and the hot gases cause the water to evaporate simultaneously. The end product is a dry power containing mostly fly ash and salts. Charcol can also be used as an absorbent. Other absorbers can also be used to pick up alcohols and benzenes. This method is very effective in dry cleaning plants, printing shops, and paint factories, food processing plants, breweries and pharmaceutical industries. Combustion of gases can also be used for petroleum industries etc.

Control through law. Like motor vehicles, standards are to be enforced by appropriate Acts for industries also. There are other conditions that could be enforced by law.

AIR QUALITY PARAMETERS

The air we breathe can consist of many contaminants including ozone, sulfur dioxide (SO_2) particulate matter, volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Each of these contaminants has specific impacts on human health and the environment and is therefore monitored by the Department of Environmental Protection. The results of this monitoring are tracked below.

Ozone

Ozone is produced by ultraviolet light from the Sun hitting the Earth's atmosphere (especially in the ozone layer), lightning, certain electric devices (such as air ionisers), and as a byproduct of other types of pollution. Ozone exists in greater concentrations at altitudes commonly flown by passenger jets. Reactions between ozone and onboard substances, including skin oils and cosmetics, can produce toxic chemicals as byproducts. Ozone itself is also irritating to lung tissue and harmful to human health. Larger jets have ozone filters to reduce the cabin concentration to safer and more comfortable levels.

Nitrogen oxides (NO_x)

Nitrogen oxides is a generic term for a group of highly reactive gases, all of which contain nitrogen and oxygen in varying amounts, which cause acid rain, ozone formation, and eutrophication of coastal waters. Burning fossil fuels, such as coal and gasoline releases NO_x into the atmosphere. The primary sources of NO_x are motor vehicles (49%), electric utilities (27%), and other industrial, commercial, and residential sources that burn fuels (24%) Health effects include: increased susceptibility to respiratory infections, increased strain on pulmonary and respiratory systems. For further information on nitrogen oxides, click on the following links.

Sulfur Dioxide (SO₂)

Sulfur Dioxide is a colorless, toxic gas with a characteristic-suffocating odor produced by power plants and industries those burn fossil fuels that contain sulfur, such as coal and oil, and by the phosphate industry through its production of sulfuric acid. The sulfur dioxide that is produced by the burning of sulfur compounds reacts with the moisture in the air to form sulfuric acid, a major component of acid rain. Health effects include: affects breathing and may aggravate existing respiratory and cardiovascular disease. For further information on Sulfur Dioxide, click on the following links.

Carbon dioxide

Carbon dioxide (CO₂) is a surrogate for indoor pollutants emitted by humans and correlates with human metabolic activity. Carbon dioxide at levels that are unusually high indoors may cause occupants to grow drowsy, get headaches, or function at lower activity levels. Humans are the main indoor source of carbon dioxide. Indoor

levels are an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity. To eliminate most Indoor Air Quality complaints, total indoor carbon dioxide should be reduced a difference of less than 600 ppm above outdoor levels. NIOSH considers that indoor air concentrations of carbon dioxide that exceed 1,000 ppm are a marker suggesting inadequate ventilation. ASHRAE recommends that carbon dioxide levels not exceed 700 ppm above outdoor ambient levels.^[7] The UK standards for schools say that carbon dioxide in all teaching and learning spaces, when measured at seated head height and averaged over the whole day should not exceed 1,500 ppm. The whole day refers to normal school hours (i.e. 9.00am to 3.30pm) and includes unoccupied periods such as lunch breaks. European standards limit carbon dioxide to 3500 ppm. OSHA limits carbon dioxide concentration in the workplace to 5,000 ppm for prolonged periods, and 35,000 ppm for 15 minutes.

Carbon monoxide

One of the most acutely toxic indoor air contaminants is carbon monoxide (CO), a colorless, odorless gas that is a byproduct of incomplete combustion of fossil fuels. Common sources of carbon monoxide are tobacco smoke, space heaters using fossil fuels, defective central heating furnaces and automobile exhaust. Improvements in indoor levels of CO are systematically improving from increasing numbers of smoke-free restaurants and other legislated non-smoking buildings. By depriving the brain of oxygen, high levels of carbon monoxide can lead to nausea, unconsciousness and death. According to the American Conference of Governmental Industrial Hygienists (ACGIH), the time-weighted average (TWA) limit for carbon monoxide (630-08-0) is 25 ppm.

Volatile organic compounds

Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. VOCs are emitted by a wide array of products numbering in the thousands. Examples include: paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper,

graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions.

Particulate Matter

Particulate matter is the generic term used for a type of air pollution that consists of complex and varying mixtures particles suspended in the air we breathe. Particulate matter is a combination of fine solids such as dirt, soil dust, pollens, molds, ashes, and soot: and aerosols that are formed in the atmosphere from gaseous combustion by-products such as volatile organic compounds, sulfur dioxide, and nitrogen oxides. Particulate matter is directly emitted into the air by sources such as factories, power plants, cars, construction activity, fires and natural windblown dust. Health effects include: effects on breathing and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defense system against foreign materials, damage to lung tissue, carcinogenesis and premature death. For further information on particulate matter, click on the following links:

Ventilation is an indication of the ability of the atmosphere to replace the air over a given point with new or fresh air which is hopefully cleaner than the air it replaces. It is dependent on the mixing layer depth and the wind speed within that layer. As the name suggests, the mixing layer is zone near the surface through which the air mixes mostly due to low level winds and also vertical mixing due do heating. The depth of this layer depends on the temperature and on the stability of the atmosphere at low level. Shallower mixing layers indicate that the pollutants will be mixed in a smaller volume of air and therefore there is less dispersion of pollutants.

Molds and other allergens

These biological chemicals can arise from a host of means, but there are two common classes: (a) moisture induced growth of mold colonies and (b) natural substances released into the air such as animal dander and plant pollen. Moisture buildup inside buildings may arise from water penetrating compromised areas of the building envelope or skin, from plumbing leaks, from condensation due to improper ventilation, or from ground moisture penetrating a building part. In areas where cellulosic materials (paper and wood, including drywall) become moist and fail to dry within 48 hours, mold mildew can propagate and release allergenic spores into the air.

In many cases, if materials have failed to dry out several days after the suspected water event, mold growth is suspected within wall cavities even if it is not immediately visible. Through a mold investigation, which may include destructive inspection, one should be able to determine the presence or absence of mold. In a situation where there is visible mold and the indoor air quality may have been compromised, mold remediation may be needed. Mold testing and inspections should be done by an independent investigator to avoid any conflict of interest and to insure accurate results; free mold testing offered by remediation companies is not recommended.

There are some varieties of mold that contain toxic compounds (mycotoxins). However, exposure to hazardous levels of mycotoxin via inhalation is not possible in most cases, as toxins are produced by the fungal body and are not at significant levels in the released spores. The primary hazard of mold growth, as it relates to indoor air quality, comes from the allergenic properties of the spore cell wall. More serious than most allergenic properties is the ability of mold to trigger episodes in persons that already have asthma, a serious respiratory disease.

Legionella

Legionellosis or Legionnaire's Disease is caused by a waterborne bacterium *Legionella* that grows best in slow-moving or still, warm water. The primary route of exposure is aerosolization, most commonly from evaporative cooling towers or showerheads. A common source of *Legionella* in commercial buildings is from poorly placed or maintained evaporative cooling towers, which often release aerosolized water that may enter nearby ventilation intakes. Outbreaks in medical facilities and nursing homes, where patients are immuno-suppressed and immuno-weak, are the most commonly reported cases of Legionellosis. More than one case has involved outdoor fountains in public attractions. The presence of *Legionella* in commercial building water supplies is highly under-reported, as healthy people require heavy exposure to acquire infection.

Asbestos fibers

The U.S. Federal Government and some States have set standards for acceptable levels of asbestos fibers in indoor air. Many common building materials used before 1975 contain asbestos, such as some floor tiles, ceiling tiles, taping muds, pipe wrap,

mastics and other insulation materials. Normally significant releases of asbestos fiber do not occur unless the building materials are disturbed, such as by cutting, sanding, drilling or building remodelling. There are particularly stringent regulations applicable to schools.

Inhalation of asbestos fibers over long exposure times is associated with increased incidence of lung cancer. Asbestos is found in older homes and buildings, but it is most dangerous in schools and industrial settings. It was once widely used in shingles, fireproofing, heating systems and floor and ceiling, tiles in older buildings. When asbestos-containing material is damaged or disintegrates, microscopic fibers are dispersed into the air. The risk of lung cancer from inhaling asbestos fibers is also greater to smokers. The symptoms of the disease do not usually appear until about 20 to 30 years after the first exposure to asbestos. Removal of asbestos-containing materials is not always optimal because the fibers can be spread into the air during the removal process. A management program for intact asbestos-containing materials is often recommended instead.

Air Quality Standards

This nation-wide programe was initiated in 1984. As on March 31, 1995, the network comprised 290 stations covering over 90 towns/cities distributed over 24 States and 4 Union Territories. The National Ambient Air Quality Monitoring (NAAQM) network is operated through the respective States Pollution Control Boards, the National Environmental Engineering Research Institute (NEERI), Nagpur and also through the CPCB. The pollutants monitored are Sulphur dioxide (SO₂), Nitrogen dioxide (NO₂) and Suspended Particulate Matter (SPM) besides the meteorological parameters, like wind speed & direction, temperature and humidity. In addition to the three conventional parameters, NEERI monitors special parameters, like Ammonia (NH₃), Hydrogen Sulphide (H₂S), Respirable Suspended Particulate Matter (RSPM) and Polyaromatic Hydrocarbons (PAH).

Based on Annual Mean Concentration (microgram per cubic meter of ambient air) of SO₂, NO₂ and SPM and the Notified Ambient Air Quality Standards, the Ambient Air Quality Status is described in terms of Low (L), Moderate (M), High (H) and Critical (C) for Industrial (I), Residential and mixed use (R) areas of Cities/Towns in different States/UTs.

Table 2.13: National Ambient Air quality Standards (NAAQS).

Pollutants	Time weighted Average	Concentration of Ambient Air			
		Industrial Area	Residential Rural and other area	Sensitive area	Method of Measurement
Sulphur Dioxide (SO ₂)	Annual Average 24 hours	80 g/m ³ 120 g/m ³	60 g/m ³ 80 g/m ³	15 g/m ³ 30 g/m ³	Improved west and Gacke
Oxides of Nitrogen (NO ₂)	Annual Average 24 hours	80 g/m ³ 120 g/m ³	60 g/m ³ 80 g/m ³	15 g/m ³ 30 g/m ³	Jacob Hochheister modified (Na-Arsentire method Gas Phase
Suspended Particulate Matter (SPM)	Annual Average 24 hours	360 g/m ³ 500 g/m ³	140 g/m ³ 200 g/m ³	70 g/m ³ 100 g/m ³	High Volume sampling (average flow rate not less than 1.1 m ³ /minute)
Respirable Particulate Matter (size Less than 10 m) RPM	Annual Average 24 hours	120 g/m ³ 150 g/m ³	60 g/m ³ 100 g/m ³	50 g/m ³ 75 g/m ³	Respirable particulate matter sampler
Lead as Pb	Annual Average 24 hours	1.0 g/m ³ 1.5 g/m ³	0.75 g/m ³ 1.0 g/m ³	0.50 g/m ³ 0.75 g/m ³	AAS method after sampling using EPM 2000 or equivalent filter paper
Carbon Monoxide	8 hours 1 hour	5.0mg/m ³ 10.0mg/m ³	2.0mg/m ³ 4.0mg/m ³	1.0mg/m ³ 2.0mg/m ³	Non disbersive infrared spectroscopy

Environmental pollution remains a serious issue in the developing world, affecting the lives of billion people, reducing their life expectancy, and damaging children's growth and development. The Government has recently revised the National Ambient Air Quality Standards (NAAQS) and limits for 12 pollutants have been notified. Area classification based on land –use has been done away with so that industrial areas have to conform to the same standards as those for residential areas. The annual average norms for Lead, Nitrogen Dioxide (No₂), Arsenic, Nickel, Benzene and Benzo(a) Pyrene in ambient air are at par with the European Union norms. However, the norms for Particulate Matter having size less than 10 micron (PM₁₀) and Particulate Matter having size less than 2.5 micron (PM_{2.5}) are more relaxed than EU norms. Indian norms for Carbon Monoxide, Ozone and Sulphur Dioxide (SO₂) are more stringent than EU norms. Ammonia is additionally included in our NAAQS.

Under the Environment Surveillance Programme, CPCB has undertaken the task of development of monitoring protocols and the infrastructure needed for monitoring and enforcement of the new ambient air quality norms. It undertakes inspection of various industrial units under the 17 categories of highly polluting industries to verify compliance to the prescribed standards. Based on the level of non-compliance observed, directions are issued to the concerned State Pollution Control Boards under section 18(I)(b) of the water (Prevention and Control of Pollution) Act, 1974 and / or The Air (Prevention and Control of Pollution) Act, 1981 as the case may be, and directly to the industries under section 5 of The Environment Protection Act, 1986. Such actions have been taken against major defaulters in sectors like Thermal Power, Cement, Fertilizers, etc., by the CPCB.

National Ambient Air Quality Standards are the limits for levels of air pollutants with an adequate margin of safety to protect the public health, vegetation and property. There were 7 parameters, namely, Sulphur Dioxide (SO₂), Oxides of Nitrogen (NO_x), Suspended Particulate Matter (SPM), Respirable Particulate Matter (RSPM,) Lead Carbon Monoxide (CO) and Ammonia (NH₃) notified under the Air Act, 1981 and the Environment (Protection) Act, 1986.

National Ambient Air Quality Standards (NAAQS) were earlier notified in the year 1994 under the Air Act. There is a difference between the World Health Organisations norms-2005 and our revised standards / NAAQS. Whereas we have prescribed 12 parameters, mainly, PM₁₀, PM_{2.5}, SO₂, NO₂, CO, NH₃, Ozone, Lead, Benzene, Benzo-a Pyrene, Arsenic and Nickle. WHO has suggested five parameters, out of which, only four are to be monitored i.e PM₁₀/ PM 2.5, Sulphur Dioxide, Nitrogen Dioxide and Ozone.

The CPCB monitors PM_{2.5}, Ozone (ground level), Carbon Monoxide, Lead, Hydrocarbons, Ammonia, Benzene, etc., at selected locations in few cities apart from Sulphur Dioxide, Nitrogen Dioxide and PM₁₀ at all locations under National Air Monitoring Programme(NAMP).

WHO Air Quality Guidelines

WHO first came up with air quality guidelines in 1987 which were updated in 1996 and subsequently revised in 2000. These were known as Air Quality Guidelines for Europe. Thereafter WHO issued guidelines in 2005 on air quality.

Execution of Air Quality Monitoring

The CPCB is executing a nation-wide programme of ambient air quality monitoring known as National Air Monitoring Programme (NAMP). The programme was started in the year 1984-85 from Agra and Anpara in Uttar Pradesh and gradually the network has been extended to various parts of the country.

Under the National Air Monitoring Programme (NAMP), the Central Pollution Control Board (CPCB) with the assistance of 26 State Pollution Control Board (SPCBs) in respective States, 5 Pollution control Committees (PCCs) in various UTs along with the National Environment Engineering Research Institute (NEERI- a laboratory of Council of Scientific and Industrial Research (are monitoring ambient air quality through 363 stations in 139 cities as on 30.11.2009 across the country.

Parameters by CPCB / SPCBs /PCCs for Air Quality

Under the National Air Quality Monitoring Programme (NAMP), three major air pollutants viz., Sulphur Dioxide (SO₂), Nitrogen Dioxide (NO₂) and Respirable Particulate Matter or fine dust (RPM/PM₁₀), are being monitored regularly. Besides these air pollutants, the CPCB is also monitoring Lead, Carbon Monoxide Benzene, and Particulate Matter with size less than 2.5 micrometre and ground level Ozone in Delhi.

Sulphur Dioxide (SO₂), Nitrogen Dioxide (NO₂) and Respirable Particulate Matter or Fine dust (RPM/PM₁₀) are the routine parameters for air quality monitoring across the country. Carbon Monoxide, ground level Ozone, Particulate Matter with size less than 2.5 micrometre (PM_{2.5}) Ammonia, etc., are the parameters which will be taken up for monitoring in a phased manner in metro cities to begin with. A roadmap is being prepared by the CPCB for the new parameters included in NAAQS which would be monitored under NAMP. Ministry of Environment and Forests on 16.11.2009 has notified National Ambient Air Quality Standards with a view to assess ambient air quality status in the country with respect to 12 pollutants.

Various air pollutants as per the standards are monitored based on the time weighted average. The monitoring of pollutants is carried out in different areas namely, industrial, residential, rural and other areas, and in ecologically sensitive areas. The notified standards also prescribe methods of measurement of the pollutants. For Each category of air polluting industry, emission standards are prescribed separately for their compliance. To revise the standards major considerations are taken into account.

Air Quality Index (AQI)

Air quality is defined as a measure of the condition of air relative to the requirements of one or more biotic species and or to any human need or purpose.



Figure 2.47: An air quality measurement station in Edinburgh, Scotland.

The Air Quality Index (AQI) (also known as the Air Pollution Index (API) or Pollutant Standard Index (PSI) is a number used by government agencies to characterize the quality of the air at a given location. As the AQI increases, an increasingly large percentage of the population is likely to experience increasingly severe adverse health effects. To compute the AQI requires an air pollutant concentration from a monitor or model. The function used to convert from air pollutant concentration to AQI varies by pollutant, and is different in different countries. Air quality index values are divided into ranges, and each range is assigned a descriptor and a color code. Standardized public health advisories are associated with each AQI range. An agency might also encourage members of the public to take public transportation or work from home when AQI levels are high.

The AQI can worsen (go up) due to lack of dilution of air emissions by fresh air. Stagnant air, often caused by an anticyclone or temperature inversion, or other lack of winds lets air pollution remain in a local area.

The Air Pollution Index (API)

The Air Pollution Index (API) levels for Hong Kong are related to the measured concentrations of ambient respirable suspended particulate (RSP), sulfur dioxide (SO₂), carbon monoxide (CO), ozone (O₃) and nitrogen dioxide (NO₂) over a 24-hour period based on the potential health effects of air pollutants.

An API level at or below 100 means that the pollutant levels are in the satisfactory range over 24 hour period and pose no acute or immediate health effects. However, air pollution consistently at "High" levels (API of 51 to 100) in a year may mean that the annual Hong Kong "Air Quality Objectives" for protecting long-term health effects could be violated. Therefore, chronic health effects may be observed if one is persistently exposed to an API of 51 to 100 for a long time. "Very High" levels (API in excess of 100) means that levels of one or more pollutant(s) is/are in the unhealthy range. The Hong Kong Environmental Protection Department provides advice to the public regarding precautionary actions to take for such levels.

Table 2.14.

API	Air Pollution Level	Health Implications
0 - 25	Low	None expected
26 - 50	Medium	None expected for the general population
51 - 100	High	Acute health effects are not expected but chronic effects may be observed if one is persistently exposed to such levels
100 - 200	Very High	People with existing heart or respiratory illnesses may notice mild aggravation of their health conditions. Generally healthy individuals may also notice some discomfort.
201 - 500	Severe	People with existing heart or respiratory illnesses may experience significant aggravation of their symptoms. There may also be widespread symptoms in the healthy population (e.g. eye irritation, wheezing, coughing, phlegm and sore throats).

API Mechanics

An individual score is assigned to the level of each pollutant and the final API is the highest of those 5 scores. The pollutants can be measured quite differently. SO₂, NO₂

and PM₁₀ concentration are measured as average per day. CO and O₃ are more harmful and are measured as average per hour. The final API value is calculated per day.

The scale for each pollutant is non-linear, as is the final API score. Thus an API of 100 does not mean twice the pollution of API at 50, nor does it mean twice as harmful. While an API of 50 from day 1 to 182 and API of 100 from day 183 to 365 does provide an annual average of 75, it does *not* mean the pollution is acceptable even if the benchmark of 100 is deemed safe. This is because the benchmark is a 24 hour target. The annual average must match against the annual target. It is entirely possible to have safe air every day of the year but still fail the annual pollution benchmark.

Table 2.15: API and Health Implications (Daily Targets).

API	Air Pollution Level	Health Implications
0 - 50	Excellent	No health implications
51 -100	Good	No health implications
101-150	Slightly Polluted	Slight irritations may occur, individuals with breathing or heart problems should reduce outdoor exercise.
151-200	Lightly Polluted	Slight irritations may occur, individuals with breathing or heart problems should reduce outdoor exercise.
201-250	Moderately Polluted	Healthy people will be noticeably affected. People with breathing or heart problems will experience reduced endurance in activities. These individuals and elders should remain indoors and restrict activities.
251-300	Heavily Polluted	Healthy people will be noticeably affected. People with breathing or heart problems will experience reduced endurance in activities. These individuals and elders should remain indoors and restrict activities.
300 +	Severely Polluted	Healthy people will experience reduced endurance in activities. There may be strong irritations and symptoms and may trigger other illnesses. Elders and the sick should remain indoors and avoid exercise. Healthy individuals should avoid out door activities.

Indoor air quality

Indoor air quality (IAQ) is a term referring to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants. IAQ can be affected by microbial contaminants (mold, bacteria), gases (including carbon monoxide, radon, volatile organic compounds), particulates, or any

mass or energy stressor that can induce adverse health conditions. Indoor air is becoming an increasingly more concerning health hazard than outdoor air. Using ventilation to dilute contaminants, filtration, and source control are the primary methods for improving indoor air quality in most buildings.

Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces and computer modelling of air flow inside buildings.

Developing countries

A major source of indoor air pollution in developing countries is the burning of biomass (e.g. wood, charcoal, dung, or crop residue) for heating and cooking. The resulting exposure to high levels of particulate matter resulted in between 1.5 million and 2 million deaths in 2000.

Effect of indoor plants

Houseplants together with the medium in which they are grown can reduce components of indoor air pollution, particularly volatile organic compounds (VOC) such as benzene, toluene, and xylene. Plants can also remove CO₂, which is correlated with lower work performance, from indoor areas. The effect was investigated in one study by NASA for use in spacecrafts. Plants also appear to reduce airborne microbes, molds, and increase humidity. However the presence of plants indoors has also been associated with higher humidity and airborne fungal concentrations.

When CO₂ concentrations are elevated indoors relative to outdoor concentrations, it is only an indicator that ventilation is inadequate to remove metabolic products associated with human occupancy. Plants require CO₂ to grow and release oxygen when they consume CO₂. A study published by the American Chemical Society on October 6, 2009 considered uptake rates of ketones and aldehydes by the peace lily (*Spathiphyllum clevelandii*) and golden pothos (*Epipremnum aureum*.) Akira Tani and C. Nicholas Hewitt found "Longer-term fumigation results revealed that the total uptake amounts were 30–100 times as much as the amounts dissolved in the leaf, suggesting that volatile organic carbons are metabolized in the leaf and/or translocated through the petiole." It is worth noting the researchers sealed the plants in Teflon bags. "No VOC loss was detected from the bag when the plants were absent.

However, when the plants were in the bag, the levels of aldehydes and ketones both decreased slowly but continuously, indicating removal by the plants"

While results do indicate house plants may be effective at removing some VOCs from air supplies, many studies neglect to consider ventilation, reductions when faced with continuous emission rather than burst, and other real world factors. A review of studies between 1989 and 2006 on the performance of houseplants as air cleaners, presented at the Healthy Buildings 2009 conference in Syracuse, NY, concluded "...indoor plants have little, if any, benefit for removing indoor air of VOC in residential and commercial buildings." Since high humidity is associated with increased mold growth, allergic responses, and respiratory responses, the presence of additional moisture from houseplants may not be desirable in all indoor settings.

HVAC design

Environmentally Sustainable Design concepts also include aspects related to the commercial and residential heating, ventilation and air-conditioning (HVAC) industry. Among several considerations, one of the topics to attended to is the issue of indoor air quality throughout the design and construction stages of a building's life. One technique to reduce energy consumption while maintaining adequate air quality, is *demand controlled ventilation*. Instead of setting throughput at a fixed air replacement rate, carbon dioxide sensors are used to control the rate dynamically, based on the emissions of actual building occupants.

For the past several years, there have been many debates among indoor air quality specialists about the proper definition of indoor air quality and specifically what constitutes "acceptable" indoor air quality. One way of quantitatively ensuring the health of indoor air is by the frequency of effective turnover of interior air by replacement with outside air. In the UK, for example, classrooms are required to have 2.5 outdoor air changes per hour. In halls, gym, dining, and physiotherapy spaces, the ventilation should be sufficient to limit carbon dioxide to 1,500 ppm. In the USA, and according to ASHRAE Standards, ventilation in classrooms is based on the amount of outdoor air per occupant plus the amount of outdoor air per unit of floor area, not air changes per hour. Since carbon dioxide indoors comes from occupants and outdoor air, the adequacy of ventilation per occupant is indicated by the concentration indoors minus the concentration outdoors. The value of 615 ppm above the outdoor

concentration indicates approximately 15 cubic feet per minute of outdoor air per adult occupant doing sedentary office work where outdoor air contains 385 ppm, the current global average atmospheric CO₂ concentration. In classrooms, the requirements in the ASHRAE standard 62.1.

Ventilation for Acceptable Indoor Air Quality would typically result in about 3 air changes per hour, depending on the occupant density. Of course the occupants aren't the only source of pollutants, so outdoor air ventilation may need to be higher when unusual or strong sources of pollution exist indoors. When outdoor air is polluted, then bringing in more outdoor air can actually worsen the overall quality of the indoor air and exacerbate some occupant symptoms related to outdoor air pollution. Generally, outdoor country air is better than indoor city air. Exhaust gas leakages can occur from furnace metal exhaust pipes that lead to the chimney when there are leaks in the pipe and the pipe gas flow area diameter has been reduced.

Dilution of indoor pollutants with outdoor air is effective to the extent that outdoor air is free of harmful pollutants. Ozone in outdoor air occurs indoors at reduced concentrations because ozone is highly reactive with many chemicals found indoors. The products of the reactions between ozone and many common indoor pollutants include organic compounds that may be more odorous, irritating, or toxic than those from which they are formed. These products of ozone chemistry include formaldehyde, higher molecular weight aldehydes, acidic aerosols, and fine and ultrafine particles, among others. The higher the outdoor ventilation rate, the higher the indoor ozone concentration and the more likely the reactions will occur, but even at low levels, the reactions will take place. This suggests that ozone should be removed from ventilation air, especially in areas where outdoor ozone levels are frequently high. Recent research has shown that mortality and morbidity increase in the general population during periods of higher outdoor ozone and that the threshold for this effect is around 20 parts per billion (ppb).

Institutional programs

The topic of IAQ has become popular due to the greater awareness of health problems caused by mold and triggers to asthma and allergies. Awareness has also been increased by the involvement of the United States Environmental Protection Agency.

They have developed an "IAQ Tools for Schools" program to help improve the indoor environmental conditions in educational institutions (see external link below).

The National Institute for Occupational Safety and Health conducts Health Hazard Evaluations (HHEs) in workplaces at the request of employees, authorized representative of employees, or employers, to determine whether any substance normally found in the place of employment has potentially toxic effects, including indoor air quality. A variety of scientists work in the field of indoor air quality including chemists, physicists, mechanical engineers, biologists, bacteriologists and computer scientists. Some of these professionals are certified by organizations such as the American Industrial Hygiene Association and the American Indoor Air Quality Council.

On the international level, the International Society of Indoor Air Quality and Climate (ISIAQ), formed in 1991, organizes two major conferences, the Indoor Air and the Healthy Buildings series. ISIAQ's journal *Indoor Air* is published 6 times a year and contains peer-reviewed scientific papers with an emphasis on interdisciplinary studies including exposure measurements, modeling, and health outcomes.

Emission standard

Emission standards are requirements that set specific limits to the amount of pollutants that can be released into the environment. Many emissions standards focus on regulating pollutants released by automobiles (motor cars) and other powered vehicles but they can also regulate emissions from industry, power plants, small equipment such as lawn mowers and diesel generators. Frequent policy alternatives to emissions standards are technology standards (which mandate Standards generally regulate the emissions of nitrogen oxides (NO_x), sulfur oxides, particulate matter (PM) or soot, carbon monoxide (CO), or volatile hydrocarbons (see carbon dioxide equivalent).

Vehicle Emission performance standard

An emission performance standard is a limit that sets thresholds above which a different type of emission control technology might be needed. While emission performance standards have been used to dictate limits for conventional pollutants such as oxides of nitrogen and oxides of sulfur (NO_x and SO_x),^[1] this regulatory

technique may be used to regulate greenhouse gasses, particularly carbon dioxide (CO₂). In the US, this is given in pounds of carbon dioxide per megawatt-hour (lbs. CO₂/MWhr), and kilograms CO₂/MWhr elsewhere in the world...

India

The first Indian emission regulations were idle emission limits which became effective in 1989. These idle emission regulations were soon replaced by mass emission limits for both petrol (1991) and diesel (1992) vehicles, which were gradually tightened during the 1990s. Since the year 2000, India started adopting European emission and fuel regulations for four-wheeled light-duty and for heavy-dc. Indian own emission regulations still apply to two- and three-wheeled vehicles. Current requirement is that all transport vehicles carry a fitness certificate that is renewed each year after the first two years of new vehicle registration.

On October 6, 2003, the National Auto Fuel Policy has been announced, which envisages a phased program for introducing Euro 2 - 4 emission and fuel regulations by 2010.

Overview of the emission norms in India by CDR

- 1991 - Idle CO Limits for Gasoline Vehicles and Free Acceleration Smoke for Diesel Vehicles, Mass Emission Norms for Gasoline Vehicles.
- 1992 - Mass Emission Norms for Diesel Vehicles.
- 1996 - Revision of Mass Emission Norms for Gasoline and Diesel Vehicles, mandatory fitment of Catalytic Converter for Cars in Metros on Unleaded Gasoline.
- 1998 - Cold Start Norms Introduced.
- 2000 - India 2000 (Eq. to Euro I) Norms, Modified IDC (Indian Driving Cycle), Bharat Stage II Norms for Delhi.
- 2001 - Bharat Stage II (Eq. to Euro II) Norms for All Metros, Emission Norms for CNG & LPG Vehicles.
- 2003 - Bharat Stage II (Eq. to Euro II) Norms for 11 major cities.
- 2005 - From 1 April Bharat Stage III (Eq. to Euro III) Norms for 11 major cities.
- 2010 - Bharat Stage III Emission Norms for 4-wheelers for entire country whereas Bharat Stage - IV (Eq. to Euro IV) for 13 major cities. Bharat Stage IV also has norms on OBD (similar to Euro III but diluted).

MEASUREMENT OF WATER QUALITY

Quantitative measurements of pollutants are necessary before water pollution can be controlled. Analytical methods used in water and wastewater engineering are standard methods given in APHA (American Public Health Association).

I. Dissolved oxygen

The amount of oxygen dissolved in water is usually measured either by an oxygen probe or the old standard wet technique, the Winkler Dissolved Oxygen Test. This test is the standard to which all other methods are compared. The chemistry of Winkler test is as follows.

Mn^{++} ions added to the sample combine with the available oxygen.

$Mn^{++} + O_2 \longrightarrow MnO_2$ forming a precipitate.

Iodide ions are added and the manganous oxide reacts with the iodide ions to form iodine

$MnO_2 + 2I^- + 4H^+ \longrightarrow Mn^{++} + I_2 + 2H_2O$

The quantity of iodine is measured by titrating with sodium thiosulphate,

$I_2 + 2S_2O_3^{2-} \longrightarrow S_4O_6^{2-} + 2I^-$

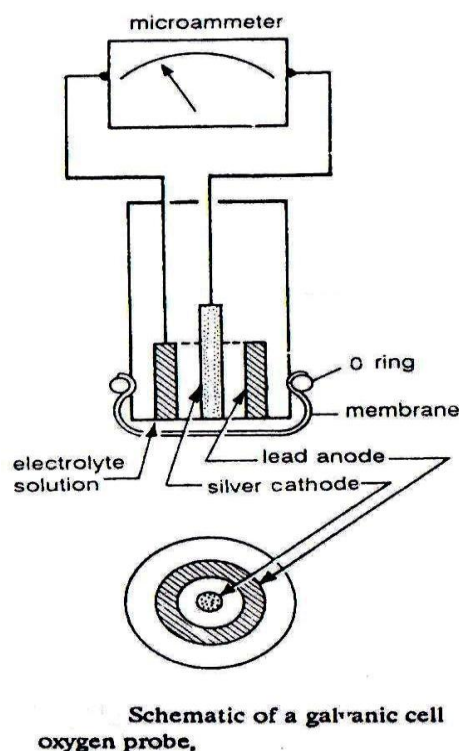


Figure 2.48: Schematic of galvanic cell oxygen probe.

All of the dissolved oxygen combines with Mn^{++} so that the quantity of MnO_2 is directly proportional to the oxygen in solution. There are some disadvantages with this test. One, chemical interference and second, to carry a wet laboratory to field or bring samples to the laboratory and third, risk of loss or gain of oxygen during transport. All these problems are overcome by using a dissolved oxygen electrode, often called a probe.

The simplest probe is shown in Fig. 2.48 and the operation is that of a galvanic cell. If lead and silver electrodes are put in an electrolyte solution with a micro ammeter between, the reaction at the lead electrode would be

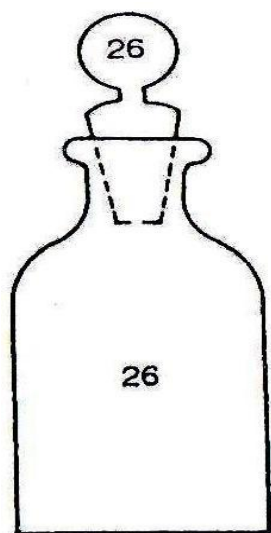


At the lead electrode, electrons are liberated which travel through the microammeter to the silver electrode where the following reaction takes place.



The reaction would not go unless free dissolved oxygen is available, and the microammeter would not register any current. The trick is to construct and calibrate a meter in such a way that electricity recorded is proportional to the concentration of oxygen in the electrolyte solution.

II. Biochemical oxygen demand (BOD)



BOD bottle.

Figure 2.49: BOD bottle

BOD is taken as indirect measure of water quality. It is infact a measure of the amount of oxygen required by microbes while stabilising decomposable organic matter. Two bottles are filled with stream water, measuring the dissolved oxygen (DO) in one and placing another in the stream. In a few days the second bottle is retrieved and the DO measured. The difference in the oxygen levels was the BOD (as mg of oxygen used per litre of sample). The BOD test is run using a standard BOD bottle (Fig. 2.49), in the dark, at 20°C for 5 days (BOD₅).

III. Chemical oxygen demand (COD)

BOD test takes five days to run. In COD organics are oxidised chemically instead of biologically, hence in a shorter time. Since nearly all organics are oxidised in COD test and only some are decomposed during the BOD test, COD values are always higher than BOD₅. Potassium dichromate is generally used as an oxidising agent. A known amount of this chemical is added to a measured amount of sample and the mixture boiled.



After boiling with an acid, the excess dichromate is measured by adding a reducing agent, usually ferrous ammonium sulphate. The difference between the chromate originally added and the one remaining, is the chromate used for oxidising the organics. The more chromate used, the more organics in sample, and hence the higher the COD.

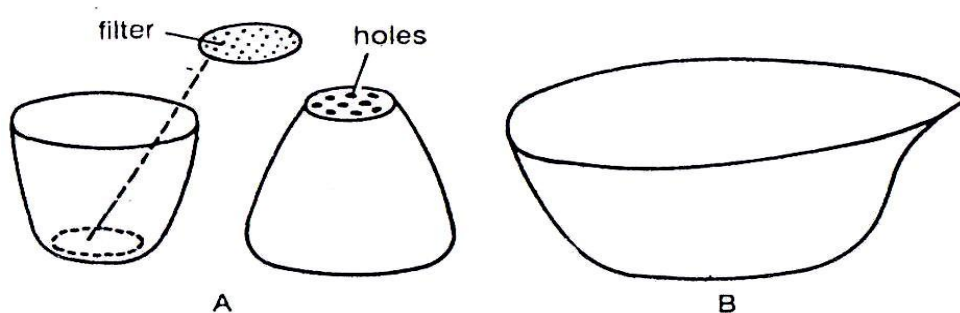


Figure 2.50: A; Gooch crucible (with filters) for suspended solids, B; Evaporating dish for total solids.

IV. Turbidity

If water is dirty i.e. light transmission inhibited, it is known as turbid water. The standard method of measuring turbidity is the Jackson Candle Turbidimeter first

developed in 1900. It consists of a long flat-bottomed glass tube under which candle is placed. Turbid water is poured into the glass tube until the outline of the flame is no longer visible. The centimeters of water in the tube are then measured and compared to the standard turbidity unit, which is
 $1\text{mg/l SiO}_2 = 1 \text{ unit of turbidity.}$

V. Solids

Total solids, are the residue left on evaporation at 103°C. Total solids have two fractions, the dissolved solids and the suspended solids. Suspended solids are separated from dissolved ones by means of a Gooch crucible (Fig. 2.50). This crucible has holes on the bottom on which a glass fiber filter is placed. The sample is drawn through the crucible with the help of a vacuum. Suspended solids are retained on the filter, whereas dissolved fraction passes through. If the initial dry weight of the crucible and filter are known, the subtraction of this from the total weight of crucible, filter and the dried solids caught on the filter yields the weight of suspended solids, expressed as mg/l.

VI. Nitrogen and phosphates

Organic nitrogen (amino acids and amines) and inorganic (NH_3) nitrogen are measured analytically by colorimetry. The ion in question is made to combine with some compound to form a colour. For example, NH_3 is combined with Nessler reagent to give a yellow-brown colloid. The color is measured photometrically, taking known concentration of NH_3 as standards.

Total phosphates are measured by first boiling the sample in acid solution, which converts all phosphates to inorganic forms. These are made to react with a chemical to produce a colour which is then subjected to photometry.

Prevention and Control of Water Pollution

Biodegradable pollutants alone are not responsible for water pollution, though these indicate level of pollution (through BOD values). Besides these, a substantial pollution load is contributed by non degradable or slow degrading pollutants, such as heavy metals, mineral oils, biocides, plastic materials etc. that are dumped into water. For biodegradable pollutants, pollution may be controlled at source by their treatment for

reuse and recycling. The non degradable toxic substances can be removed from water by suitable methods.

In addition to these methods, some standards, conditions and requirements are to be legally enforced by the Govt, through Acts. We shall deal with such methods separately under control of pollution by law. The various ways/techniques suggested for control of water pollution are as follows.

I. Stabilisation of the ecosystem

This is the most scientific way to control water pollution. The basic principles involved are the reduction in waste input (thus control at source), harvesting and removal of biomass, trapping of nutrients, fish management and aeration. Various methods may be used (biological as well as physical) to restore species diversity and ecological balance in the water body to prevent pollution.

II. Reutilisation and recycling of waste

Various kinds of wastes which include industrial effluents (as paper pulp or other industrial chemicals), sewage/sullage of municipal and other systems and thermal pollutants (waste water etc), may be recycled to beneficial use. For instance, urban waste (sewage/sullage) may be recycled to generate cheaper fuel gas and electricity. The NEERI, Nagpur could develop technology for management of radioactive wastes and chemical wastes of atomic power plants, reclamation of waste water and to supply cheap piped gas and generate electricity by recycle of urban waste.

In Okhla, New Delhi, one large treatment plant for sewage recycle is already in operation. NEERI is also involved in development of suitable technology for waste water reclamation through aquaculture, utilisation of domestic and industrial waste water in agriculture and detoxification of phenol, and cyanides in waste by biological means. One distillery in Gujarat is able to treat 450,000 litres of waste daily and generating energy equal to that produced by 10 tons of coal.

I. Removal of pollutants

Various pollutants (radioactive, chemical, biological) present in water body can be removed by appropriate methods such as adsorption, electrodialysis, ion-exchange, reverse-osmosis etc. Reverse-osmosis is based on the removal of salts and other

substances by forcing the water through a semipermeable membrane under a pressure exceeding the osmotic pressure. Due to this, flow occurs in reverse direction. For this, we use a powers membrane that attracts the solvent and repulses the solute. Reverse-osmosis is commonly used to desalinate the brackish water and can also be used for purifying water from sewage.

Council of Scientific & Industrial Research, New Delhi could devise the following techniques for successful removal of different pollutants from water.

1. Ammonia: This could be removed from waste water of industry by ion-exchange technique. There is developed a weak acidic cation exchange, which removes NH_3 in the form of ammonium sulphate. This can be used for fertilisers.

2. Mercury: This could be removed from chloralkali effluent plants by using mercury-selective ion exchange resin.

3. Phenolics: This could be removed from waste waters of pulp and paper mills, carbonisation plants, petroleum refineries, tanneries and resin plants by use of polymeric absorbents.

4. Decolorisation of water: The waste water from printing and sari dying industries could be decolorised by an electrolyte decomposition technique.

5. Sodium salts: These could be removed by reverse osmosis method. Sodium sulphate from a rayon mill effluent could be easily removed. The water for reuse could also be recovered by this method. From cheese whey, we may recover 70% of protein and 80% of lactose by this method.

Very recently, researchers of some American laboratories (reported by the Wall Street Journal) have claimed to use solar power for cleaning up polluted waters cheaply. Experiments showed that a combination of sunlight and a catalyst such as titanium dioxide can break down chemical toxicants of water. Such photocatalytic reactions can destroy pesticides, explosives, solvents, PCBs, dioxins and cyanides.

Water Quality Management in India

We have already referred to some aspects of water quality management under water pollution. Here I will present the area of water management particularly in context of our country. So far we have mainly concentrated on the quantitative management of this resource with reference to growing demand for consumptive uses namely-irrigation,

power, domestic and industrial. We must also give equal emphasis to the quality of water that deteriorates due to its repeated use for consumption.

By 2000 A.D. India is likely to use more than half of the total available water (1900 thousand million m³) annually. This value is ecologically higher than the permissible (not more than half). There is lot of industrial liquid waste, there are very poor urban sewerage and sewage treatment facilities, and there is heavy pollution load on water.

Status of water pollution and control

We have already indicated under water pollution the status of sewerage facility and sewage treatment in Indian cities/towns. The chief reasons for such gross inadequacy in sewerage and sewage treatment systems are the following.

- 1. Human settlements:** There are no proper infrastructure facilities for proper collection, treatment and disposal of liquid and solid wastes including sewage.
- 2. Industrial sources:** This is a huge build up of industrial sector in post independence era. There are large, medium and small establishments - about 3,000 to 4,000 in total. How many of these are equipped with waste, wastewater and efficient treatment plants?
- 3. Documentation and implementation programmes for industry-specific pollution control.** The progress made so far has been along the following lines of approach at national level.
 - a. Industry documents.** Comprehensive documents have been under preparation by pollution regulating agencies- Pollution Control Boards (at central as well as state levels). Such documents could prescribe the specific maximum limits of concentration of individual pollutant for effluents of industries. The industry-specific Minimal National Standards (MINAS) are evolved. We will describe them under pollution control by law.
 - b. Implementation programmes.** National implementation programmes could be planned in each five-year plan period for different industries. These are to be implemented by Central and State Pollution Control Boards.

Status of surface water quality

There could be planned effective programme for monitoring the status of surface water quality.

1. Monitoring network. There is a national network of monitoring surface water quality. CPCB has established a number of monitoring stations along the entire river network all over the country for measuring the water quality.

2. Ganga water quality. The Central Ganga Authority could finalise Ganga Action Plan to restore the quality of water of this river. Three state governments, U.P., Bihar and W. Bengal have been given adequate funds by the Centre for this purpose. This will be described later under Ganga Action Plan.

Status of subsurface water quality

There are efforts going on to monitor the ground water quality also.

1. Ground water network. The task of setting up hydrogeologic system in different hydrographic stations was begun by the Geological Survey of India in 1969. Later, Central Ground Water Board (CGWB) could assist the plan and helped establishment more such stations. There are several thousand such stations in the country. Most state governments have also set up such stations.

2. Naturally acquired ground water quality. The ground water in some parts of Andhra Pradesh, Karnataka, Punjab and Haryana has excess of fluoride. Several districts of M.P., Punjab, Rajasthan and Tamil Nadu have excess of nitrates in their ground waters.

3. Anthropometrically acquired ground water quality. Ground water becomes polluted by industrial pollutants. CGWB monitors the industrial effluents for pollution load. There is problem of well water pollution by heavy metals and other toxicants. In Delhi, Ahmedabad, some areas of Punjab, Rajasthan and Tamil Nadu there is such problem.

Status of coastal water quality

Coastal waters become polluted due to activities in ports and harbours, sewage discharge from human settlements along the coast and the industrial effluents. Also rivers discharge the entire load lastly to seas (the ultimate sink). There are many coastal cities in country. The CPCB could constitute a network to monitor the quality of coastal waters for pollution levels. There are 17 class I and 13 class II coastal cities/towns in India.

Water quality management issues

To manage water quality we must evolve both, short as well as long-term measures before it is too late and we go nowhere.

1. Short-term measures

These include the following

- (i) pollution control at urban settlement sources,
- (ii) proper pattern of sewage collection systems
- (iii) Sewerage regulation (discharge of effluents only in municipal sewers, and to ensure that these do not harm the system and workmen, and the processes therein),
- (iv) Pollution control at industrial sources,
- (v) Environmental planning guides for industrial estates,
- (vi) Protection of drinking water sources, and
- (vii) Coastal management.

2. Long term measures

For this pollution control programmes are to be planned on the basis of each river basin. Such plans would include.

- (i) Preparation of water use map (to classify and zone river waters based on best uses),
- (ii) Evaluation of pollution potential in the river basin, and
- (iii) Preparation of water quality map on the basis of continuous water quality monitoring.

Rural water supply

The UN water Conference, held in Mar Del Plata (Argentina) in March 1977 decided to observe 1981-90 as the International Drinking Water Supply and Sanitation Decade (IDWSSD) during which all nations of world would undertake concerted efforts to provide safe drinking water and adequate sanitation for all people. India set forth target for 100% water and 25% sanitation facility to rural area (80% sanitation to urban area).

There are over 500 million in rural areas, of which hardly 170 million have access to safe drinking water. Govt of India undertook country wide survey and formulated Rural Water Supply Scheme for 14 major states. Adequate funds and other facilities are being provided. But lot is still to be done on this front.

Future outlook

Though Water (Prevention and Control of Pollution) Act was promulgated in 1974 (and amended in 1988), a serious concern about water quality control could be generated only recently. The CPCB in collaboration with SPCB is tackling this problem at war footing. The Water (Prevention and Control of Pollution) Cess Act, 1977 could recognise the value of this resource. Every drop of water used in the industry is levied. There should be less waste of water.

Chronic power crisis is limited factor on pollution control. Waste treatment needs power. We must evolve low power-requiring technology. Sewage pollution from large human settlements is the major cause of water pollution in our country. Thus the country as a whole will need to look into the problem very seriously.

To avoid establishment of new industries without pollution control of source, we must revise the policy of licensing and subsequent follow-up action. While setting up a new industry, environment impact assessment is necessary for making correct decisions about possible negative impact. In urban sector, a proper land use plan is to be evolved to contain the stress of environmental pollution on residents.

Water Quality Parameters

Water quality measurements include chemical, physical and biological parameters. The following is a brief description of some commonly used parameters.

Chemical

Chlorophyll: Chlorophyll is the pigment that allows plants, including algae, to convert sunlight into organic compounds through photosynthesis. Measuring chlorophyll a concentrations in water is a surrogate for an actual measurement of algae biomass. Excessive amounts of chlorophyll a indicate the presence of blooms, which usually consist of a single species of algae - typically one that is not desirable for consumption by fish and other predators. Unconsumed algae sink to the bottom and decay, depleting deeper water of oxygen.

Suspended Minerals: Suspended minerals are a measure of the amount of sediment moving along in a stream. It is highly dependent on the flow of water and usually

increases during and immediately after rain events. As the sediment settles out of the water, aquatic habitats are often destroyed.

Colored Dissolved Organic Carbon: Colored dissolved organic carbon, also referred to as fulvic acid and humic acid, contributes to the brownish tan color of a waterway. Tannins are one example of such compounds. In a nutrient-poor environment, it can serve as a nutrient allowing for the growth of algae whereas in a nutrient-rich environment, it can be given off as a byproduct from the decay of algae.

Turbidity: Turbidity is a measure of the amount of particulate matter that is suspended in water. Water that has high turbidity appears cloudy or opaque. High turbidity can cause increased water temperatures because suspended particles absorb more heat and can also reduce the amount of light penetrating the water.

Secchi Depth: Secchi depth is the depth to which one can see into a lake and is an indication of water clarity. This measurement is obtained by lowering a black and white disk into the water and recording the depth at which it is no longer visible.

Dissolved Oxygen: Although water molecules contain an oxygen atom, aquatic organisms rely upon a small amount of oxygen that is actually dissolved in the water. In general, rapidly moving water contains more dissolved oxygen than slow or stagnant water and colder water contains more dissolved oxygen than warmer water. Bacteria consume oxygen as organic matter decays. As a result, an oxygen-deficient environment can develop in lakes and rivers with excess organic material. These conditions can eventually lead to fish kills.

Physical

Temperature: Water temperature affects the ability of water to hold oxygen, the rate of photosynthesis by aquatic plants and the metabolic rates of aquatic organisms. Causes of temperature change include weather, removal of shading streambank vegetation, impoundments, discharge of cooling water, urban storm water, and groundwater inflows to the stream.

pH: pH is a term used to indicate the alkalinity or acidity of a substance as ranked on a scale from 1.0 to 14.0. Acidity increases as the pH gets lower. A pH of 7.0 is neutral. Aquatic organisms differ as to the range of pH in which they flourish.

Stream flow: Stream flow, or discharge, is the volume of water that moves over a designated point over a fixed period of time. It is often expressed as cubic feet per second (ft³/sec). The flow of a stream is directly related to the amount of water moving off the watershed into the stream channel. It is affected by weather as it increases during rainstorms and decreases during dry periods, and also varies by season.

Biological

Benthic Macroinvertebrates: Macroinvertebrates are organisms that are large (macro) enough to be seen with the naked eye and lack a backbone (invertebrate). Benthic refers to the bottom of a waterway. Examples of benthic macroinvertebrates include insects in their larval or nymph form, crayfish, clams, snails, and worms. Most live part or most of their life cycle attached to submerged rocks, logs, and vegetation. The basic principle behind the study of macroinvertebrates is that some are more sensitive to pollution than others. Therefore, if a stream site is inhabited by organisms that can tolerate pollution and the more pollution-sensitive organisms are missing a pollution problem is likely.

Submerged Aquatic Vegetation: Submerged aquatic vegetation (SAV) provides invaluable benefits to aquatic ecosystems. It not only provides food and shelter to fish and invertebrates but also produces oxygen, traps sediment and absorbs nutrients such as nitrogen and phosphorus. Whereas SAV are dependent upon the transmission of sunlight through the water, the location of individual species depends upon a variety of factors such as salinity, depth and bottom sediment.

Temperature

Temperature of water is a very important factor for aquatic life. It controls the rate of metabolic and reproductive activities, and determines which fish species can survive. Temperature also affects the concentration of dissolved oxygen and can influence the activity of bacteria and toxic chemicals in water.

Measurement of Temperature

Temperature is measured using a thermometer, and is recorded in either degrees Celsius (° C) or degrees Fahrenheit (° F). While air temperatures reported on television and the newspaper in the U.S. are given in degrees Fahrenheit, scientists

usually record temperatures in Celsius, because this is the unit designated by the International System of Units. To convert from ° F to ° C, use this equation:

$$T^{\circ} \text{C} = [T^{\circ} \text{F} - 32^{\circ} \text{F}] * 5^{\circ} \text{C} / 9^{\circ} \text{F}$$

For example, the freezing temperature of water is 32° F; this translates to 0° C. The boiling temperature of water is 212° F, or 100° C.

Factors Affecting Temperature

Riparian Vegetation: Riparian vegetation, or trees and plants growing along the banks of a river or creek, provide shade, preventing the sun from heating up the water. If the sun shines directly on water, the water can warm up very quickly, and to very high temperatures.

Flow Rate: During dry seasons, there is less water in a river or creek, and it flows more slowly. This allows the water to warm up more quickly, and to warmer temperatures.

Paved Surfaces: As business and housing developments are built, previously open lands are covered with buildings and pavement. This covered area is called "impermeable surface." Less rain water is soaked into the ground, and more of it runs over land into streams during storms. This runoff also moves faster into the stream than would natural runoff because it travels through straight concrete or plastic storm drain pipes. This increased volume and velocity of runoff scours the stream channel and widens it. During dry weather between storms, the channels have a very shallow flow.

Industrial Discharge: Some industries use water as a coolant during processing. This water is sometimes discharged to a stream or lake. When this water is discharged to a creek, it is much warmer than the water in the creek, and the temperature of the creek becomes higher. This phenomenon is called thermal pollution. This can cause the period of ice cover on the water to be shortened, and can increase the metabolic rate of plants and animals, producing an increase in oxygen demand.

Sewage Outflow: Water discharged from treatment plants is warm, because of the wastewater entering the plant (coming from our homes and businesses) is warm. This is another form of thermal pollution.

Specific Conductance (SC)

Specific Conductance (SC) is a measure of how well water can conduct an electrical current. Conductivity increases with increasing amount and mobility of ions. These ions, which come from the breakdown of compounds, conduct electricity because they are negatively or positively charged when dissolved in water. Therefore, SC is an indirect measure of the presence of dissolved solids such as chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, and iron, and can be used as an indicator of water pollution.

Measurement of SC

Specific Conductance measures how well water can conduct an electrical current for a unit length and unit cross-section at a certain temperature. More specifically, it is defined as the "reciprocal (opposite) of the resistance in ohms measured between opposite faces of a centimeter cube of an aqueous solution at a specified temperature" (Hem, 1985). That is, $\text{conductance} = 1 / \text{resistance}$.

Specific conductance is measured using a sensor which measures resistance. Resistance means how well something can *resist* an electrical current, and is reported in ohms. The unit of conductance was originally ohm spelled backwards – "mho." More recently, however, the name "siemen" has been used to match the term used by the International System of Units. So both "mho" and "siemen" are sometimes seen in water quality reports. One siemen is equal to one mho. Because SC in natural waters is usually much less than 1 siemen/cm, SC is usually reported in microsiemens (1/1,000,000 siemen) per centimeter, or $\mu\text{S}/\text{cm}$. SC is affected by temperature, so for consistency SC values are converted to what they would be at room temperature (25° C).

Factors Affecting SC

Geology and soil in the watershed: Some rock and soil release ions very easily when water flows over them; for example, if acidic water flows over rocks containing calcite (CaCO_3), such as calcareous shales, calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions will dissolve into the water. Therefore, SC will increase. However, some rocks, such as quartz (SiO_2), are very resistant, and don't dissolve easily when water flows over them (and even if SiO_2 does dissolve, it is not conductive). SC of waters draining

areas where the geology only consists of quartz or other resistant rocks will be low (unless other factors are involved).

Agricultural runoff: Runoff from farms can contain fertilizers, which contain phosphate and nitrate. In addition, irrigation return flow can leach salts from the soil.

Road runoff: Runoff from roads can contain leaked automobile fluids and salts from chemicals used in road de-icing, such as sodium chloride (NaCl) and magnesium chloride (MgCl₂).

pH

pH represents the effective concentration (activity) of hydrogen ions (H⁺) in water. This concentration could be expressed in the same kind of units as other dissolved species, but H⁺ concentrations are much smaller than other species in most waters. The activity of hydrogen ions can be expressed most conveniently in logarithmic units. pH is defined as the negative logarithm of the activity of H⁺ ions: $\text{pH} = -\log [\text{H}^+]$ where [H⁺] is the concentration of H⁺ ions in moles per liter (a mole is a unit of measurement, equal to 6.022×10^{23} atoms). Because H⁺ ions associate with water molecules to form hydronium (H₃O⁺) ions, pH is often expressed in terms of the concentration of hydronium ions. In pure water at 22° C (72° F), H₃O⁺ and hydroxyl (OH⁻) ions exist in equal quantities; the concentration of each is 1.0×10^{-7} moles per liter (mol/L).

Therefore, $\text{pH of pure water} = -\log (1.0 \times 10^{-7}) = -(-7.00) = 7.00$. Because pH is defined as $-\log [\text{H}^+]$, pH decreases as [H⁺] increases (which will happen if acid is added to the water). Since pH is a log scale based on 10, the pH changes by 1 for every power of 10 change in [H⁺]. A solution of pH 3 has an H⁺ concentration 10 times that of a solution of pH 4. The pH scale ranges from 0 to 14.

Measurement of pH

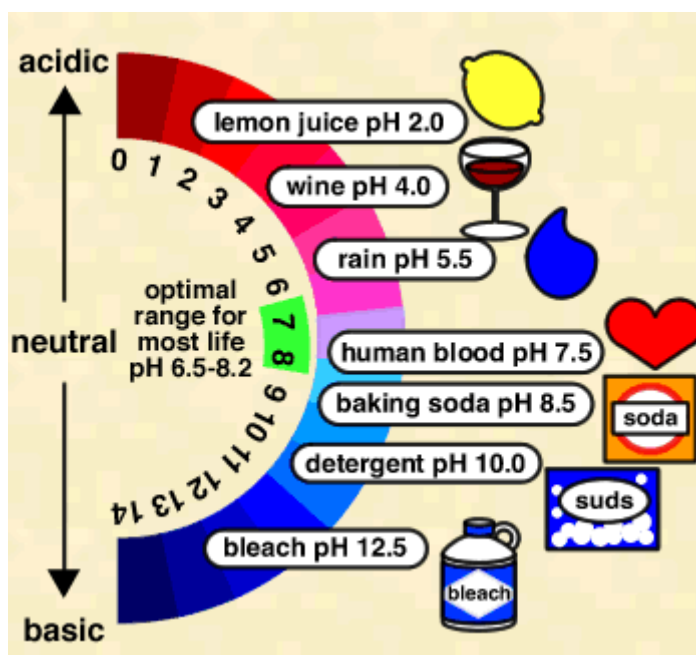


Figure 2.51: pH.

The pH of water can be measured with a pH meter, which is an electronic device with a probe. The probe contains an acidic aqueous solution enclosed by a glass membrane that allows migration of H^+ ions. The electrical potential of the glass electrode depends on the difference in $[H^+]$ between the reference solution and the solution into which the electrode is dipped. pH can also be measured with pH paper or by adding a reagent (indicator solution) to the water sample and recording the color change.

Factors Affecting pH

The concentration of carbon dioxide in the water: Carbon dioxide (CO_2) enters a water body from a variety of sources, including the atmosphere, runoff from land, release from bacteria in the water, and respiration by aquatic organisms. This dissolved CO_2 forms a weak acid. Natural, unpolluted rainwater can be as acidic as pH 5.6, because it absorbs CO_2 as it falls through the air. Because plants take in CO_2 during the day and release it during the night, pH levels in water can change from daytime to night. For an example of how pH typically varies over a daily cycle, select here.

Geology and Soils of the watershed: Acidic and alkaline compounds can be released into water from different types of rock and soil. When calcite ($CaCO_3$) is present,

carbonates (HCO_3 , CO_3^{-2}) can be released, increasing the alkalinity of the water, which raises the pH. When sulfide minerals, such as pyrite, or "fool's gold," (FeS_2) are present, water and oxygen interact with the minerals to form sulfuric acid (H_2SO_4). This can significantly drop the pH of the water. Drainage water from forests and marshes is often slightly acidic, due to the presence of organic acids produced by decaying vegetation.

Drainage from Mine Sites: Mining for gold, silver, and other metals often involves the removal of sulfide minerals buried in the ground. When water flows over or through sulfidic waste rock or tailings exposed at a mine site, this water can become acidic from the formation of sulfuric acid. In the absence of buffering material, such as calcareous rocks, streams that receive drainage from mine sites can have low pH levels.

Dissolved Oxygen (DO)

Dissolved Oxygen (DO) is found in microscopic bubbles of oxygen that are mixed in the water and occur between water molecules. DO is a very important indicator of a water body's ability to support aquatic life. Fish "breathe" by absorbing dissolved oxygen through their gills. Oxygen enters the water by absorption directly from the atmosphere or by aquatic plant and algae photosynthesis. Oxygen is removed from the water by respiration and decomposition of organic matter.

Measurement of DO

Dissolved Oxygen can be measured with an electrode and meter or with field test kits. The electronic meter does not measure oxygen directly; rather, it uses electrodes to measure the partial pressure of oxygen in the water, which is converted to oxygen mass weight concentration. The field test kits (such as a drop bottle, a microburet, or a digital titrator) involve adding a solution of known strength to a treated sample of water from the stream. The amount of solution required to change the color of the sample reflects the concentration of DO in the sample. The amount of oxygen dissolved in water is expressed as a concentration, in milligrams per liter (mg/l) of water.

Dissolved oxygen levels are also often reported in percent saturation. Temperature affects DO concentrations, and calculating the percent saturation will factor out the

effect of temperature. The "saturation level" is the maximum concentration of dissolved oxygen that would be present in water at a specific temperature, in the absence of other factors. Scientists have determined the saturation DO level for various temperatures. Saturation levels also vary with elevation. Percent saturation is calculated by dividing the measured dissolved oxygen concentration by the saturation level and multiplying by 100.

This equation is shown as: % Saturation = (DO / Saturation Level) x 100

Factors Affecting DO

Volume and velocity of water flowing in the water body: In fast-moving streams, rushing water is aerated by bubbles as it churns over rocks and falls down hundreds of tiny waterfalls. These streams, if unpolluted, are usually saturated with oxygen. In slow, stagnant waters, oxygen only enters the top layer of water, and deeper water is often low in DO concentration due to decomposition of organic matter by bacteria that live on or near the bottom of the reservoir.

Climate/Season: The colder the water, the more oxygen can be dissolved in the water. Therefore, DO concentrations at one location are usually higher in the winter than in the summer. During dry seasons, water levels decrease and the flow rate of a river slows down. As the water moves slower, it mixes less with the air, and the DO concentration decreases. During rainy seasons, oxygen concentrations tend to be higher because the rain interacts with oxygen in the air as it falls.

The type and number of organisms in the water body: During photosynthesis, plants release oxygen into the water. During respiration, plants remove oxygen from the water. Bacteria and fungi use oxygen as they decompose dead organic matter in the stream. The type of organisms present (plant, bacteria, fungi) affect the DO concentration in a water body. If many plants are present, the water can be supersaturated with DO during the day, as photosynthesis occurs.

Altitude: Oxygen is more easily dissolved into water at low altitudes than at high altitudes, because of higher atmospheric pressure.

Dissolved or suspended solids: Oxygen is more easily dissolved into water with low levels of dissolved or suspended solids. Waters with high amounts of salt, such as the

ocean (which contains about 35 grams of salt for each 1000 grams of water) have low concentrations of DO. Freshwater lakes, streams, and tap water generally contain much less salt, so DO concentrations are higher. As the amount of salt in any body of water increases, the amount of dissolved oxygen decreases. An increase in salt concentration due to evaporation of water from an ecosystem tends to reduce the dissolved oxygen available to the ecosystem's inhabitants.

Amount of nutrients in the water: Nutrients are food for algae, and water with high amounts of nutrients can produce algae in large quantities. When these algae die, bacteria decompose them, and use up oxygen. This process is called eutrophication. DO concentrations can drop too low for fish to breathe, leading to fish kills.

Organic Wastes: Organic wastes are the remains of any living or once-living organism. Organic wastes that can enter a body of water include leaves, grass clippings, dead plants or animals, animal droppings, and sewage. Organic waste is decomposed by bacteria; these bacteria remove dissolved oxygen from the water when they breathe. If more food (organic waste) is available for the bacteria, more bacteria will grow and use oxygen, and the DO concentration will drop.

Riparian Vegetation: Shading tends to lower average summer temperature and reduce the daily duration of higher temperature. Removing trees reduces shade on the creek, allowing the sun to warm the water. This can affect DO concentrations in different ways. As mentioned above, in general, as water temperature increases, DO drops. Also, the bare soil exposed from removing the tree can erode, increasing the amount of dissolved and suspended solids in the water.

Groundwater Inflow: The amount of groundwater entering a river or stream can influence oxygen levels. Groundwater usually has low concentrations of DO, but it is also often colder than stream water. Therefore, groundwater may at first lower the DO concentration, but as groundwater cools the stream or river, the ability of the water to hold oxygen improves.

Total Organic Carbon (TOC)

Organic matter plays a major role in aquatic systems. It affects biogeochemical processes, nutrient cycling, biological availability, chemical transport and

interactions. It also has direct implications in the planning of wastewater treatment and drinking water treatment. Organic matter content is typically measured as total organic carbon and dissolved organic carbon, which are essential components of the carbon cycle.

Measurement of TOC

The TOC in Boulder Creek samples is analyzed at the U.S. Geological Survey on a Sievers Model 800 Carbon Analyzer. TOC concentration is not directly measured; the Analyzer measures total carbon (TC) and total inorganic carbon (TIC) and subtracts TIC from TC to obtain TOC. An oxidizer and an acid are added to the sample. The acid reacts with bicarbonate and carbonate ions present in the sample to release carbon dioxide (CO_2). The CO_2 released from bicarbonate and carbonate ions represents the TIC in the sample. The sample is then subjected to ultra-violet (UV) radiation, which reacts with the oxidant and breaks down all remaining carbon bonds in the sample to release CO_2 . The CO_2 released from both the acid reaction and the UV radiation represents all the carbon (TC) released from the sample. TOC is then obtained by subtracting TIC from TC.

The TOC of a water body is affected by several factors, including:

- i. Vegetation
- ii. Climate
- iii. Treated Sewage

Alkalinity

Alkalinity is a measure of the buffering capacity of water, or the capacity of bases to neutralize acids. Measuring alkalinity is important in determining a stream's ability to neutralize acidic pollution from rainfall or wastewater. Alkalinity does not refer to pH, but instead refers to the ability of water to resist change in pH. The presence of buffering materials help neutralize acids as they are added to the water. These buffering materials are primarily the bases bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}), and occasionally hydroxide (OH^-), borates, silicates, phosphates, ammonium, sulfides, and organic ligands.

Waters with low alkalinity are very susceptible to changes in pH. Waters with high alkalinity are able to resist major shifts in pH. As increasing amounts of acid are

added to a water body, the pH of the water decreases, and the buffering capacity of the water is consumed. If natural buffering materials are present, pH will drop slowly to around 6; then a rapid pH drop occurs as the bicarbonate buffering capacity (CO_3^{2-} and HCO_3^-) is used up. At pH 5.5, only very weak buffering ability remains, and the pH drops further with additional acid. A solution having a pH below 4.5 contains no alkalinity, because there are no CO_3^{2-} or HCO_3^- ions left.

Measurement of Alkalinity

Alkalinity is measured by titration. An acid of known strength (the titrant) is added to a volume of a treated sample of water. The volume of acid required to bring the sample to a specific pH level reflects the alkalinity of the sample. The pH end point is indicated by a color change. Alkalinity is expressed in units of milligrams per liter (mg/l) of CaCO_3 (calcium carbonate).

Factors Affecting Alkalinity

Geology and Soils: Carbonates are added to a water system if the water passes through soil and rock that contain carbonate minerals, such as calcite (CaCO_3). Where limestone and sedimentary rocks and carbonate-rich soils are predominant, (such as the eastern part of the Boulder Creek watershed) waters will often have high alkalinity. Where igneous rocks (such as granite) and carbonate-poor soils are predominant (such as the western part of the Boulder Creek watershed) waters will have low alkalinity.

Changes in pH: Because alkalinity and pH are so closely related, changes in pH can also affect alkalinity, especially in a poorly buffered stream. See the section on pH for more information on factors affecting pH.

Sewage Outflow: The effluent from Wastewater Treatment Plants (WWTPs) can add alkalinity to a stream. The wastewater from our houses contains carbonate and bicarbonate from the cleaning agents and food residue that we put down our drains.

Nitrogen

Nitrogen is required by all organisms for the basic processes of life to make proteins, to grow, and to reproduce. Nitrogen is very common and found in many forms in the environment. Inorganic forms include nitrate (NO_3), nitrite (NO_2), ammonia (NH_3),

and nitrogen gas (N_2). Organic nitrogen is found in the cells of all living things and is a component of proteins, peptides, and amino acids. Nitrogen is most abundant in Earth's environment as N_2 gas, which makes up about 78 percent of the air we breathe.

The Nitrogen Cycle

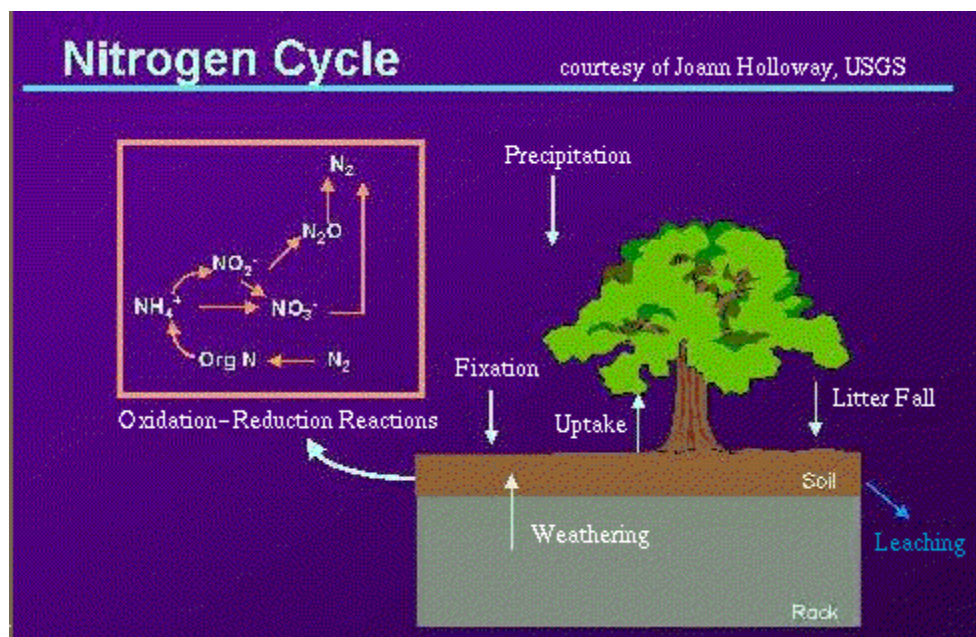


Figure 2.52: Nitrogen cycle.

Nitrogen is recycled continually by plants and animals. This recycling of nitrogen through the environment is called the "nitrogen cycle." Most organisms (including humans) can't use nitrogen in the gaseous form N_2 for their nutrition, so they are dependent on other organisms to convert nitrogen gas to nitrate, ammonia, or amino acids. "Fixation" is the conversion of gaseous nitrogen to ammonia or nitrate. The most common kind of fixation is "biological fixation" which is carried out by a variety of organisms, including blue-green algae, the soil bacteria *Azobacter*, and the association of legume plants and the bacteria *Rhizobium*. Additionally, nitrogen can be fixed by some inorganic processes. For example, "high-energy fixation" occurs in the atmosphere as a result of lightning, cosmic radiation, and meteorite trails. Atmospheric nitrogen and oxygen combine to form nitrous oxides (NO_x), which fall to the earth as nitrate.

When plants and animals die, proteins (which contain organic nitrogen) are broken down by bacteria to form ammonia (NH_3). This process is called "ammonification."

Ammonia is then broken down by other bacteria (*Nitrosomonas*) to form nitrite (NO_2), which is then broken down by another type of bacteria (*Nitrobacter*) to form nitrate (NO_3). This conversion of ammonia to nitrate and nitrite is called "nitrification."

Common Forms of Nitrogen in Water

Nitrate and Nitrite: Nitrate (NO_3) is highly soluble (dissolves easily) in water and is stable over a wide range of environmental conditions. It is easily transported in streams and groundwater. Nitrates feed plankton (microscopic plants and animals that live in water), aquatic plants, and algae, which are then eaten by fish. Nitrite (NO_2) is relatively short-lived in water because it is quickly converted to nitrate by bacteria.

Excessive concentrations of nitrate and/or nitrite can be harmful to humans and wildlife. Nitrate is of most concern for humans. Nitrate is broken down in our intestines to become nitrite. Nitrite reacts with hemoglobin in human blood to produce methemoglobin, which limits the ability of red blood cells to carry oxygen. This condition is called methemoglobinemia or "blue baby" syndrome (because the nose and tips of ears can appear blue from lack of oxygen).

High concentrations of nitrate and/or nitrite can produce "brown blood disease" in fish. Nitrite enters the bloodstream through the gills and turns the blood a chocolate-brown color. As in humans, nitrite reacts with hemoglobin to form methemoglobin. Brown blood cannot carry sufficient amounts of oxygen, and affected fish can suffocate despite adequate oxygen concentration in the water. This accounts for the gasping behavior often observed in fish with brown blood disease, even when oxygen levels are relatively high (Mississippi State University, 1998).

Ammonia

Ammonia, another inorganic form of nitrogen, is the least stable form of nitrogen in water. Ammonia is easily transformed to nitrate in waters that contain oxygen and can be transformed to nitrogen gas in waters that are low in oxygen. Ammonia is found in water in two forms - the ammonium ion (NH_4^+), and dissolved, unionized (no electrical charge) ammonia gas (NH_3). Total ammonia is the sum of ammonium and unionized ammonia. The dominant form depends on the pH and temperature of the water. The reaction between the two forms is shown by this equation:

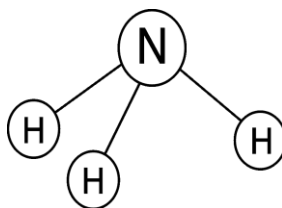


Figure 2.53: Ammonia.



The form of ammonia changes easily when pH changes. As pH increases, H^+ concentration decreases, and OH^- concentrations increase. This makes the equation above move left, increasing the amount of aqueous NH_3 . When the pH is below 8.75, NH_4^+ predominates. At pH 9.24, about half of aqueous NH_3 is transformed to NH_4^+ . Above pH 9.75, NH_3 predominates (Hem, 1985). Unionized ammonia (NH_3) is much more toxic to aquatic organisms than the ammonium ion (NH_4^+).

Toxic concentrations of ammonia in humans may cause loss of equilibrium, convulsions, coma, and death. Ammonia concentrations can affect hatching and growth rates of fish; changes in tissues of gills, liver, and kidneys may occur during structural development.

Measurement of Nitrogen Forms

There are many ways of measuring nitrogen forms. Total nitrogen can be determined by adding chemicals to convert all of the nitrogen forms in a sample to nitrate, and then measuring nitrate concentration. Nitrate and nitrite can be measured together or separately. Nitrate and nitrite are most often measured using a colorimetric method, which means the color of treated sample reflects the concentration of the parameter. A chemical is added to the water sample, and the darker the color of the sample, the more nitrate and/or nitrite present. This test can be done visually, comparing the treated sample to a set of reference colors. However, it is more accurate to use an electronic colorimeter, which uses a light source and a photodetector to find the concentration based on how much light is absorbed by the sample. If nitrate and nitrite are reported separately, concentrations are given as nitrite as nitrogen ($\text{NO}_2\text{-N}$) and nitrate as nitrogen ($\text{NO}_3\text{-N}$). If they are reported together, concentrations are given as nitrite plus nitrate as nitrogen ($\text{NO}_2 + \text{NO}_3\text{-N}$). Nitrate and nitrite can be measured in the field using a portable colorimeter, such as a Hach kit.

Factors Affecting Nitrate + Nitrite Concentrations

Wastewater and Septic System Effluent: Human waste is significant contributor of nitrogen to water. Ammonia, nitrite, and nitrate are decomposition products from urea and protein, which are in human waste. Ammonia is an ingredient in many household cleaning products and is sometimes used to remove carbonate from hard water. Therefore, these nitrogen species go down the drains in our houses and businesses, and can enter streams from wastewater treatment plant (WWTPs) effluent, illegal sanitary sewer connections, and poorly functioning septic systems. Nutrients in sewage effluent have been among the primary targets of pollution-control legislation, beginning with the Clean Water Act in 1972. Organic forms of nitrogen have largely been controlled by upgrading treatment plants, and advanced treatment processes have been used to decrease ammonia discharge.

Fertilizer Runoff: Fertilizer is a major influence on nitrogen concentrations in the environment. Commercial nitrogen fertilizers are applied either as ammonia or nitrate, but ammonia is rapidly converted to nitrate in the soil. Animal manure is also used as a nitrogen fertilizer in some areas. Organic nitrogen and urea in the manure are converted to ammonia and, ultimately, to nitrate in the soil. Nitrate that is not used by plants washes from farmlands and residential and commercial lawns into storm drains and nearby streams, or seeps into groundwater.

Animal Waste: A significant amount of nitrogen is released in the wastes produced by animals. This can be a serious problem in waters near cattle feedlots, hog farms, dairies, and barnyards. Ducks and geese contribute a heavy load of nitrogen if they are present in large numbers. Excretions of aquatic organisms are very rich in ammonia, a decay product of animal proteins, but the amount of nitrogen they add to waters is usually small. Through the process of nitrification, ammonia is oxidized to nitrite and then to nitrate in water.

Fossil Fuels: The burning of fossil fuels such as gasoline and coal in cars, trucks, and power plants produces many by-products. Coal and petroleum generally contain about 1 percent nitrogen (Hem, 1985). Part of the nitrogen is converted to the gas nitric oxide (NO) during the burning of the fuel. Nitric oxide is converted by sunlight and photochemical processes in air to nitrogen oxide gases (NO and NO₂, which are commonly referred together as NO_x), which are a major component of smog. Nitrogen oxide gases are a major contributor to acid rain.

Eutrophication

Eutrophication is a process that results from accumulation of nutrients in lakes or other water bodies. Eutrophication is a natural process, but can be greatly accelerated by human activities that increase the rate at which nutrients enter the water.

Algae growth is limited by the available supply of phosphorus or nitrogen, so if excessive amounts of these nutrients are added to the water, algae and aquatic plants can grow in large quantities. When these algae die, they are decomposed by bacteria, which use dissolved oxygen. This process is called "eutrophication." Dissolved oxygen concentrations can drop too low for fish to breathe, leading to fish kills. Excessive amounts of algae grow into scum on the water surface, decreasing recreational value and clogging water-intake pipes. Rapid decomposition of dense algae scums with associated organisms can give rise to foul odors. In freshwater lakes and rivers, phosphorus is often the growth limiting nutrient, because it occurs in the least amount relative to the needs of plants. In estuaries and coastal waters, nitrogen is generally the growth limiting nutrient.

"Eutrophic" waters are characterized by high nutrient concentrations, resulting in high productivity of plant growth. Such waters are often shallow, with algal blooms and periods of oxygen deficiency. Slightly or moderately eutrophic water can support a complex web of plant and animal life. However, such waters are generally undesirable for drinking water and other needs. Waters with extreme nutrient concentrations are called "hypereutrophic." "Oligotrophic" waters are characterized by extremely low nutrient concentrations, resulting in moderate plant productivity. Oligotrophic lakes are those low in nutrient materials and consequently poor areas for the development of extensive aquatic plants and animals. Such lakes are often deep, with sandy bottoms and very limited plant growth, but with high dissolved-oxygen levels.

Some scientists have categorized trophic status according to phosphorus concentration. Lakes with phosphorus concentrations below 0.010 mg/L are classified as oligotrophic, phosphorus concentrations between 0.010 and 0.020 mg/L are indicative of mesotrophic lakes, and eutrophic lakes have phosphorus concentrations exceeding 0.020 mg/L (Muller and Helsel, 1999).

Turbidity

Turbidity is a measure of the cloudiness of water- the cloudier the water, the greater the turbidity. Turbidity in water is caused by suspended matter such as clay, silt, and organic matter and by plankton and other microscopic organisms that interfere with the passage of light through the water (American Public Health Association, 1998). Turbidity is closely related to total suspended solids (TSS), but also includes plankton and other organisms. Turbidity itself is not a major health concern, but high turbidity can interfere with disinfection and provide a medium for microbial growth. It also may indicate the presence of microbes (U.S. EPA Office of Water, Current Drinking Water Standards).

Measurement of Turbidity

Turbidity is a measure of how much of the light traveling through water is scattered by suspended particles. The scattering of light increases with increasing suspended solid and plankton content. Turbidity in slow moving, deep waters can be measured using a device called a Secchi disk. A Secchi disk is a black and white, 20-cm diameter disk. The disk is lowered into the water until it just disappears from sight. The depth at which the disk disappears is called the Secchi depth, and is recorded in meters.

A Secchi disk does not work in shallow, fast-moving streams. In these waters, a turbidimeter (sometimes called a nephelometer) is used. A turbidimeter measures the scattering of light, and provides a relative measure of turbidity in Nephelometric Turbidity Units (NTUs).

Factors Affecting Turbidity

Because one of the primary factors affecting turbidity is total suspended solids, the factors affecting TSS will also affect turbidity. In addition, organic matter contributes to turbidity.

High Flow Rates: The flow rate of a water body is a primary factor influencing turbidity concentrations. Fast running water can carry more particles and larger-sized sediment. Heavy rains can pick up sand, silt, clay, and organic particles from the land and carry it to surface water. A change in flow rate also can affect turbidity; if the

speed or direction of the water current increases, particulate matter from bottom sediments may be resuspended (WATERSHEDSS).

Soil Erosion: Soil erosion is caused by disturbance of a land surface. Soil erosion can be caused by *Building and Road Construction, Forest Fires, Logging, and Mining*. The eroded soil particles can be carried by stormwater to surface water. This will increase the turbidity of the water body.

Urban Runoff: During storm events, soil particles and debris from streets and industrial, commercial, and residential areas can be washed into streams. Because of the large amount of pavement in urban areas, natural settling areas have been removed, and sediment is carried through storm drains to creeks and rivers.

Wastewater and Septic System Effluent: The effluent from Wastewater Treatment Plants (WWTPs) can add suspended solids and organic material to a stream. The wastewater from our houses contains food residue, human waste, and other solid material that we put down our drains. Most of the solids and organic material are removed from the water at the WWTP before being discharged to the stream, but treatment can't eliminate everything.

Decaying Plants and Animals: As plants and animals present in a water body die and decay, suspended organic particles are released and can contribute to turbidity.

Bottom-Feeding Fish: Bottom-feeding fish (such as carp) can stir up sediments as they remove vegetation. These sediments can contribute to turbidity.

Algal Blooms: Algal blooms can contribute to turbidity. Algal production is enhanced when nutrients are released from bottom sediments during seasonal turnovers and changes in water current.

Total Solids

The term "total solids" refers to matter suspended or dissolved in water or wastewater, and is related to both specific conductance and turbidity. Total solids (also referred to as total residue) is the term used for material left in a container after evaporation and drying of a water sample. Total Solids includes both total suspended solids, the portion of total solids retained by a filter and total dissolved solids, the portion that

passes through a filter (American Public Health Association, 1998). Total solids can be measured by evaporating a water sample in a weighed dish, and then drying the residue in an oven at 103 to 105° C. The increase in weight of the dish represents the total solids. Instead of total solids, laboratories often measure total suspended solids and/or total dissolved solids.

Total Suspended Solids (TSS)

Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life.

High TSS can block light from reaching submerged vegetation. As the amount of light passing through the water is reduced, photosynthesis slows down. Reduced rates of photosynthesis causes less dissolved oxygen to be released into the water by plants. If light is completely blocked from bottom dwelling plants, the plants will stop producing oxygen and will die. As the plants are decomposed, bacteria will use up even more oxygen from the water. Low dissolved oxygen can lead to fish kills. High TSS can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight. This can cause dissolved oxygen levels to fall even further (because warmer waters can hold less DO), and can harm aquatic life in many other ways, as discussed in the temperature section. (Mitchell and Stapp, 1992; KanCRN website). The decrease in water clarity caused by TSS can affect the ability of fish to see and catch food. Suspended sediment can also clog fish gills, reduce growth rates, decrease resistance to disease, and prevent egg and larval development. When suspended solids settle to the bottom of a water body, they can smother the eggs of fish and aquatic insects, as well as suffocate newly hatched insect larvae. Settling sediments can fill in spaces between rocks which could have been used by aquatic organisms for homes.

Measurement of Total Suspended Solids

To measure TSS, the water sample is filtered through a pre-weighed filter. The residue retained on the filter is dried in an oven at 103 to 105° C until the weight of the filter no longer changes. The increase in weight of the filter represents the total

suspended solids. TSS can also be measured by analyzing for total solids and subtracting total dissolved solids.

Factors Affecting Total Suspended Solids

High Flow Rates: The flow rate of the water body is a primary factor in TSS concentrations. Fast running water can carry more particles and larger-sized sediment. Heavy rains can pick up sand, silt, clay, and organic particles (such as leaves, soil, tire particles) from the land and carry it to surface water. A change in flow rate can also affect TSS; if the speed or direction of the water current increases, particulate matter from bottom sediments may be resuspended. (WATERSHEDSS website)

Soil Erosion: Soil erosion is caused by disturbance of a land surface. Soil erosion can be caused by *Building and Road Construction, Forest Fires, Logging, and Mining*. The eroded soil particles can be carried by stormwater to surface water. This will increase the TSS of the water body.

Urban Runoff: During storm events, soil particles and debris from streets and industrial, commercial, and residential areas can be washed into streams. Because of the large amount of pavement in urban areas, infiltration is decreased, velocity increases, and natural settling areas have been removed. Sediment is carried through storm drains directly to creeks and rivers.

Wastewater and Septic System Effluent: The effluent from Wastewater Treatment Plants (WWTPs) can add suspended solids to a stream. The wastewater from our houses contains food residue, human waste, and other solid material that we put down our drains. Most of the solids are removed from the water at the WWTP before being discharged to the stream, but treatment can't eliminate everything.

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) are solids in water that can pass through a filter (usually with a pore size of 0.45 micrometers). TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is necessary for aquatic life. Changes in TDS concentrations can be harmful because the density of the water determines the flow of

water into and out of an organism's cells (Mitchell and Stapp, 1992). However, if TDS concentrations are too high or too low, the growth of many aquatic life can be limited, and death may occur.

TDS is used to estimate the quality of drinking water, because it represents the amount of ions in the water. Water with high TDS often has a bad taste and/or high water hardness, and could result in a laxative effect.

Measurement of Total Dissolved Solids

To measure TDS, the water sample is filtered, and then the filtrate (the water that passes through the filter) is evaporated in a pre-weighed dish and dried in an oven at 180°C , until the weight of the dish no longer changes. The increase in weight of the dish represents the total dissolved solids, and is reported in milligrams per liter (mg/l). The TDS concentration of a water sample can be estimated from specific conductance if a linear correlation between the two parameters is first established. Depending on the chemistry of the water, TDS (in mg/l) can be estimated by multiplying specific conductance (in micromhos/cm) by a factor between 0.55 and 0.75.

Factors Affecting Total Dissolved Solids

Geology and Soil in the Watershed: Some rock and soil release ions very easily when water flows over them; for example, if acidic water flows over rocks containing calcite (CaCO_3), such as calcareous shales, calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions will dissolve into the water. Therefore, TDS will increase. However, some rocks, such as quartz-rich granite, are very resistant to dissolution, and don't dissolve easily when water flows over them. TDS of waters draining areas where the geology only consists of granite or other resistant rocks will be low (unless other factors are involved).

Urban Runoff: During storm events, pollutants such as salts from streets, fertilizers from lawns, and other material can be washed into streams and rivers. Because of the large amount of pavement in urban areas, natural settling areas have been removed, and dissolved solids are carried through storm drains to creeks and rivers.

Fertilizer Runoff: Fertilizer can dissolve in stormwater and be carried to surface water during storms, and contribute to TDS.

Wastewater and Septic System Effluent: The effluent from Wastewater Treatment Plants (WWTPs) adds dissolved solids to a stream. The wastewater from our houses contains both suspended and dissolved solids that we put down our drain. Most of the suspended solids are removed from the water at the WWTP before being discharged to the stream, but WWTPs only remove some of the TDS. Important components of the TDS load from WWTPs include phosphorus, nitrogen, and organic matter.

Soil Erosion: Soil erosion is caused by disturbance of a land surface. Soil erosion can be caused by *Building and Road Construction, Forest Fires, Logging, and Mining*. The eroded soil particles may contain soluble components that can dissolve and be carried by stormwater to surface water. This will increase the TDS of the water body.

Soil Quality Parameters

Soil quality affects and is affected by food, feed, and fiber production practices. It is also directly linked to environmental quality (i.e. water and air quality, global warming, and energy use for production practices). Unfortunately, moderate to severe soil degradation through erosion, compaction, leaching, and loss of biodiversity, structure, and tilth continues in America and around the world due to previously unrecognized consequences of traditional soil and crop management practices (e.g., intensive tillage, excessive nutrient and pesticide applications, and over-consumption of fossil fuels). Reports on the state of our land suggest that soil (deposited off-site as sediment or dust), nutrients, and organic matter have been lost at rates far exceeding a sustainable level. The result is that traditional agricultural practices have had enormous direct and indirect consequences on productivity, profitability, and environmental quality throughout America (NRC, 1993; USDA-NRCS, 1996).

There is nothing in the whole of nature that is more important or deserves as much attention as the soil. Truly it is the soil that makes the world a friendly environment for humankind. It is the soil that nourishes and provides for the whole of nature; the whole of creation depends on the soil, which is the ultimate foundation of our existence. Recognizing that revitalization of the land requires social, scientific, and ethical considerations; a growing population of agriculturists across America have focused renewed attention on developing locally led, high-quality food production systems to achieve a global vision of environmental stewardship. Organic agricultural systems offer opportunities to substantially improve soil quality and agricultural

sustainability. The diversity of organic agricultural systems in different ecoregions of America warrants a broad assessment of how organic management systems might affect soil quality.

Relatively limited research has been conducted on soil quality in organic agricultural systems. A more focused research effort is proposed to assess the magnitude and extent of change in soil quality that can be achieved with adoption of organic agricultural systems. This Critical Issue Report describes a scientific approach to cost-effectively monitor and compare soil quality between conventional and organic agricultural systems across a diversity of ecoregions in America. The proposed minimum-data-set approach for soil quality assessment should not be perceived as all-encompassing. It is simply an approach to highlight how soil quality in organic agricultural systems can be assessed using the current paradigm of soil testing sample submission, data evaluation, and management interpretation. The proposed minimum-data-set approach will serve as the foundation for a national survey of soil quality that *The Organic Center* plans to implement during the next two years.

What is Soil Quality?

Scientific assessment of soil quality is essential to monitor the sustainability of agricultural systems. Soil quality is a complex subject, encompassing the many valuable services humans derive from soil and the many ways soils impact terrestrial ecosystems. Different definitions of soil quality have been proposed, each reflecting a different perspective on the use and value of soils.

- The potential utility of soils in landscapes resulting from the natural combination of soil chemical, physical, and biological attributes (Johnson et al., 1992);
- The capability of soil to produce safe and nutritious crops in a sustained manner over the long-term, and to enhance human and animal health, without impairing the natural resource base or harming the environment (Parr et al., 1992);
- The capacities of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Doran and Parkin, 1994);
- The capacity of soil to function (Karlen et al., 1997); and
- How well soil does what we want it to do (Schjønning et al., 2003).

Most definitions link soil quality to some defined use of soil. The use-dependent nature of soil quality definitions has created some debate among scientists about the concept of soil quality and raised provocative questions of how soil quality should be subjected to rigorous scientific investigation (Sojka and Upchurch, 1999). Notwithstanding, we see soil quality as a scientific tool for land managers that will help them adaptively manage soil resources for sustainable future use (Andrews and Moorman, 2002). Curiously, the impetus to define and assess soil quality has occurred primarily from outside the scientific community, because of societal concerns for the health of the environment (Carter, 2002). Since soil quality emphasizes maintenance or improvement in the natural resource base, it has become an integral component of sustainable agriculture (Miller and Wali, 1995; Warkentin, 1995).

Soil quality can be sensed

- From the way soil feels, e.g. does it crumble into aggregates when broken in the hand or does it break into hard clods?
- From how soil smells, e.g. does it have an earthy aroma from the compounds (geosmin) produced by actinomycetes (soil bacteria), or does it smell of fermenting byproducts from a lack of oxygen?
- From how soil looks, e.g. does it have a dark color rich from organic matter and teeming with organisms or does it simply look like dirt?

Soil quality can

- i. Deteriorate rapidly with poor management
- ii. Stabilize with time under adequate management, but undergo minor variations due to weather and crop conditions
- iii. Improve with time using best-available, adaptive techniques that restore key soil functions

How is Soil Quality Determined?

Soil quality can be determined from a variety of soil properties or processes (i.e., indicators), the selection of which may be partially dependent upon land use. Indicators of soil quality will reflect important soil functions (Magdoff and Weil, 2004), including.

- Producing vigorous and healthy plants.

- Cycling and retaining globally important nutrients, e.g. (a) storing nitrogen in soil and releasing it to roots for efficient plant production and (b) storing carbon in soil and releasing it to the atmosphere in a dynamic balance that stabilizes atmospheric concentration of CO₂.
- Supplying plants with water, nutrients, and plant-growth promoting compounds
- Protecting water quality (both ground water and surface water) from nutrient and pathogenic contamination.
- Providing physical stability and support for vegetation, buildings, and roads.
- Enabling animal habitat and serving as a reservoir for biodiversity (microscopic and visible).
- Buffering against toxic accumulation and transport of natural and synthetic compounds.
- Filtering elements to protect animals, plants, and the environment from undesirable exposure.

Soil quality assessments often use a small group of indicators (i.e., a minimum data set) to economically and efficiently characterize selected key soil functions. Land managers and scientists do not have unlimited time and resources to study all of the potential functions served by soil in a region, nor can they predict future needs or demands on soil resources.

A minimum data set for soil quality assessment is designed to establish a reliable estimate of the capacity of soil to perform a defined set of functions and to assess changes in soil quality over time. A well-designed minimum data set should allow us to monitor changes in soil functions brought about as a result of a particular cropping pattern, tillage system, and overall management. Specifically, a minimum data set is proposed that should reliably detect changes in soil quality as farmland shifts from conventional to organic production.

Because of the competing uses and inherent limitations for soils, the components of a minimum data set cannot be considered universal. Of vital importance to the selection of soil quality indicators that reflect key soil functions is the definition of primary management goals (Andrews et al., 2004). In organic agriculture, management goals will often focus on.

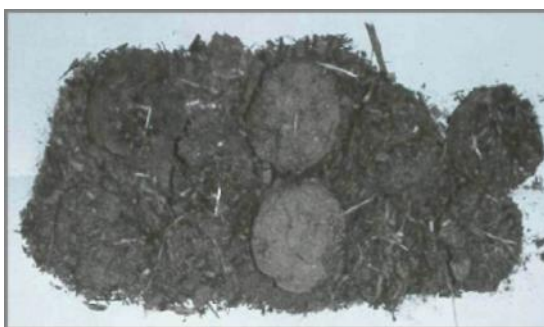


Figure 2.54.

A soil sample rich in organic matter due to improved grassland management, despite having coarse texture and collected from the warm, humid region of the southeastern USA. Texture and climate broadly control soil organic matter content, but improved management can overcome these limitations.

- Productivity
- Creating a biologically active soil food web
- Avoidance of synthetic inputs
- Providing a healthy food supply
- Environmental protection

Soil quality assessment distinguishes between static and dynamic soil properties.

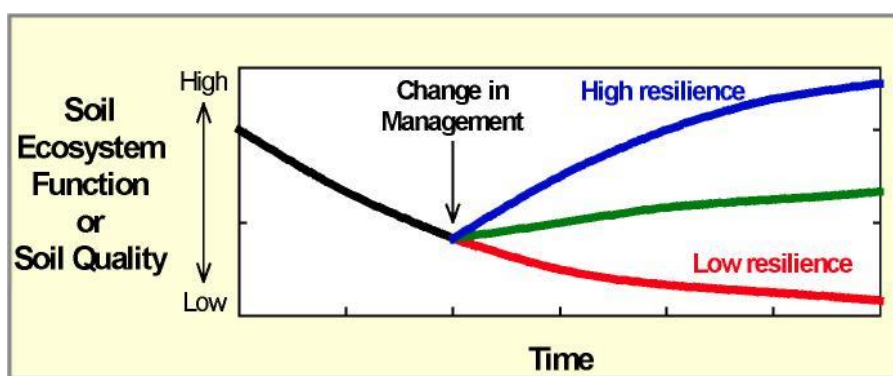


Figure 2.55.

Static soil properties reflect the inherent characteristics of a particular site, e.g. soil texture, mineralogy, and classification, all of which are influenced by geologic history and climatic conditions. In addition, topography, hydrology, and climate are factors that affect productivity and environmental quality of a site, somewhat independent of management. Static soil properties have been adequately characterized in North America with regional sampling approaches by the USDA's Natural Resources

Conservation Service through the periodic National Resources Inventory (Brejda et al., 2000). Similar efforts have been conducted by Agriculture and Agri-Food Canada (MacDonald et al., 1995). Static soil properties provide the contextual background for how soil management practices might eventually alter dynamic soil properties.

Dynamic soil properties are those properties that can change value over relatively short time periods (e.g., months, years, and decades). Dynamic soil properties are at the leading edge of soil quality assessment, because they change quickly, and oftentimes dramatically, in response to management. Dynamic soil properties can indicate whether a farm uses agronomically and ecologically sustainable practices.

Changes in soil properties with time are a key component of dynamic soil quality assessment. Sustainable cropping systems that improve soil quality indicators with time will lead to incrementally higher soil quality. Practices and strategies proven to enhance soil quality across a broad range of ecosystems include diverse crop rotations, minimal use of tillage for weed control and seedbed preparation, and addition of organic amendments like animal manures, crop residues, and compost. Management systems that cause a decline in soil quality indicators with time will lead to lower soil quality; often induced by cropping systems with low residue production, intensive tillage, and near monoculture cultivation. Two concepts are helpful in assessing change in soil quality – the resistance of soils to degradation, and the resiliency of soils to bounce back after a period of declining soil quality.

Resistance of soil to degradation can be assessed by determining the extent of change in dynamic soil quality indicators, such as during a period of intensive tillage. Low resistance of a soil property to disturbance might induce a permanent and damaging change in soil functional capabilities. High resistance to disturbance is a positive attribute, reflected in strong functional capabilities that are supported by a range of management approaches. Resilience of soil is another desirable soil characteristic that can be assessed by determining how fast a dynamic soil quality indicator rebounds from a period of poor management.

Soil Quality Indicators

Soil quality indicators are often divided into three main classes: Soil chemical properties or processes.

- Soil physical properties or processes
- Soil biological properties or processes

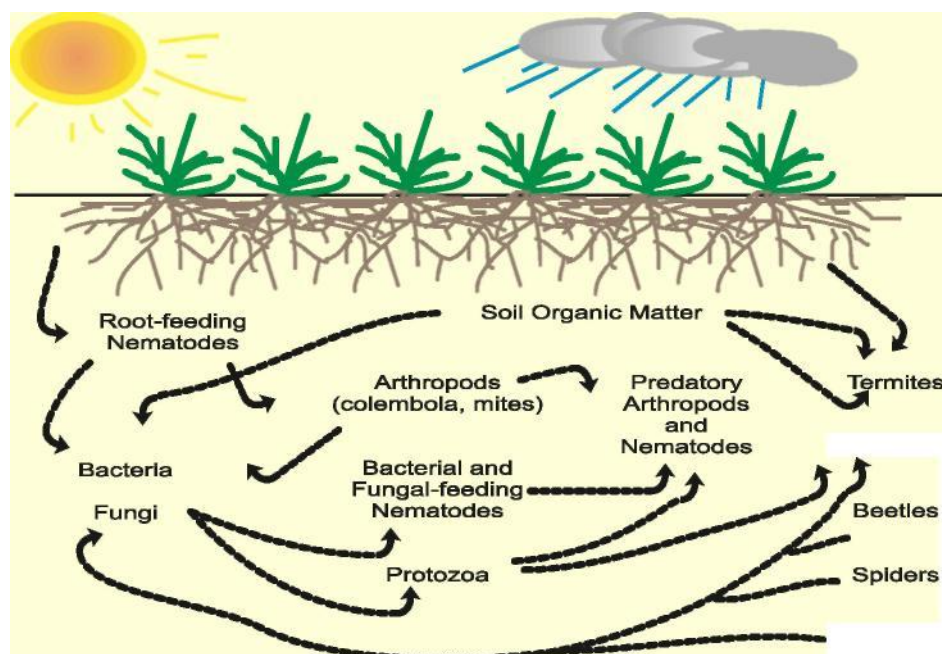


Figure 2.56: A strong, functioning soil food web will allow a plethora of soil organisms to decompose, incorporate, and redistribute carbon and other nutrients within the soil profile. Soil organic matter and plant roots and residues are the sources of carbon for a cascade of feeding activity by soil fauna and microorganisms. A biologically active soil food web is essential to the success of all organic agricultural systems.

Within each of these classes, a variety of soil properties or processes can be selected to indicate soil functional capabilities. Currently, most commercial soil testing laboratories offer a variety of soil tests to determine soil physical and chemical properties, but few have tests for rapid and reliable determination of soil biological activity and condition. In organic agriculture especially, soil biological properties and processes are of great importance, since the majority of nutrients are derived from microbial decomposition of various fractions of organic matter, instead of from fertilizers bought off the farm, as the case on most conventional farms. The structure and function of highly active soil microbial communities may also impart plant

protection mechanisms to ward off diseases and create less stressful conditions for plant growth.

A few comparative studies have been conducted to look at soil quality under conventional and organic agricultural systems. At the Rodale Institute in Pennsylvania, organically managed soil had greater soil organic carbon and total nitrogen and lower nitrate leaching loss than conventionally managed soil (Drinkwater et al., 1998), as well as greater biological soil quality (Yakovchenko et al., 1996). At the end of 4 years of management of an apple orchard in Washington, soil bulk density, water-filled pore space, and nitrate-N were lower under organic than conventional management, while soil microbial biomass carbon was greater under organic than conventional management (Glover et al., 2000).

All other soil properties measured were not different between conventional and organic management (i.e., aggregate stability, total nitrogen, extractable phosphorus, cation exchange capacity, pH, electrical conductivity, microbial biomass nitrogen, organic carbon, and earthworm population). At the end of 40-47 years of dairy farm management in Denmark, organically managed soil had greater fragment size, aggregate stability in water, and microbial biomass carbon than conventionally managed soil (Schjønning et al., 2002). Several other physical and biological properties were not different between management systems, but ergosterol, an indicator of soil fungi, was lower in abundance under organic than conventional management systems for some unknown reason.

At the end of 21 years of crop rotation management in Switzerland, soil organic carbon and total nitrogen were greater under biodynamic management than conventional management, but organic management and integrated management (combination of manures, inorganic fertilizers, and herbicides) were intermediate (Fließbach et al., 2006). Soil microbial biomass carbon and dehydrogenase activity were greater under organic than under conventional management, but basal soil respiration was not different between systems. Among 5 paired farms in North Dakota and Nebraska, total and microbial carbon and nitrogen, and mineralizable carbon and nitrogen were greater under organic than under conventional management (Liebig and Doran, 1999). The authors stated that the capacity of organic production practices to

improve soil quality was mainly due to use of more diverse crop sequences, application of organic amendments, and less frequent tillage.

The aforementioned comparative studies had consistently greater soil microbial biomass carbon under organic than under conventional management. Depending upon the suite of soil properties measured, various other soil microbial activity assays (dehydrogenase activity, mineralizable carbon, and mineralizable nitrogen) were also greater under organic than conventional management. Total organic carbon and nitrogen were sometimes greater under organic management, but not always. Various soil physical properties, when measured, were often greater under organic than under conventional management, but this effect was not consistent. From the relatively few studies available, we conclude that total and biologically active fractions of soil organic matter will be important response variables characteristic of organic management systems. In addition, there is a great need to quantitatively assess the difference between conventional and organic agricultural systems across a wide range of ecological conditions using a consistent suite of soil biological, physical, and chemical indicators. Inherent conditions within a particular ecoregion may be strikingly different, resulting in significant variation in how soil responds to organic management.

Potential soil quality indicators are listed in Appendix 1. For many soil properties and processes, there are several approaches that can be used by soil scientists and testing laboratories. Several specialized tests have been developed, or adapted for application in unique circumstances. All of these methods can produce valid information when properly applied, but none are perfect for all applications. The challenge in selecting and applying a minimum data set for soil quality assessment is to gain the most in-depth and reliable quantitative measure of soil quality with the minimum number of indicators. In addition, indicators should be selected mindful of the time and expense required for accurate and reliable determination.

We propose a selection of the indicators listed in Appendix 1. Measurement of these indicators with time will produce a minimum data set that can be used to quantitatively assess the changes in soil quality.

- Prior to the adoption of organic agriculture

- During the transition to organic farming practices
- Following successful implementation of organic farming for an extended period of time.

The proposed minimum data set combines the need to describe critical soil functions with the need for indicators that are relatively simple, rapid, and reliable. *The proposed minimum data set is based solely on laboratory techniques from soil samples collected from the field.* In-field measurements of plant productivity (indicated by crop yield and total plant biomass), rooting conditions (indicated by rooting depth, soil compaction, or water infiltration), environmental threats (indicated by nitrous oxide emission, nutrient and sediment runoff, or airborne particulate matter), and soil biodiversity (indicated by earthworms, nematodes, and soil microarthropods) should also be considered for a more thorough evaluation of how management systems might be affecting soil quality at a particular site.

The minimum data set for soil quality assessment in organic agriculture builds upon previous knowledge of soil quality assessment in more traditional and conventional agricultural systems. However, soil quality assessment in organic agricultural systems relies more heavily on soil biological indicators, because of the inherent reliance on microbial processes that control organic matter decomposition for efficient nutrient cycling and biological-environmental interactions that suppress diseases and promote plant health. The proposed minimum data set for soil quality assessment in organic agriculture includes.

Soil organic carbon and total nitrogen reflecting the functional capability of soil to supply nutrients to plants, serve as an organic nutrient reserve, mitigate greenhouse gas accumulation, and provide organic resources for stabilizing the soil surface against erosion, for filtering of water, for buffering against nutrient extremes, and for promoting a biologically diverse and healthy microbial population. Soil organic matter can be related to most other indicators of soil quality, but by itself does not adequately reflect the breadth of ecological processes occurring in soil. Soil organic matter is a key component of productivity, avoidance of synthetic inputs, healthy food supply, and environmental protection goals.

Water-stable aggregation and stability reflecting the functional capability of soil to provide physical stability and resistance against water erosion. Soil aggregate stability reduces runoff of sediments and pathogens, as well as nutrients and pesticides bound to soil particles. Soil aggregation is an important component in all conservation systems designed to protect water quality.

Flush of CO₂ following rewetting of dried soil reflecting the functional capability of soil to cycle nutrients, decompose organic amendments, and catalyze and stabilize ecosystem processes through the interactions among a diversity of organisms. The flush of CO₂ following rewetting of dried soil is highly related to soil microbial biomass, potential microbial activity, and potentially mineralizable nitrogen. The flush of CO₂ following rewetting of dried soil is an important component of soil productivity, limiting reliance on synthetic inputs, progress toward safer and more nutritious food, and achieving environmental protection goals.

Microbial substrate utilization reflecting the functional capability of soil to provide biodiversity and habitat, cycle nutrients, decompose organic amendments, filter water passing through soil, and provide biological resilience to soil disturbance. Microbial substrate utilization is a measure of the functional diversity of soil microbial communities, deserving closer attention in both conventional and organic farm management systems.

Inorganic nitrogen, extractable phosphorus, and soil pH reflecting the functional capability of soil to supply readily available nutrients. Inorganic nutrients are important for meeting the goal of crop productivity, but excessive accumulation can be a threat to a healthy food supply and environmental protection. Inorganic nutrients are some of the most commonly determined soil properties in the world and a large database exists for comparison.

Outlook

The proposed minimum data set will be used to develop a widespread, scientifically defensible database to identify and support agricultural management practices that contribute to high soil quality and sustainable land management. A similar approach was recently undertaken to evaluate soil quality under alternative compared with conventional management systems in the Great Plains region of the USA (e.g.,

conservation tillage rather than inversion tillage, intensive cropping sequences rather than bare fallow rotations, and sod-based rotations rather than continuous row-cropping) (Varvel et al., 2006). Sensitive soil indicators to management included total organic carbon, microbial biomass carbon, and aggregate stability (Wienhold et al., 2006). We propose to use these and additional indicators in our minimum data set.

Our proposed soil quality assessment with a minimum-data-set approach should reveal clues as to how and when soil quality is affected when land is converted from conventional to organic agriculture, as well as why soil quality changes, if evaluated on farms in different ecoregions and with different management strategies. Evaluated across a variety of soils throughout America, we will be able to estimate the potential agronomic, water quality, and global warming benefits of conversion to organic agriculture.

Reasons for selecting the relatively few number of soil tests were cost of analysis (total cost of <\$100/sample), time required to complete analyses, minimizing overlapping information obtained, and relevance to important soil functions. The development of quantitative relationships among soil quality, environmental protection, and human health will provide farmers, consumers, and policy analysts critical new information to make decisions about the relative merits of different food-production systems and technologies. Ultimately this information, and new insights derived from it, will empower society to promote and reward progress toward more sustainable and healthy food and fiber production systems.

CHAPTER II

CLIMATE CHANGE, GREEN HOUSE EFFECT, ACID RAINS AND UV RADIATION

CLIMATE CHANGE

Every moment at any spot on the earth, the *troposphere* (the inner layer of the atmosphere containing most of the earth's air) has a particular set of physical properties.

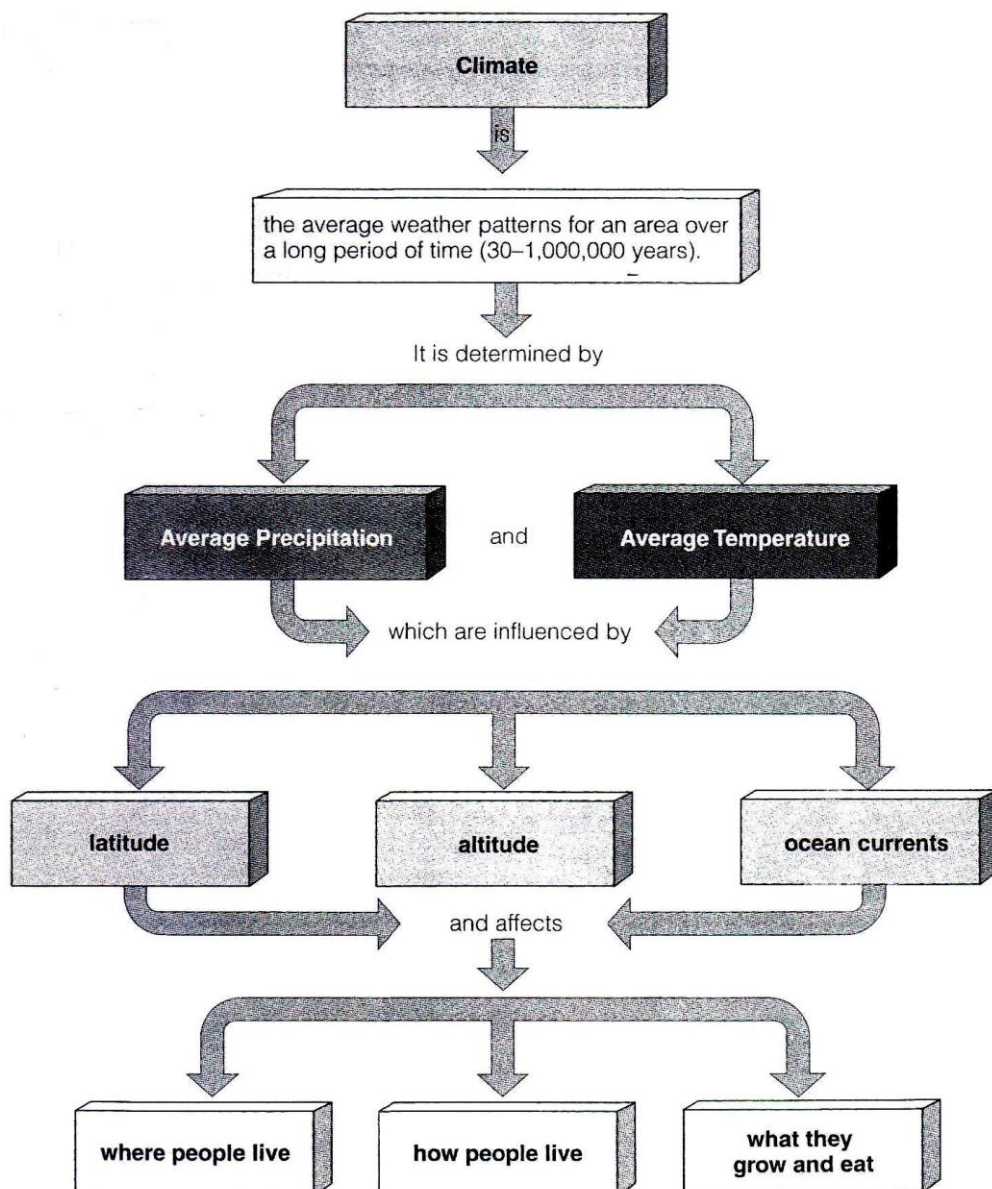


Figure 2.57: Climate and its effects

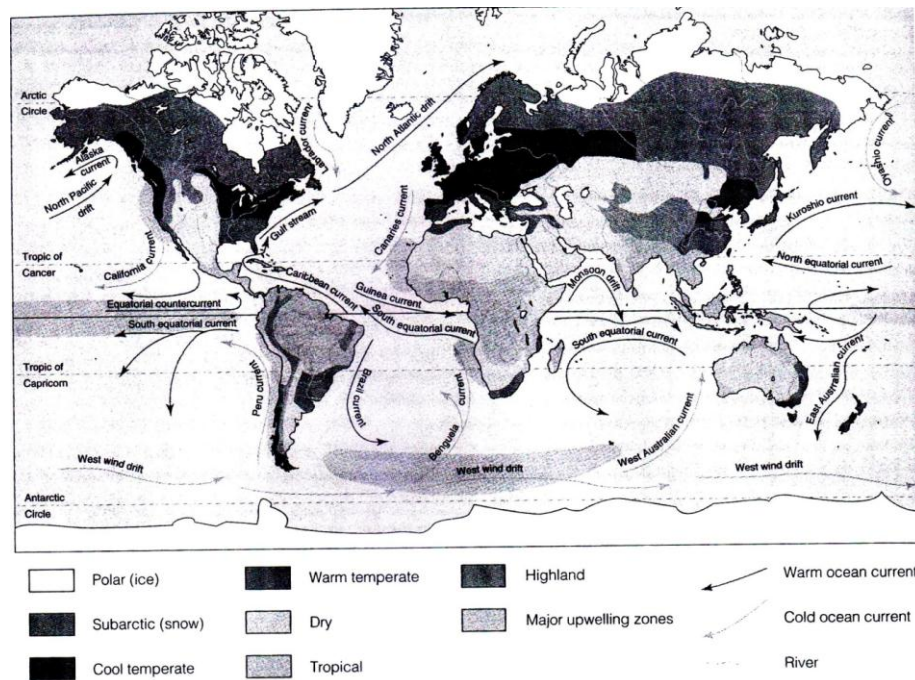


Figure 2.58: Generalized map of global climate zones, showing the major contributing ocean currents and drifts.

Examples are temperature, pressure, humidity, precipitation, sunshine, cloud cover, and wind direction and speed. These short-term properties of the troposphere at a particular place and time are weather. Meteorologists use equipment on weather balloons, aircraft, ships, and satellites, as well as radar and stationary sensors, to obtain data on weather variables. These variables include atmospheric pressures, precipitation, temperatures, wind speeds, and locations of air masses and fronts.

The data are fed into computer models to draw weather maps for each of seven levels of the troposphere, ranging from the ground to 19 kilometers (12 miles) up. Computer models use the map data to forecast the weather in each box of the seven-layer grid for the next 12 hours. Other computer models project the weather for the next several days by calculating the probabilities that air masses, winds, and other factors will move and change in certain ways.

Climate is a region's general pattern of atmospheric or weather conditions over a long period. *Average temperature* and *average precipitation* are the two main factors determining a region's climate and its effects on people (Figure 2.57). Figure 2.58 is a generalized map of the earth's major climate zones.

How Does Global Air Circulation Affect Regional Climates? The temperature and precipitation patterns that lead to different climates (Figure 2.58) are caused primarily by the way air circulates over the earth's surface. Five major factors determine a global air circulation pattern first is the *uneven heating of the earth's surface*. Air is heated much more at the equator (where the sun's rays strike directly throughout the year) than at the poles (where sunlight strikes at an angle and thus is spread out over a much greater area). These differences in incoming solar energy help explain why tropical regions near the equator are hot, Polar Regions are cold, and temperate regions in between generally have intermediate average temperatures.

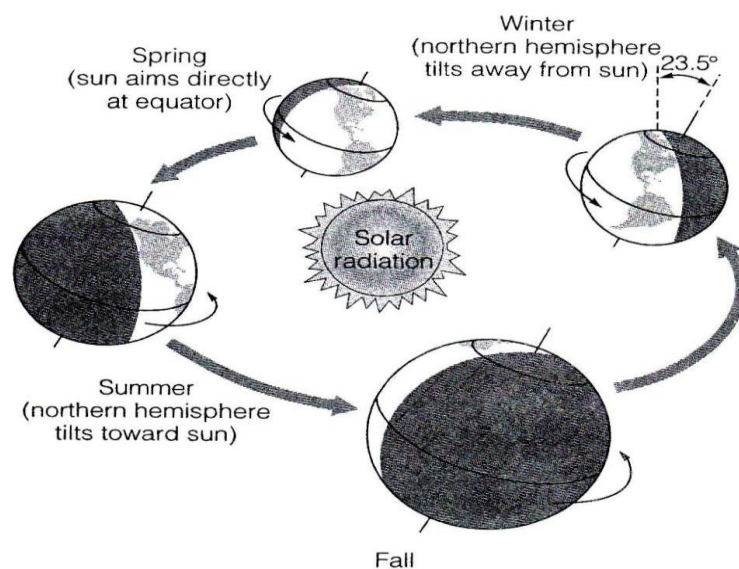


Figure 2.59: The effects of the earth's tilted axis on climate. As the planet makes its annual revolution around the sun on an axis tilted about 23.5°, various regions are tipped toward or away from the sun. The resulting variations in the amount of solar energy reaching the earth create the seasons.

A second factor is seasonal changes in temperature and precipitation. The earth's axis (an imaginary line connecting the north and south poles) is tilted. As a result, various regions are tipped toward or away from the sun as the earth makes its yearlong revolution around the sun (Figure 2.59). This creates opposite seasons in the northern and southern hemispheres.

A third factor is the rotation of the earth on its axis. As the earth rotates its surface turns faster beneath air masses at the equator and slower beneath those at the poles. This deflects air masses moving north and south to the west or east. This results in the

formation of six huge convection cells of swirling air masses (three north and three south of the equator) that transfer heat and water from one area to another (Figure 2.60). The direction of air movement in these cells sets up belts of prevailing winds that distribute air and moisture over the earth's surface. *Fourth*, there are *long-term variations in the amount of solar energy striking the earth*. These are caused by occasional changes in solar output and slight planetary shifts in which the earth's axis wobbles (22,000-year cycle) and tilts (44,000-year cycle) as it revolves around the sun.

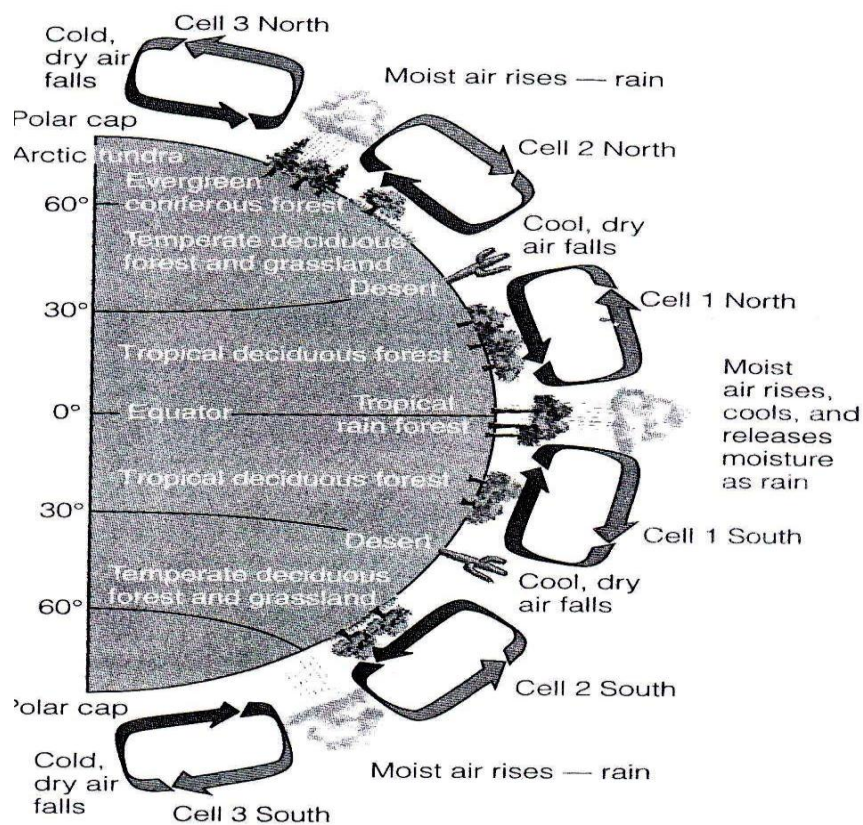


Figure 2.60: Model of global air circulation and biomes. Heat and moisture are distributed over the earth's surface by vertical currents that form six large convection cells (called Hadley cells) at different latitudes. The direction of air flow and the ascent and descent of air masses in these convection cells determine the earth's general climatic zones. The resulting uneven distribution of heat and moisture over the planet's surface leads to the forests, grasslands, and deserts that make up the earth's biomes.

Finally, properties of air and water affect global air circulation patterns. Heat from the sun evaporates ocean water and transfers heat from the oceans to the atmosphere, especially near the hot equator. This creates cyclical convection cells that transport

heat and water from one area to another. The resulting convection cells circulate air, heat, and moisture both vertically and from place to place in the troposphere. This leads to different climates and patterns of vegetation (Figure 2.60).

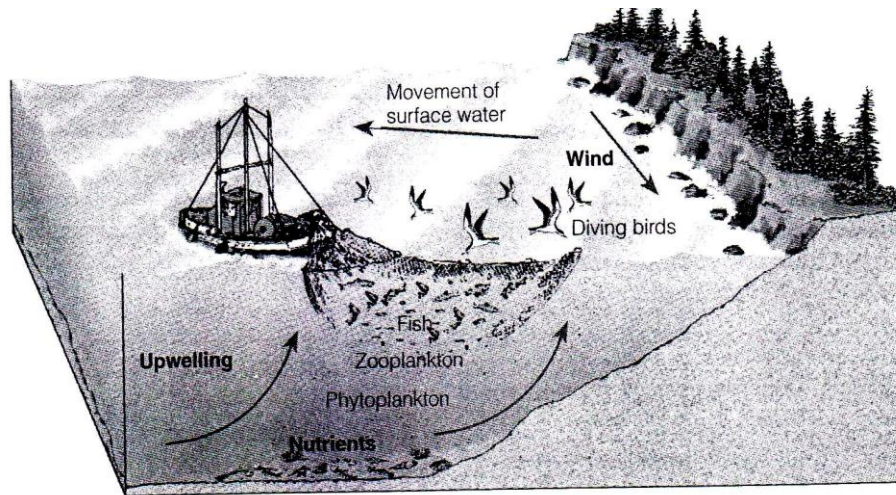


Figure 2.61: A *shore upwelling* (shown here) occurs when deep, cool, nutrient-rich waters are drawn up to replace surface water moved away from a steep coast by wind flowing along the coast toward the equator. Such areas support large populations of phytoplankton, zooplankton, fish, and fish-eating birds. *Equatorial upwellings* occur in the open sea near the equator when northward and southward currents interact to push deep waters and their nutrients to the surface, thus greatly increasing primary productivity in such areas.

How Do Ocean Currents Affect Regional Climates? The factors just listed, plus differences in water density, create warm and cold ocean currents (Figure 2.58). These currents, driven by winds and the earth's rotation redistribute heat received from the sun and thus influence climate and vegetation, especially near coastal areas.

For example, without the warm Gulf Stream, which transports 25 times more water than all the world's rivers, the climate of northwestern Europe would be subarctic. If the ocean's currents suddenly stopped flowing, there would be deserts in the tropics and thick ice sheets over northern Europe, Siberia, and Canada. Currents also help mix ocean waters and distribute nutrients and dissolved oxygen needed by aquatic organisms.

What Are Upwelling's? The winds blowing along some steep western coasts of continents toward the equator push surface water away from the land. This outgoing

surface water is replaced by an up-welling of cold, nutrient-rich bottom water (Figure 2.61). Upwelling's, whether far from shore or near shore (Figure 2.58); bring plant nutrients from the deeper parts of the ocean to the surface. In turn, these nutrients support large populations of phytoplankton, zooplankton, fish, and fish-eating seabirds.

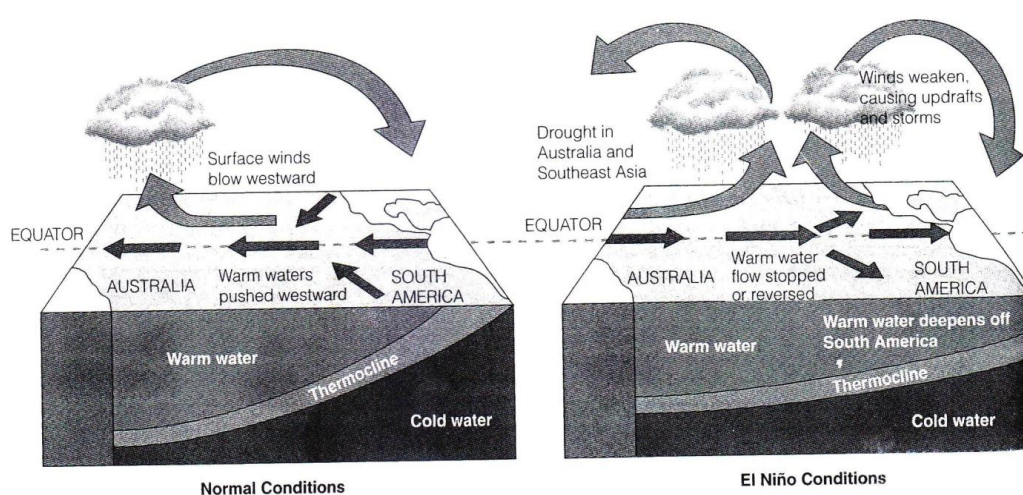


Figure 2.62: Normal surface winds blowing westward cause shore upwellings of cold, nutrient-rich bottom water in the tropical Pacific Ocean near the coast of Peru (left). A zone of gradual temperature change called the *thermocline* separates the warm and cold water. Every few years a climate shift known as the *E! Nino-Southern Oscillation (ENSO)* disrupts this pattern. Westward surface winds weaken, which depresses the coastal upwellings and warms the surface waters off South America (right). When an ENSO lasts 12 months or longer, it severely disrupts populations of plankton, fish, and seabirds in upwelling areas and can trigger extreme weather changes over much of the globe.

What Is the El Nino-Southern Oscillation? Every few years in the Pacific Ocean, normal shore upwelling's (Figure 2.62 left) are affected by changes in climate patterns called the *El Nino-Southern Oscillation*, or *ENSO* (Figure 2.62, right). In an ENSO, often called *El Nino*, the prevailing westerly winds weaken or cease and surface water along the South and North American coasts becomes warmer. This suppresses the normal upwellings of cold, nutrient-rich water. The decrease in nutrients reduces primary productivity and causes a sharp decline in the populations of some fish species. A strong ENSO can trigger extreme weather changes over at least two-thirds of the globe, especially in lands along the Pacific and Indian Oceans.

What Is La Nina? The cooling counterpart of El Nino is *Ea Nina*. Typically La Nina means more Atlantic Ocean hurricanes, colder winters in Canada and the northeastern United States, warmer and drier winters in the southeastern and southwestern United States, wetter winters in the Pacific Northwest, and torrential rains in Southeast Asia, lower wheat yields in Argentina, and more wildfires in Florida.

Table 2.16: Major regions of the Atmosphere.

Region	Altitude Range, Km	Temperture Range °C	Important chemical Species
Troposphere	0 – 11	15 to -56	N ₂ , O ₂ , CO ₂ , H ₂ O
Stratosphere	11 – 50	-56 to -2	O ₂
Mesosphere	50 – 85	-2 to -92	O ₂ ⁺ , NO ⁺
Thermosphere	85 - 500	-92 to 1200	O ₂ ⁺ , O ⁺ , NO ⁺

Atmosphere Structure

The atmosphere may be broadly divided into four regions as shown in Table 2.16. It extends up to 500 km with temperature varying from a minimum of 2° C to a maximum of 1200° C. The troposphere contains 70% of the mass of the atmosphere. The upper limit of the Troposphere may vary by kilometer or more, depending on factors such as temperature, nature of terrestrial surface, etc. Air is far from uniform, with respect to density and temperature. Density decreases exponentially with increasing altitude. In respect of composition, the Troposphere is more or less homogeneous in the absence of air pollution, mainly due to the constant circulation of air masses in this region. The water content, however, varies due to the global energy flow arising from imbalances of heating and cooling rates between the equator and the poles.

The temperature in the troposphere falls off uniformly with increasing altitude. The air near ground level is heated by radiation from the earth. The cold layer (-56° C) at the top of the troposphere is called the tropopause, which marks temperature inversion, i.e. transition from negative to positive lapse rates (slope of temperature-altitude curve: Fig. 2.63). The stratosphere is a calm layer having a positive lapse rate. The temperature increases with increase in altitude, with a maximum of -2°C at the upper limit of the stratosphere. As discussed earlier ozone in this region absorbs ultraviolet radiation and raises the temperature causing a positive lapse rate and because of slow mixing in the stratosphere, the residence times of molecules or particles in this region are quite long.

If the pollutants can somehow reach or are injected into the stratosphere, they pose long-term global hazards compared to their impact in the much denser troposphere.

The mesosphere shows negative lapse rate, i.e. temperature falls with increasing altitude. This is due to low levels of ultraviolet absorbing species, particularly ozone. In the thermosphere immediately above the mesosphere, the temperature rises once again, giving a positive lapse rate (maximum temperature 1200°C). Here, the atmosphere gases, particularly oxygen and nitric oxide, split into atoms and also undergo ionization after absorption of solar radiation in the far ultraviolet region.

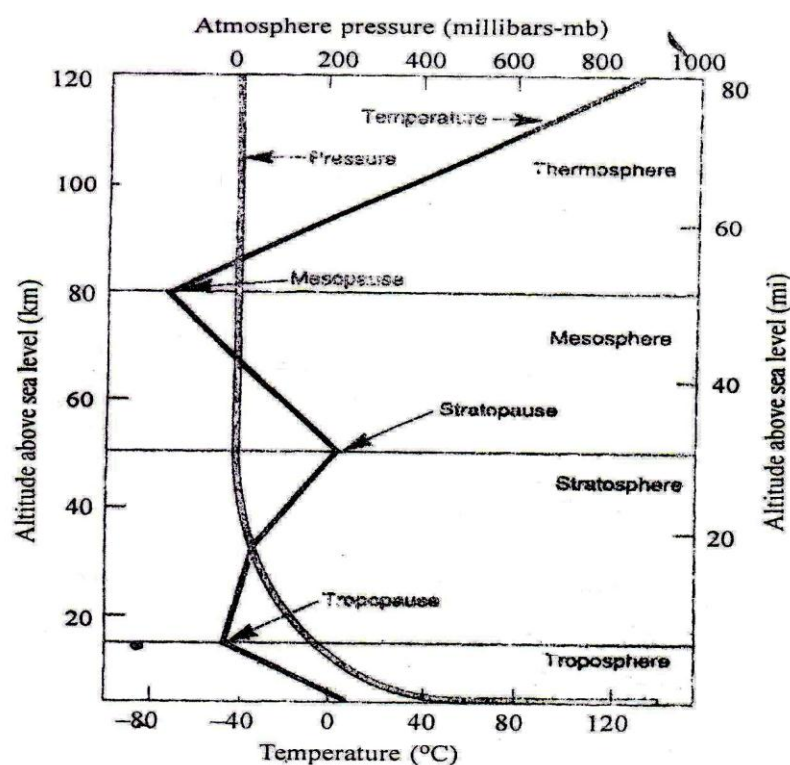


Figure 2.63: Temperature altitude profile of atmosphere.

Weather

At any given place and time on Earth, the troposphere (the inner layer of the atmosphere containing most of Earth's air) has a particular set of physical properties, including temperature, pressure, humidity, precipitation, sunshine, cloud cover, and wind direction and speed which is called *weather*. *Climate* is the average long-term weather of an area; it is a region's general pattern of atmospheric or weather conditions, seasonal variations, and weather extremes (such as hurricanes, or prolonged drought or rain) averaged over a long period (at least 30 years).

Global Air Circulation and Biomes

The two most important factors determining the climate of an area are temperature and precipitation. The temperature and precipitation patterns that lead to different climates are caused mostly by the way air circulates over Earth's surface. The following factors determine these patterns of global air circulation.

- a. Even slight changes in solar output slight planetary shifts in which Earth's axis wobbles (22,000 year cycle) and tilts 44,000 year cycle as it revolves around the sun, and minute changes in the shape of its orbit around the sun (100,000 year cycle) result in long term variations in the extent of solar radiation received by the earth.
- b. As air is heated more strongly at the equator than at the poles, where sunlight strikes at an angle and is thus spread out over a much greater area, earth's surface will be heated unevenly results in the existence of hot tropical regions near the equator, cold Polar Regions, and temperate regions with intermediate average temperatures.
- c. As earth makes its annual revolution the Earth's axis is tilted; various regions are tipped toward or away from the sun creating opposite seasons in the northern and southern hemispheres.
- d. Due to CORIOLIS effect while earth rotates on its axis it prevents air currents from moving from north and south and forces in the atmosphere created by this rotation deflect winds to the right in the northern hemisphere.

Driving Forces for the Horizontal Movement of Winds

The principal driving forces for the horizontal movement of the wind in the atmosphere, are uneven heating of the earth's surface modified by the effect of the earth's rotation (Coriolis force) and the frictional resistance offered by the ground and the sea. Averaged over the year, the solar heat flow to the earth's surface at the equator is 2.4 times than that at the poles. The atmosphere moves in response to this difference in heating, and in so doing transports heat from the tropics to the poles, resulting in temperature difference from equator to poles.

As the equator is directly under the sun, the air there will be heated, become buoyant, and rise. As that air approaches the tropopause. it begins to turn, some heading north and some south. An eighteenth century meteorologists, George Hadley, postulated that the air would continue to the poles before descending. In actuality, it descends at latitude of about 30° and then returns to the equator, forming what are

known as a Hadley cell. In similar fashion, though not as distinct, there are Hadley cells, linked as in a chain, between 30° and 60° latitude, and between 60° and the poles. The descending air at 30° creates a persistent high pressure zone with corresponding lack of clouds or rainfall that is contributing factor to the creation of the world's great deserts. Any odd number of such cells could exist in each hemisphere; on the earth. There are normally three cells in each, as shown in Fig. 2.64.

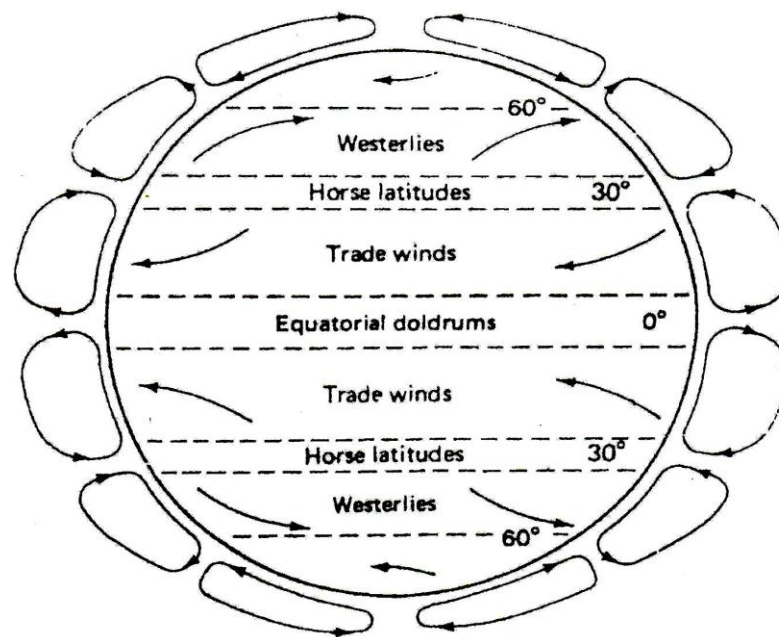


Figure 2.64: Schematic representation of the general circulation of the atmosphere.

In the Northern Hemisphere the circulation cells sketched at the edges of the figure indicating a south-to-north flow at high altitude and a north-to-south flow at the surface in the tropical and polar cells with oppositely directed flows in the temperate cell. There are seven boundaries between cells on the globe, one at the equator and two in each hemisphere and two at the poles (Fig. 2.65). At the boundary equator and the two between the temperate and polar cells the air is rising; at the boundaries between tropical and temperate cells and at the poles (which are "hole in the donut" boundaries) the air is sinking. The rising air will be cooled due to adiabatic expansion and produces rain, while sinking air is heated and becomes relatively dry. The rising boundaries (equator and temperate-polar boundaries) are regions of higher than average rainfall; most of the world's rain forests are located near the equatorial rising

zone, and the great temperate forests are near the temperate-polar rising zones. The sinking boundaries (the poles and the tropical temperate boundaries) are regions of lower than average rainfall; most of the world's great deserts are located near the temperate-tropical sinking zones (Fig.2.65).

Heat and moisture are distributed over Earth's surface by vertical convection currents that form into six large convection cells (called Hadley cells) at different latitudes. The direction of air flow and the ascent and descent of air masses in these convection cells determines Earth's general climatic zones. The uneven distribution of heat and moisture over the planet's surface leads to the forests, grasslands and deserts that make up Earth's biomes. The major contributing ocean currents and drifts. Large variations climate are dictated mainly by temperature, with its seasonal variations, and by the quantity and distribution of precipitation.

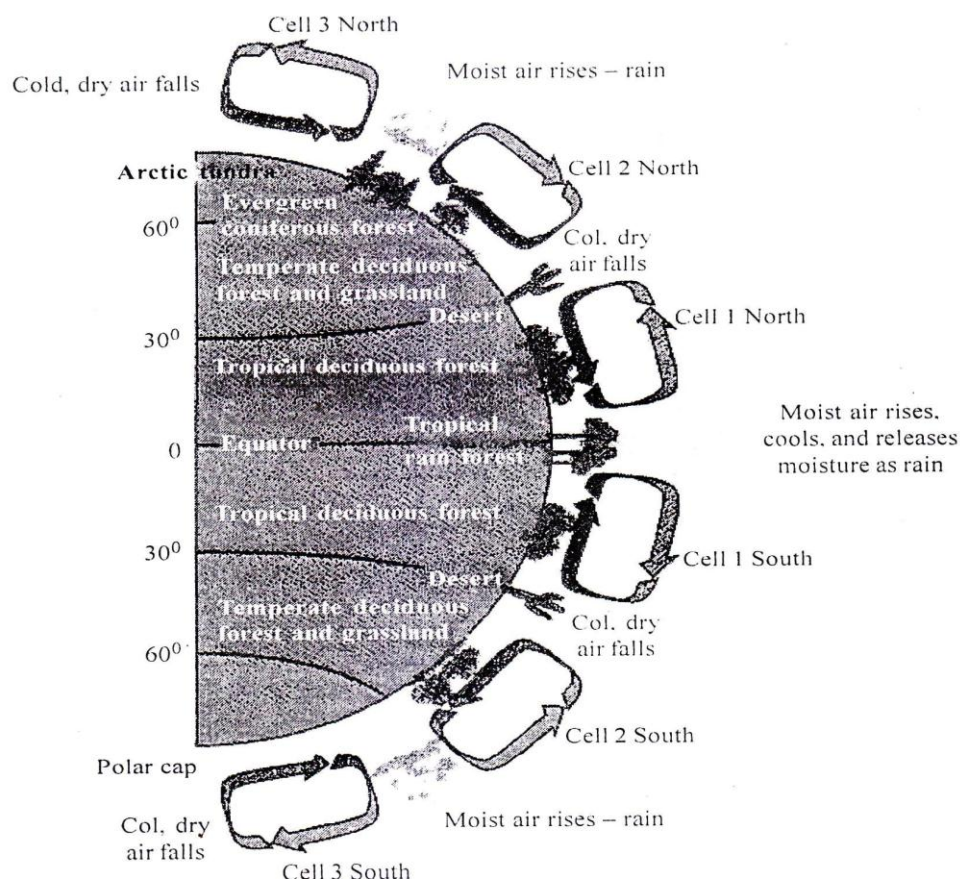


Figure 2.65: Global air circulation and biomes.

The main types of natural vegetation in different undisturbed land areas, mostly results shown differences in climate. Each biome contains many ecosystems whose

communities have adapted to differences in climate, soil and other environmental factors, within the biome. In reality, people have removed or altered much of this natural vegetation for farming, livestock grazing, harvesting lumber and fuel wood, mining and constructing villages and cities thereby altering the biomes. Winds directly under regions of subsiding air often are light and variable. Rising air at the equator creates doldrums where the winds at about 60° north, called the polar front, tends to block the southward flow of cold polar air. The southern hemisphere has more stable wind patterns because it has more oceans and less landmass than the northern hemisphere.

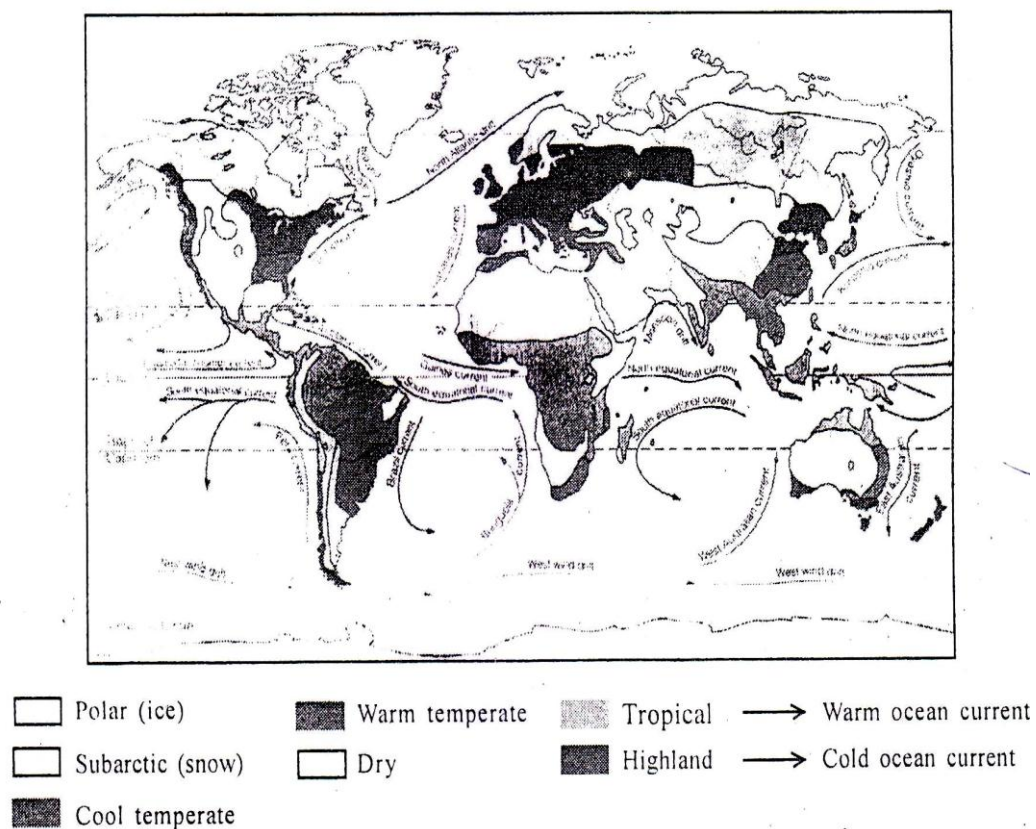


Figure 2.66 a: Generalized map of global climate zones.

Pressure Gradient

A series of disturbances like high pressure zones (anti cyclone zones) and low pressure zones (cyclone) are formed from a large scale instabilities often involving turbulence between these circulation zones in each hemisphere and their relationships are given in Table 2.17. When the planetary boundary layer is unstable there is vertical motion in the lower atmosphere and thus a great deal of momentum transfer

between the planetary boundary layer and the geotropic wind. Thus, unstable atmospheres have higher ground-level wind velocities than stable ones.

Table 2.17: Behavior of High and Low Pressure Areas.

	High	Low
Pressure, compared with average atmospheric pressure	High, typical 1020 to 1030mb	Low, typically 980 to 990 mb.
Average vertical air motion near the ground	Sinking	Rising
Behavior of moisture in the air they contain	Evaporates, causing clear skies	Condenses, causing clouds and precipitation
Winds they generate	Out from the centre, clockwise in the northern hemisphere, weak	In toward the centre, counterclockwise in the northern hemisphere, strong

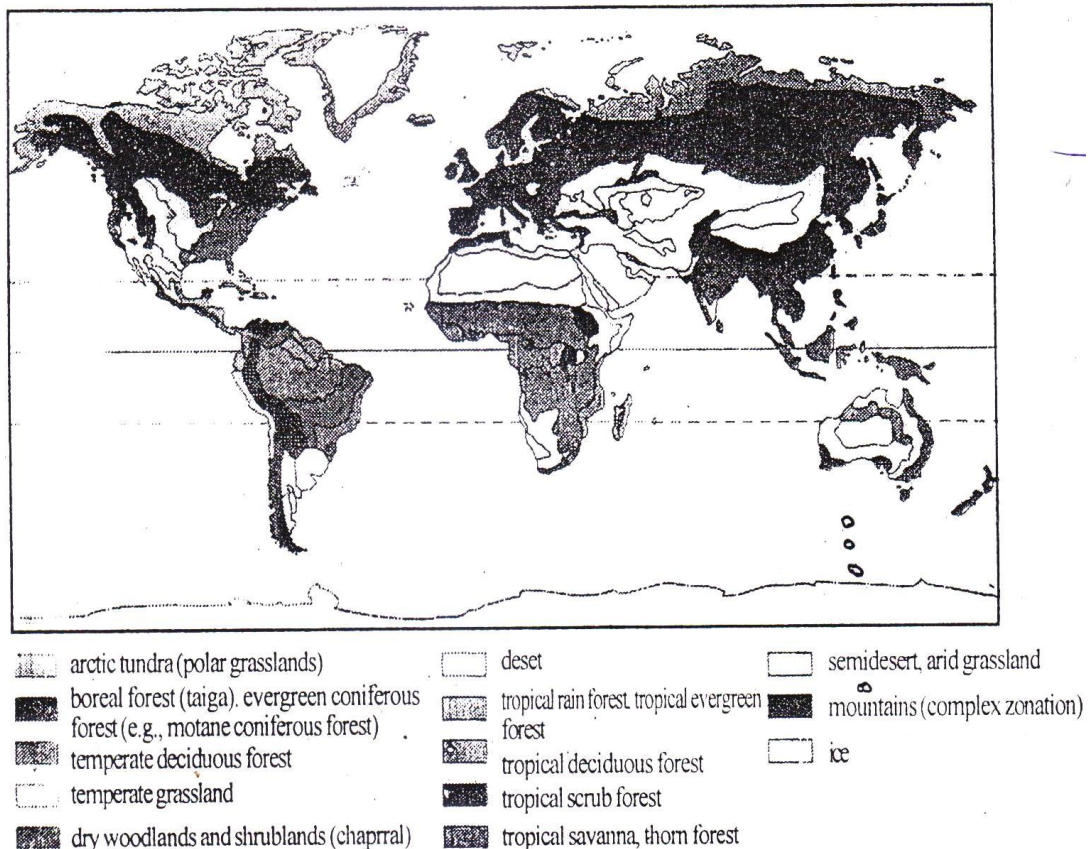


Figure 2.66 b: Earth's major biomes.

Thus, climate and global air circulation are affected by the properties of air and water. When heated by the sun, ocean water evaporates and removes heat from the oceans to the atmosphere, especially near the hot equator. This moist, hot air expands, becomes less fairly narrow vortices that spiral upward, creating an area of low

pressure at Earth's surface. As this moisture laden air rises, it cools and releases moisture as condensation (because cold air can hold less water vapor than warm air). The heat released when water vapor condenses radiates into space. The resulting cooler, drier air becomes denser, sinks (subsides), and creates an area of high pressure. As this air mass flows across Earth's surface, it picks up heat and moisture and begins to rise again. The resulting small and giant convection cells circulate air, heat, and moisture both vertically and from place to place in the troposphere, leading to different climates and patterns of vegetation.

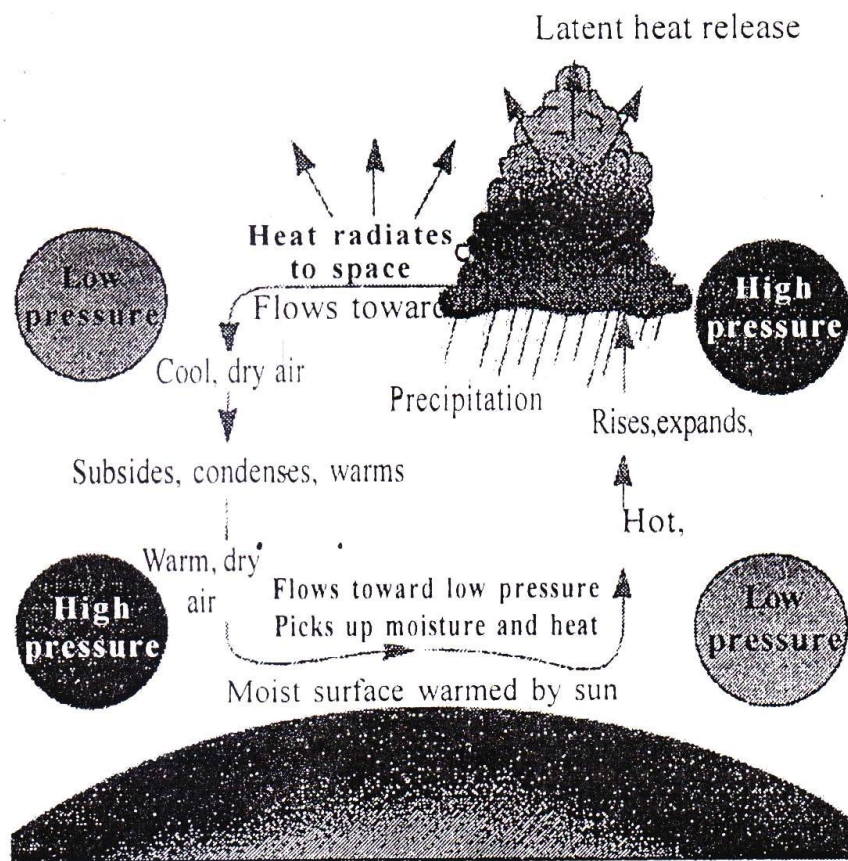


Figure 2.67: Convection currents and latent energy cause atmospheric circulation and redistribute heat and water around the globe.

For example heat and moisture are transported from the Sahara Desert in Africa to rain forest soils in Brazil. Iron rich dust blowing from China's Gobi Desert falls into the Pacific Ocean between Hawaii and Alaska six or seven times a year and stimulates the growth of phytoplankton, the minute producers that support ocean food webs. But the winds also transport harmful substances. Sulphur compounds and soot from oil well fires in Kuwait have been detected over Wyoming, deposits of DDT

and PCBs have been turning up. One of the things that connect all life on earth is wind, a vital part of the planet's circulatory system. Without wind, most of earth would be uninhabitable. The tropics would be unbearably hot, and most of the rest of the planet would freeze.

Winds also transport nutrients from one place to another. Dust rich in phosphates blows across the seas. Movement of soil particles from one place to another by wind and water is a natural phenomenon, but when the soil is undisturbed left unprotected, the process will be hastened.

Frontal Weather

The boundary between two air masses of different temperature and density is called a front. Front may be moving or stationary.

Cold Front

When cooler air displaces warmer air, we call the moving boundary a cold front. Since cold air tends to be denser than warm air, a cold front will hug ground and push under warmer air as it advances (Fig. 2.67). As warm air is forced upward, it cools adiabatically and its cargo of water vapor condenses and precipitates. Upper layers of a moving cold air mass move faster than those in contact with the ground because of surface friction or drag, so the boundary profile assumes a curving, "bull nose" appearance (Fig. 2.68). The region of cloud formation and precipitation will be relatively narrow. Cold fronts generate strong convective currents and often are accompanied by violent surface winds and destructive storms.

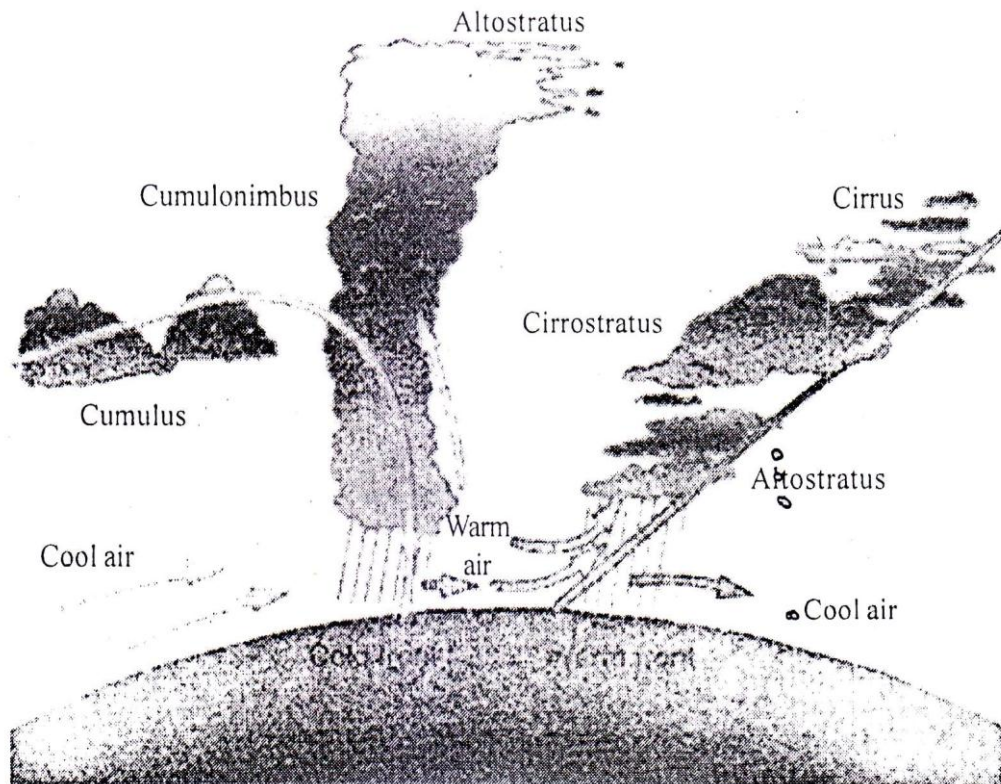


Figure 2.68: Bubbulus bullnore of cold front.

An approaching cold front generates towering clouds called thunderheads that reach into the stratosphere where the jet stream pushes the cloud tops into a characteristic anvil shape. The weather after the cold front passes is usually clear, dry, and invigorating. A cold front assumes a bulbous, "bull nose" appearance because ground drag retards forward movement of surface air. As warm air is lifted up over the advancing cold front, it cools, producing precipitation. When warm air advances, it slides up over cooler air in front and produces a long, wedge-shaped zone of clouds and precipitation. The high cirrus clouds that mark the advancing edge of the warm air mass may be 1,000 km and 48 hours ahead of the front at ground level.

Warm Front

If the advancing air mass is warmer than local air, a warm front results. Since warm air is less dense than cool air, an advancing warm front will slide up over cool, neighboring air parcels, creating a long, wedge-shaped profile with a broad band of clouds and precipitation. Gradual uplifting and cooling of air in the warm front avoids the violent updrafts and strong convection currents that accompany a cold front. A warm front will have many layers of clouds at different levels. The highest layers are

often wispy cirrus (mare's tail) clouds that are composed mainly of ice crystals. They may extend 1,000km ahead of the contained zone with the ground and appear as much as forty-eight hours before any precipitation. A moist warm front can bring days of drizzle and cloudy skies.

When the transition zone between warm and cold air forces not move one way or the other, it is called a 'stationary factor'. A number of local variations both in space and time are likely to influence the ground level wind patterns. The highest ground-level wind velocities are those in tornadoes, up to 200 mi/h (89.54 m/s). Cyclones two weather extremes are violent storms called tornadoes, or twisters, which form over land, and tropical cyclones, which form over warm ocean waters and sometimes pass over coastal land.

Tornadoes occur when a mass of cool, dry air overruns warm, humid air. This condition leads to thunderstorms and extremely turbulent conditions, and in some cases results in the formation of a tornado, a funnel of spinning air on the underside of a cloud that can descend to the ground. Moving at speeds up to 480 kilometers (300 miles) per hour and roaring like a freight train, this spinning column of wind and debris can uproot trees, flatten entire neighborhoods, and fling large objects through the air. Tropical cyclones are giant circular storm systems that develop over warm tropical waters, usually in the late summer or early fall. Tropical cyclones are called hurricanes in the Atlantic and typhoons in the Pacific. Their violent winds, which may blow at up to 320 kilometers.

Wind speed increases with elevation, most of the time, in most of the troposphere. The reason is that ground friction slows the wind. Typically the wind will reach its frictionless velocity (called the geostrophic or gradient velocity) at about 500 m (1640 ft) above the ground. The region below this elevation, where ground friction plays a significant role, is the planetary boundary layer. The ground-level wind velocity is largely determined by how well this layer is coupled to the fast-moving geostrophic layer above it. When the atmosphere is stable or has an inversion, there is little vertical movement; and the coupling between the planetary boundary layer and the geostrophic wind is weak. Thus, inversions and stable atmospheres are normally associated with low ground-level wind velocities.

Wind speed less than about 2 'mi/h known as *calm*. If one could feel a 2 mi/h wind, the only way you can tell which way the wind is blowing is to observe the behavior of leaves, flags, smoke, or steam plumes, which will show that there is a wind even if you cannot feel it. Most weather services report any wind less than about 2 mi/h as "calm" because the wind-measuring instruments (anemometers) become unreliable for such low velocities.

Impact of Ocean Currents on Global climate, EL NINO Effect

EL Nino Phenomenon

Spanish word meaning "*the Christ child*" known as the December phenomenon in the El Nino phenomenon. Normally, the water of Eastern Pacific off equator Peru and Northern Chile are cold. 10°C cooler than the waters of Western Pacific-rich in fish due to high nutrients. During El Nino years, a large pool of warm water in the western Pacific causes convection currents that result in a stable tropical low-pressure cell and heavy rain in Indonesia and Southeast Asia. Subsiding air in the eastern Pacific brings dry weather to the west coast of South America.

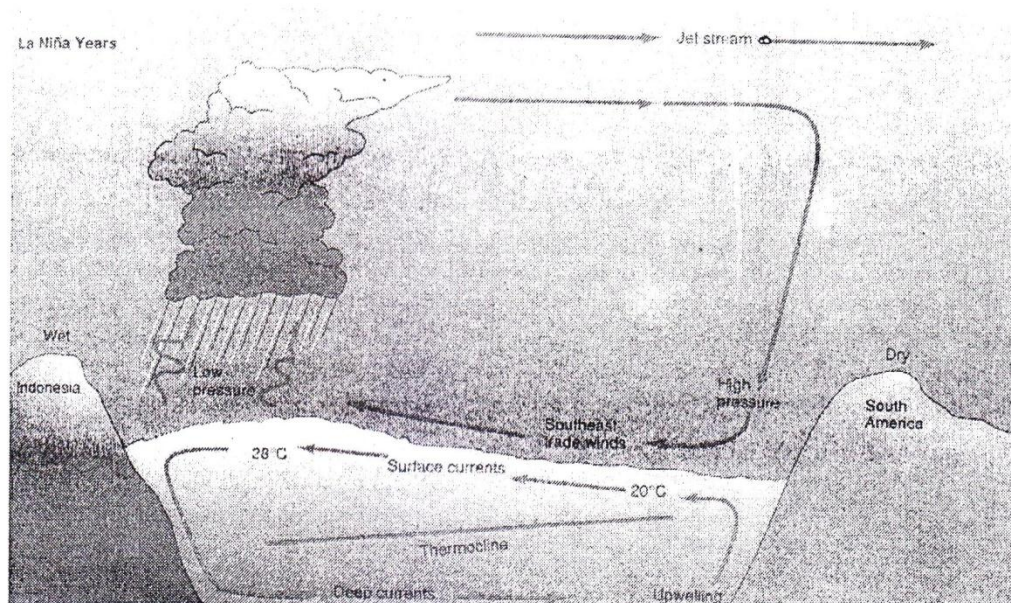


Figure 2.69: EL NINO Effect.

Trade winds flowing back toward the low pressure cell push warm surface water westward, allowing upwelling of cold, nutrient rich deep waters that support vast schools of fish and flocks of seabirds along the coast of Peru. In El Niño years, the warm water shifts back eastward, reversing the wind flow and ocean surface currents,

bringing torrential rains to South America and droughts to Australia and South East Asia. This oscillating pattern is called the El Nino Southern Oscillation (ENSO). Every few years in the Pacific Ocean, normal coastal upwelling is affected by changes in climate patterns called the El Nino Southern Oscillation (ENSO Fig. 2.69).

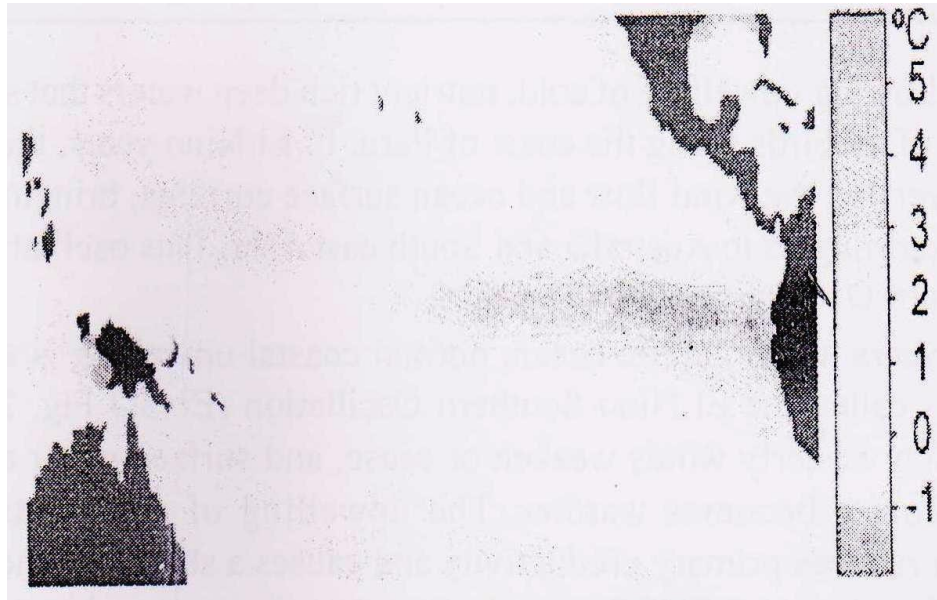


Figure 2.70: EL NINO: sea temperature anomalies in January 1998.

In the ENSO event, the prevailing westerly winds weaken or cease, and surface water along the south and North American coasts becomes warmer. The upwelling of cold, nutrient rich water is suppressed, which reduces primary productivity and causes a sharp decline in the populations of some fish species. A strong ENSO can trigger extreme weather changes over at least two thirds of the globe, especially in lands along the Pacific and Indian oceans. Normal surface winds blowing westward cause shore upwelling's of cold, nutrient rich bottom water in the tropical Pacific Ocean near the coast of Peru Fig. 2.70. The warm and cold water are separated by a zone of gradual temperature change called the thermocline. Every few years a climate shift known as the El Nino Southern Oscillation (ENSO) disrupts this pattern. Westward surface winds weaken which depresses the coastal upwellings and warms the surface waters off South America.

ENSO typically last for several months to over a year and occur every three or four years, although the interval has been as long as seven years. When an ENSO lasts 12 months or longer, it severely disrupts populations of plankton, fish and seabirds in

upwelling areas and can trigger extreme weather changes over much of the globe. Climate over half globe effected due to El Nino resulting in Sand storms in Australia, cyclones in Tahiti, floods along California Tempests ravaging S. Am. Pacific coast. Due to El Nino in 1982 a loss of 3 billion US dollars occurred. El Nino southern oscillations just localized and irregular but recurrent relationship between atmospheric pressure and sea surface temperature on S. E. Pacific and Indian Ocean can cause extreme weather related disasters.

More significant effects were observed in Dec-1982 resulting global impact India food production dropped by 4%, China grain yield dropped by 4%, Indonesia Starvation-deaths Bolivia, Peru-floods South pacific commission which Coordinates and Keeps tract of ocean levels, temperature, salinity levels, wind patterns observed connections between Green house effect and EL NINO effect.

The Influence of the Ground and the Sea

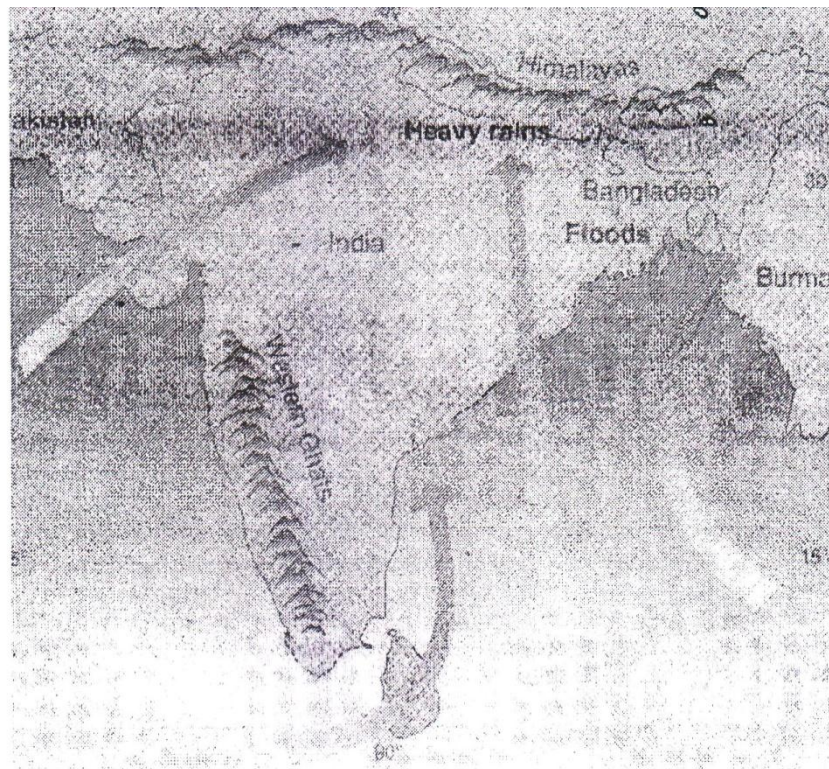


Figure 2.71: Summer monsoon air flows over the Indian Subcontinent.

The surface of the ground heats and cools rapidly from day to night and from summer to winter because solid ground is a poor conductor of heat. The surface of oceans and lakes heat and cool slowly, mostly because their surface layers are stirred by the winds and

by natural convection currents, thus mixing heat up and down. Solid ground is not stirred by the wind or convection currents, so heat cannot mix up and down; its surface temperature changes more rapidly than that of bodies of water. Thus the heating (or cooling) of the air layer adjacent to solid ground is much faster than that of air over bodies of water. Probably the most spectacular example of this phenomenon is the monsoon weather of India and parts of East Africa. The summer sun warms the air above India more than the air over the surrounding oceans, which causes strong upward motion of the air over India. Moist air from over the surrounding warm oceans flows inward to fill the low-pressure region caused by this rising air (Fig.2.71).

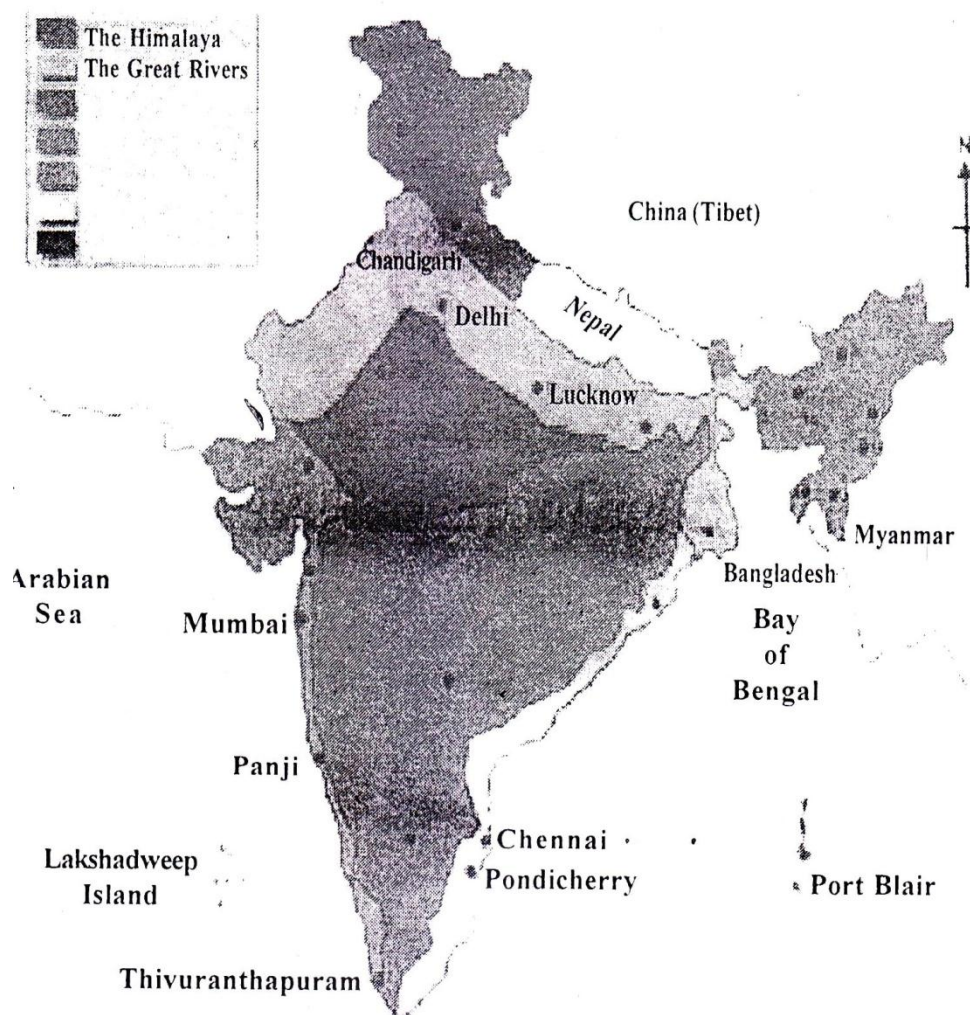


Figure 2.72: Physiographic map of India.

This moist air raises, cools, and forms the monsoon rains on which Indian agriculture depends. As the summer heats the semiarid regions of India, a strong low-pressure system develops. Flow of cool air from the north is blocked by the Karakoram and

Himalayan mountains. A continuous flow of moisture-laden air from the subtropical high pressure area over the Arabian sea sweeps around the tip of India and up into the Ganges Plain and the Bay of Bengal. As the on shore winds are driven against the mountains and rise, the air cools and drops its load of water. During the four months of the monsoon, which usually lasts from June until August, 1,000cm of rain may fall on Nepal, Bangladesh, and western India. The same phenomenon leads to summer thunderstorms over the southwestern.

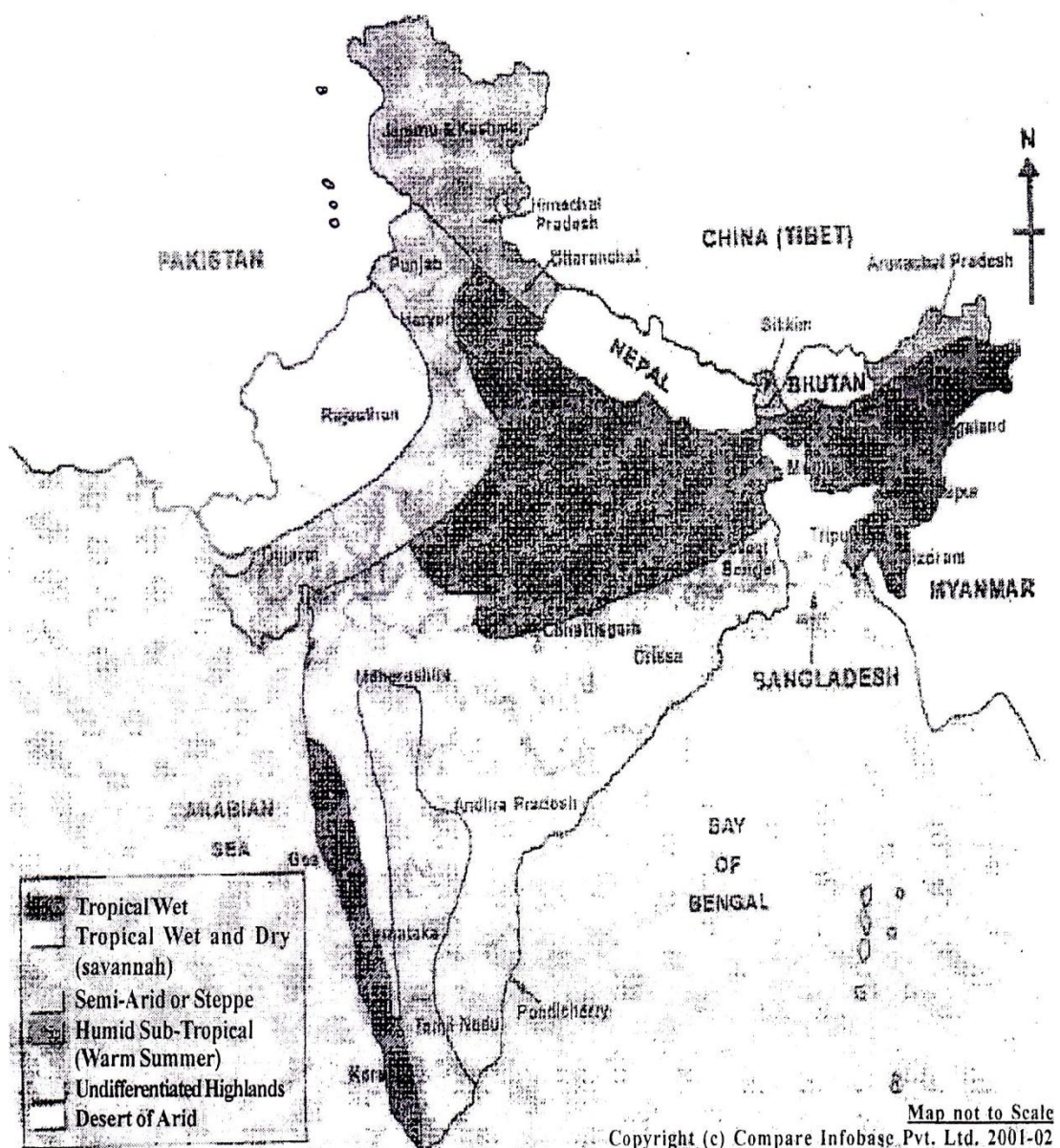


Figure 2.73: India climatic regions.

Climate of India

The Indian subcontinent is geographically situated completely entirely to the north of the equator between latitudes 8° and 36°N mainly exhibits a tropical climate through, the northern part the Gangetic Plain exhibits temperate zone. The climate of the country is mainly influenced by the physiography of several hills and ranges, as Himalayan range, mountain ranges of Meghalaya and Arunachal and the Western Ghats together with the Nilgiris and eastern ghat in south. The maps show the physiography, climate, rainfall and temperature. The following are the four seasons which cover the climate of India and presented in Fig. 2.72 to 2.75 as Indian Meteorological Department (IMD).

1. The seasons of the north-east monsoon
 - i. The 'cool season', from mid-December to February
 - ii. The 'hot dry season', from March to mid-June
2. The seasons of the south east monsoon
 - iii. The 'wet season', from mid-June to mid-September.
 - iv. The 'season of retreating monsoon', from mid-September to mid-December.

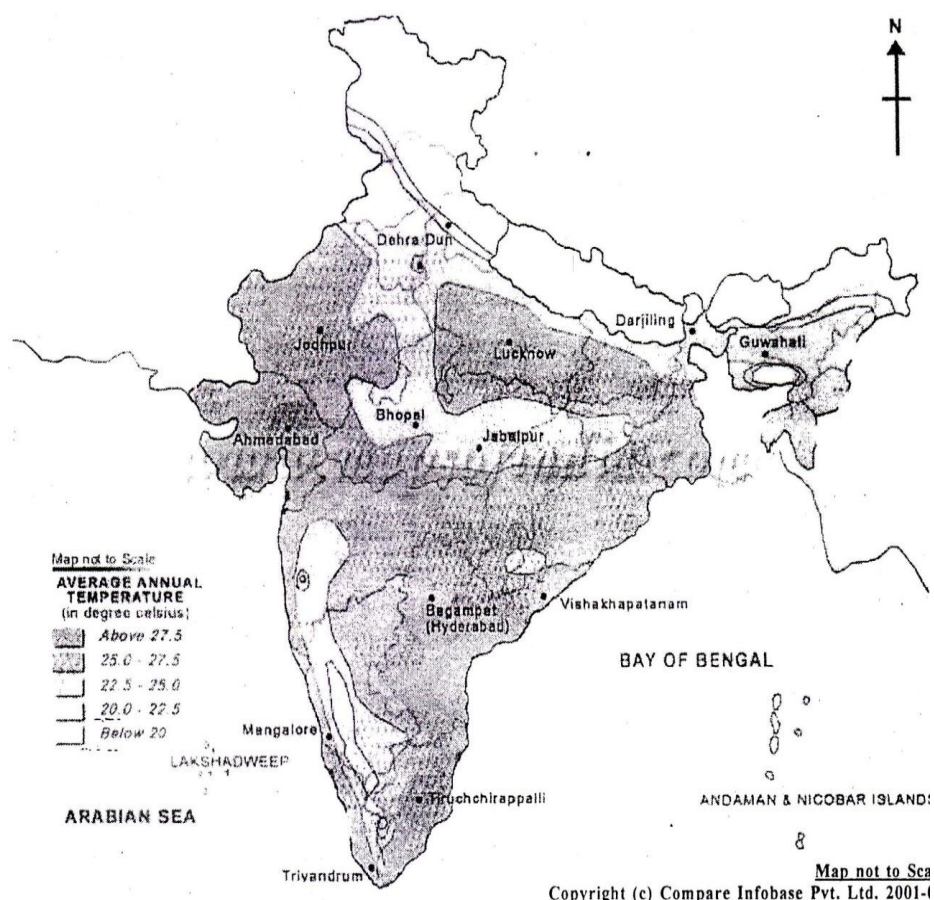


Figure 2.74: Annual temperature.

Indian Climatic Regions

A number of climatic factors operating in various kinds of physiography various types of geographical climates occur. Being a tropical country, rainfall and not temperature, has been taken as the chief criterion for climate types and on the basis of annual precipitation, the country has been divided into the following four climatic regions.

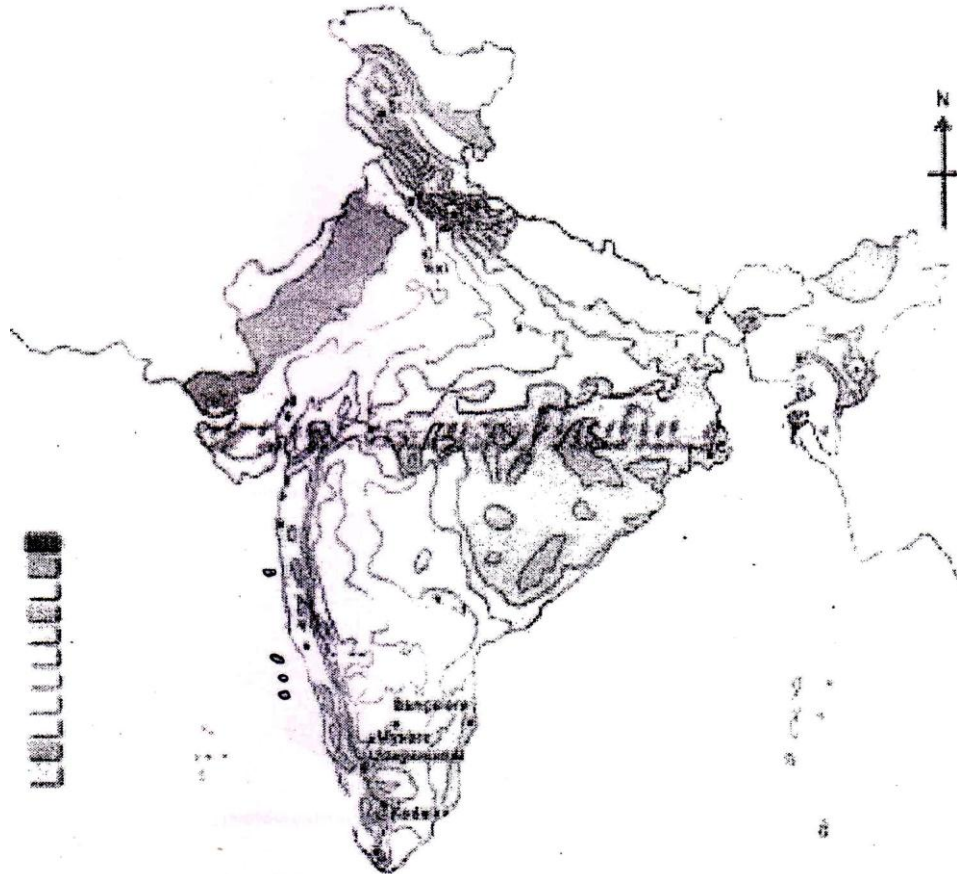


Figure 2.75: Annual rainfall.

1. **Wet zone:** Western slopes of the Western Ghats and hills of Meghalaya and Bengal and the tarai regions of Bihar and U.P. which have more than 200 cm rainfall are covered in this zone. The northern halves of the western slopes have long and the southern half short dry seasons. The vegetation is chiefly of evergreen forests type and paddy is the main crop.
2. **Intermediate zone:** Part of West Bengal, Bihar, Orissa, eastern M.P., foot-hills of Himalayas, northern U.P, H.P., Jammu, north-east Andhra Pradesh, eastern a slope of Western Ghats and east Tamilnadu come under this zone and experiences a

rainfall between 100 to 200cms. The chief vegetation is of deciduous forests where most of the trees shed their leaves during hot weather.

3. **Dry zone :** In this zone rainfall is moderate between 50-100 cm's and includes Punjab, U.P., Delhi, western M.P., Gujarat, Maharashtra, Karnataka, southern Andhra Pradesh and Tamilnadu, thus comprising Carnatic, north-west Deccan, upper Ganges plain and upper Punjab plain. The chief vegetation is of dry, deciduous and thorn scrub type. In some localities, there are present dry deciduous forests of the type found in intermediate zone. Wheat and millets are the chief agricultural crops.

Green House Gases and Global Warming

The Green House Effect is caused by gases such as carbon dioxide, water vapour, trace amounts of ozone, methane, nitrous oxide, chlorofluorocarbons and other gases that trap infrared waves that radiate from the Earth's surface (Fig. 2.76).

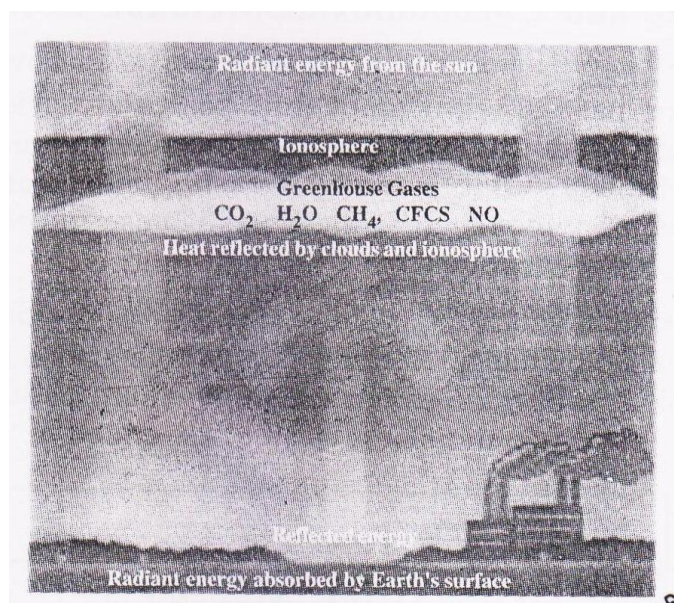


Figure 2.76: Green house gas effect.

Collectively these gases, known as green house gases act somewhat like the glass planes of a green house. They allow light, infrared radiation, and some ultraviolet radiation from the sun to pass through the troposphere. Earth's surface absorbs much of this solar energy and degrades it to longer wave, infrared radiation-that is heat-which then rises into the troposphere. Some of this heat escapes into space; some is absorbed by molecules of greenhouse gases, warming the air and some radiated back

toward Earth's surface. This natural trapping of heat in the troposphere is called the green house effect.

The primary heat trapping gas in the atmosphere is water vapor: However, its concentration in the atmosphere averages 1- 5% and the inputs of water vapour from human activities have little effect on the green house effects. By contrast, because of the concentration of carbon dioxide in the atmosphere is so small (0.036%) the fairly large input of CO₂ from human activities can significantly affect the amount of heat trapped in the atmosphere. As a result of human activity such as the consumption of fossil fuels, the carbon dioxide level has risen more than 20 percent in the past century-Fossil fuel consumption alone is responsible for the annual release of 5 billion metric tons of carbon into the air or roughly 1 metric ton for each person on earth.

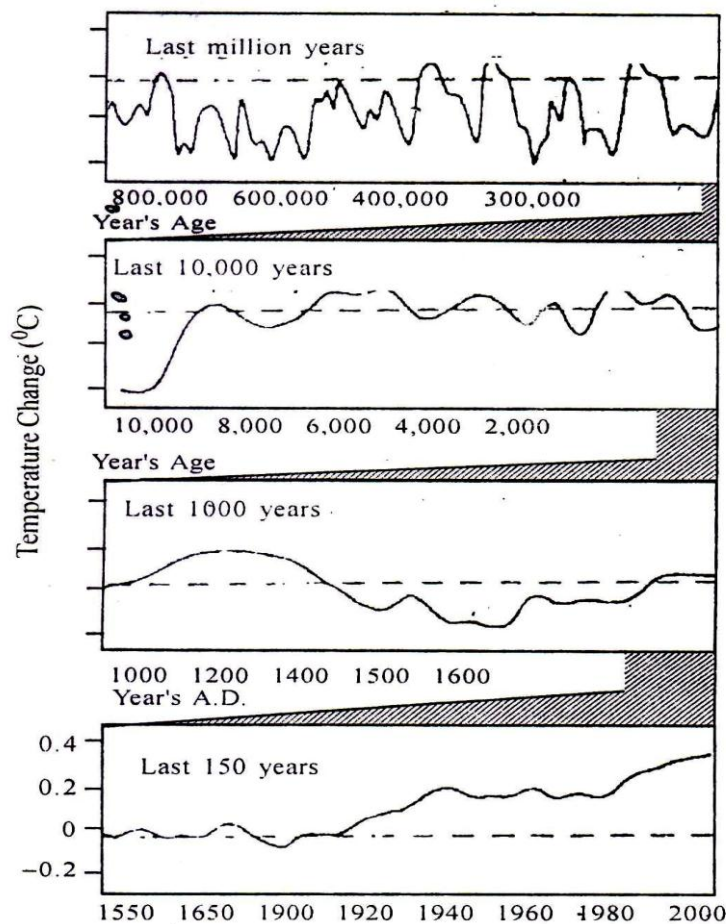


Figure 2.77 (a): Changes in mean global temperatures in the past over different time scales until the present time. All values of temperature change are expressed relative to that in year 1990 shown as a horizontal dashed line.

Thus Principal Greenhouse Gases are carbon Dioxide CO_2 , Methane CH_4 Nitrous Oxide N_2O , Halocarbons. The gases differ in terms of atmospheric concentrations rates of increase of concentration warming potential per molecule atmospheric lifetime their relative contributions to total potential warming depend on the time horizon considered and the emissions scenarios used. CO_2 is the major contributor - over a 100 year horizon, it contributes 70%+ of the total greenhouse gas radiative forcing.

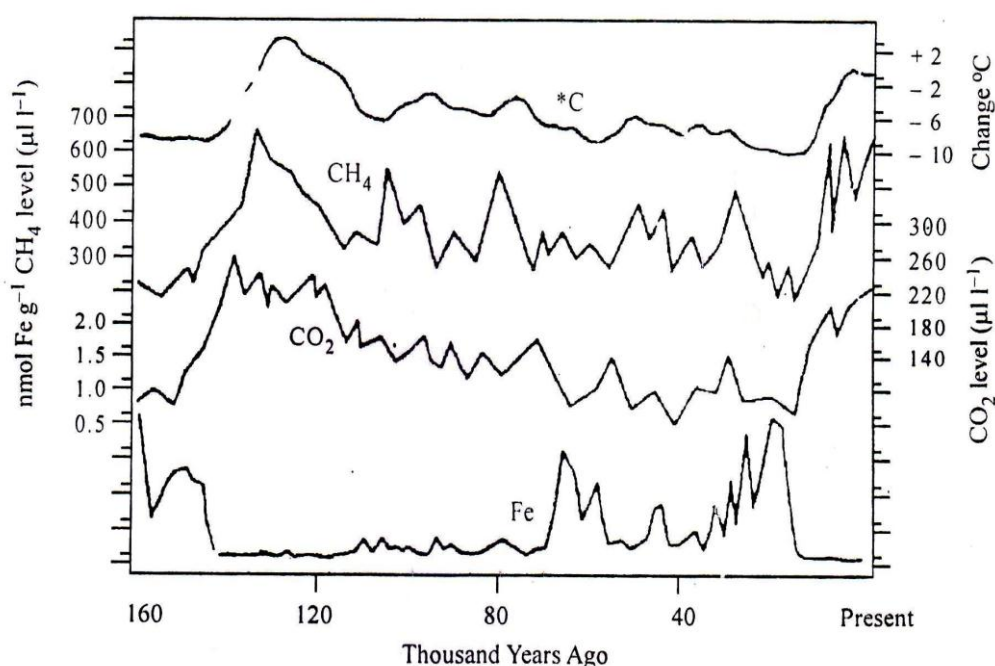


Figure 2.77 (b): Correlation of local temperatures over the last 160000 years with analyses of ice core samples from Antarctica (Vostok) for trapped CO_2 and CH_4 as well as with iron deposition.

1. Past Temperature and Carbondioxide/Methane Levels

Probable temperatures in the past over different time scales are shown in the Fig 2.77 (a) & (b). By themselves, they provide little indication for future trends, but past records of green house gases such as CO_2 and CH_4 established by measurements taken from ice cores agree with local temperatures which have existed at the poles. These indicate that the large swings ($\pm 3.5^\circ\text{C}$) in temperature across the various ice ages and interglacial periods correlate closely with coexisting CO_2 and CH_4 concentrations.

The climatic record, based on the studies of ice cores taken from Greenland and Antarctica, suggests that CO_2 may serve as a king of global thermos which resets the Earth's

temperature as the CO₂ level rises and falls. Since the last great ice age ended about 10,000 years ago, we have enjoyed a warm interglacial period. Fig. 2.77 (c) shows the remarkable correlation between atmospheric CO₂ and concentration of Antarctic surface temperatures. During glacial periods CO₂ is low while in the warmer interglacial periods CO₂ is very high. Changes in tropospheric levels of carbon dioxide, a major greenhouse gas, correlate closely with changes in the earth's mean surface temperature and thus its climate, although other factors also influence global climate.

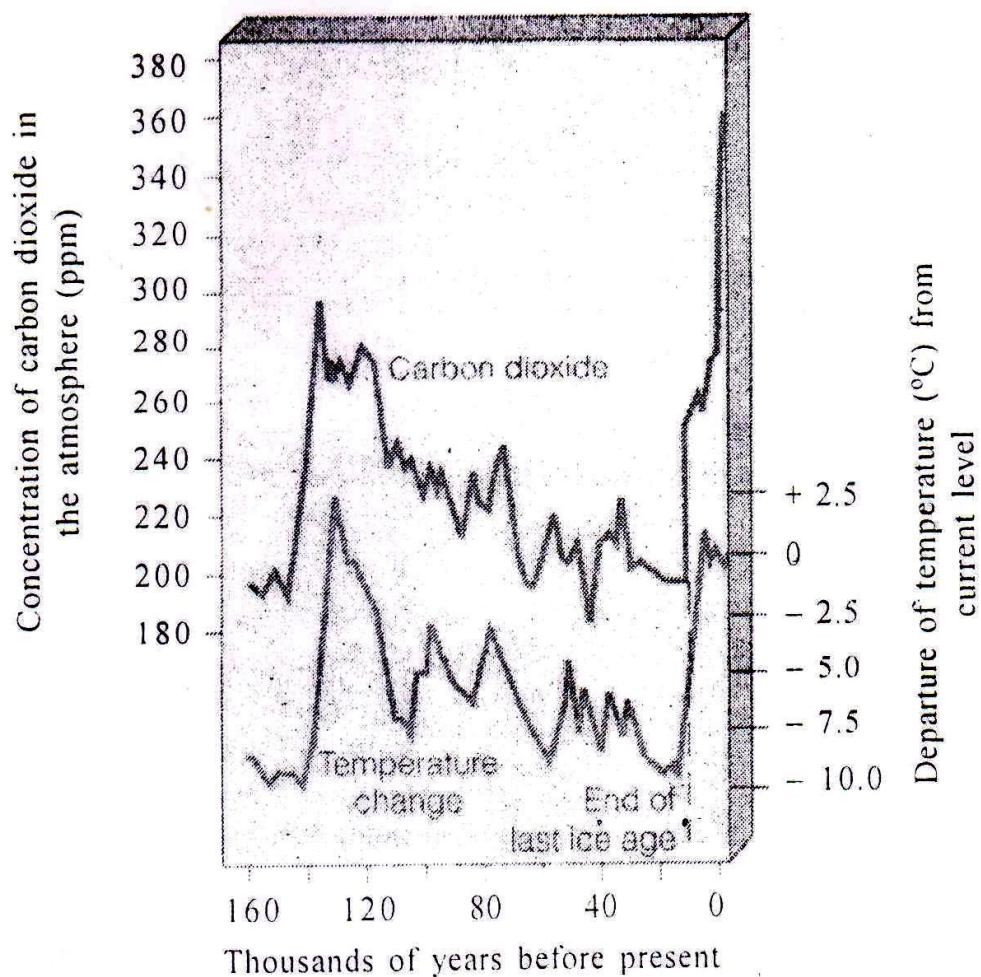


Figure 2.77 (c): Estimated long term variation in mean global surface temperature and average tropospheric carbon dioxide levels over past 160,000 years.

International committees of scientists commissioned by different world governments to provide a definitive verdict on what is happening to the weather around the globe in the past decade". The report states that the world has been warming up since the

1980s. The world has already warmed up by about 0.5°C . It is expected to get 4°C warmer by the year 2030.

2. Current Trends in the growth of Green house gases carbon dioxide

The first assessments of the carbon dioxide content of the atmosphere at the beginning of the Industrial era indicate levels of CO_2 in the lower atmosphere (troposphere) are raising year by year (Fig.2.78). During the last ice age, they were below 300 ppm, and they are still around 280 ppm before the industrial revolution, but they have risen to 360 ppm by 1990. Over the period 1860-1960, the rise in CO_2 was $9\% \text{ a}^{-1}$ and by the year 2000, the increase over the century as a whole was been $25\% \text{ a}^{-1}$ (Fig. 2.78). According to present information, the overall average temperature is rising by 0.5°C (0.9°F) for each increase in the carbon dioxide content by 18% with a net increase of 1°C by the end of 2005.

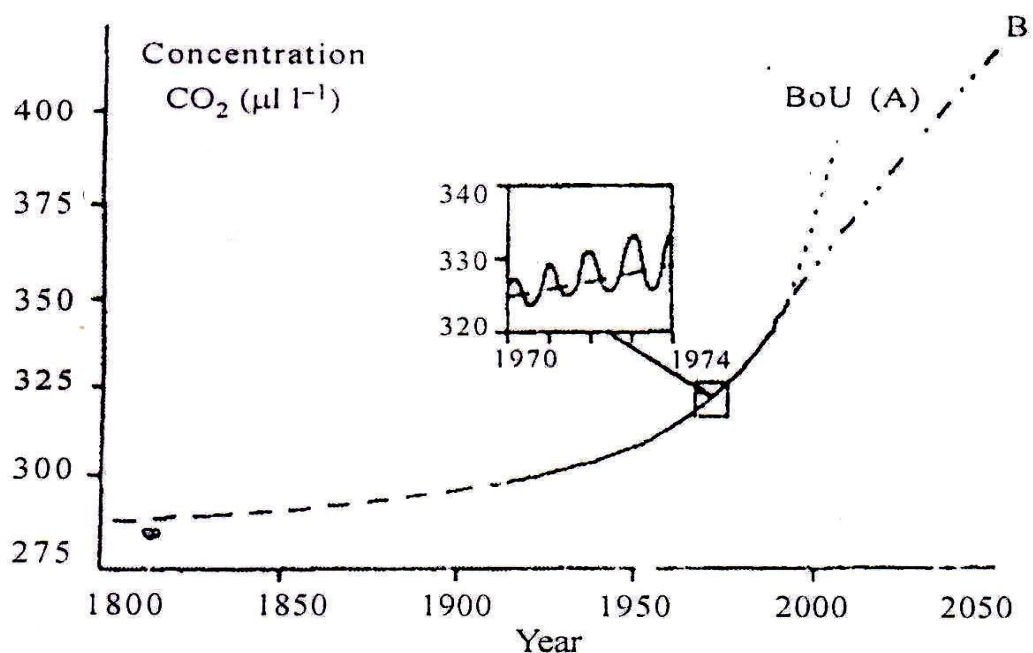


Figure 2.78: Global changes in atmospheric CO_2 with time. The solid part of the graph represents actual measured values and the dashed regions on the right are those most likely to occur in the future either with 'business as usual-BaU (A)-or if the IPCC predictions of Scenario B (B) are brought into reality by international implementation. Typical seasonal fluctuations are shown in the inset Fig. Values in the northern summer are lowest because of the higher photosynthetic activity of northern forest.

The current global trends in deforestation along with increased combustion of fossil fuels have a cumulative effect on the net increase in carbon dioxide content. Forests are the areas where a great deal of photosynthesis occur through which they act as sinks for CO₂. Moreover, they maintain vast reservoirs of fixed but readily oxidizable carbon in the form of wood and humus. The overall result is that they serve to maintain a balance in the atmospheric CO₂ level.

The major sink for CO₂ is the ocean which contains the bulk of dissolved carbon dioxide as bicarbonate. Covering some 70 percent of the planet, the oceans act as gigantic fly-wheel in the Earth's machinery. As a huge reservoir of carbon, the oceans regulate the atmospheric CO₂ level and hence global climate. Another important sink is the biomass viz. living green plants, in which the photosynthesis rate is known to accelerate with increase in the carbon dioxide level.

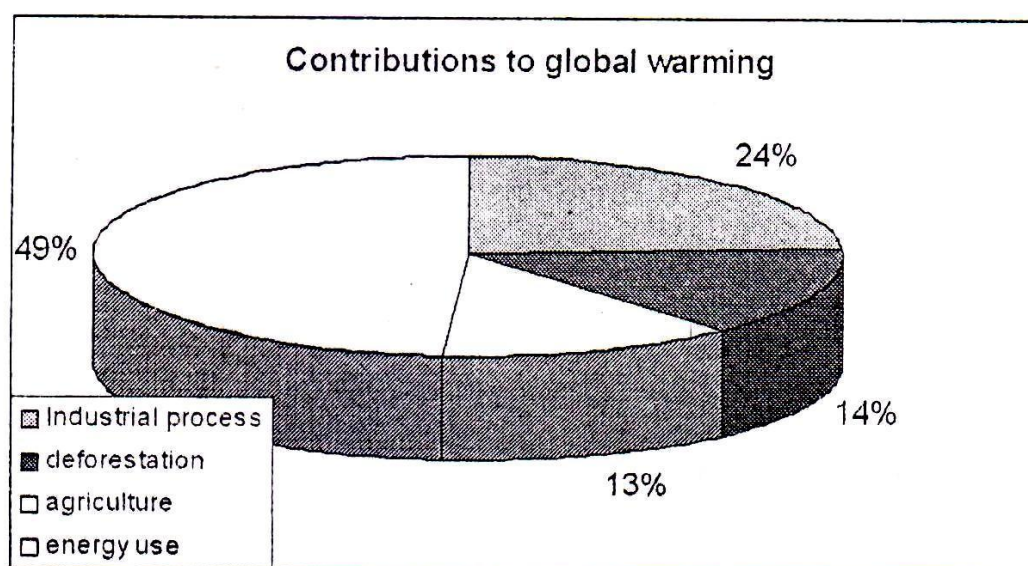


Figure 2.79: Contributions to global warming by different types of human activities in 1991.

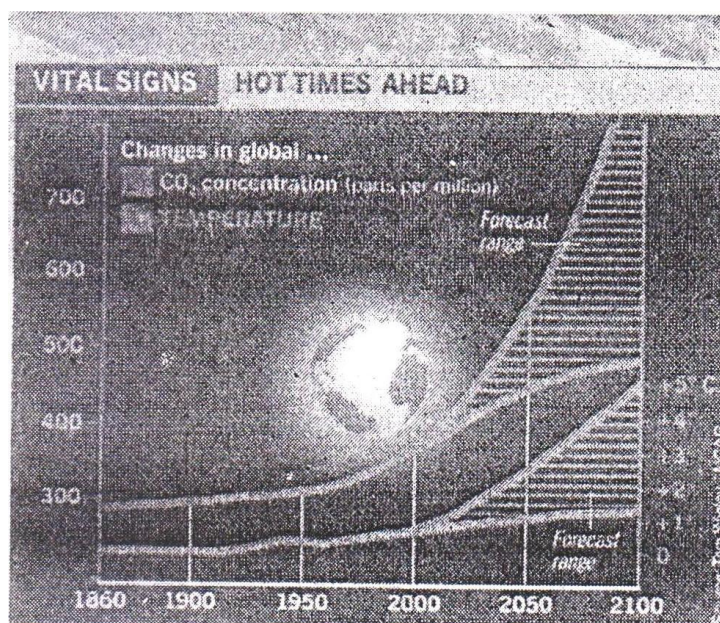


Figure 2.80: Correlation between CO₂ levels and global temperature.

Most scientists now agree that the global temperature increases are due to various human activities (Fig. 2.79). By burning large quantities of fossil coal or oil, and destroying tropical rain forests at the rate of 0.5 ha s^{-1} and replacing them with grasslands and waste scrub, human activity has tipped the net balance of the natural carbon cycle in favour of more CO₂ being returned to the atmosphere than at any time since the end of the last ice age. When expressed in global quantities of carbon exchanged over one year the full extent of this imbalance can be appreciated. The 5 Tt of fossil fuels burned in 1976, for example, contributed an extra 2.3 ppm CO₂ to the atmosphere. Of this total, 1.6 ppm was either absorbed by the oceans or added to biomass, leaving a net increase of 0.7 ppm CO₂ in the atmosphere by the end of 1976.

If current trends continue, preindustrial CO₂ concentrations will be doubled by the year 2075. (Fig. 2.80) Computer models predict that doubling atmospheric CO₂ could cause global temperatures to rise 1.5°C to 4.5 °C based on contribution of different human activities for global warming (Fig. 2.80). This may not sound like much change, but the difference between the temperature now and the last ice age about 10,000 years ago when glaciers covered much of North America was only about 5°C.

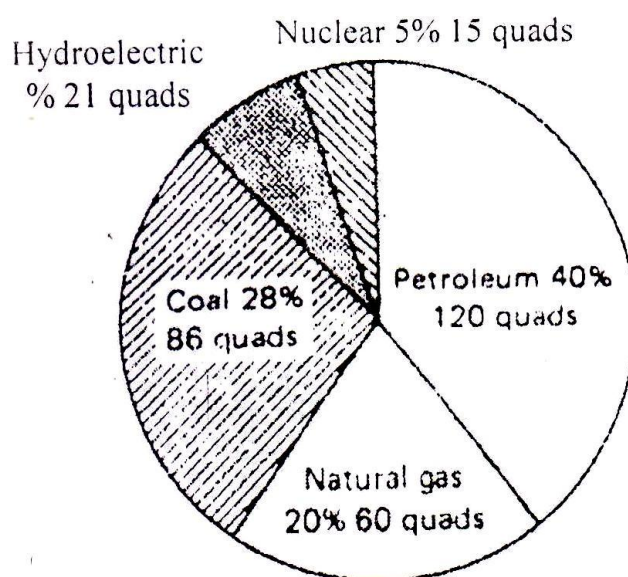


Figure 2.81: World primary energy production by fuel source (omitting biomass) 1985.

3. Emissions of Carbon from Fossil Fuels

Eighty eight percent of (nonbiomass) world energy needs are supplied by fossil fuels while the balance coming from hydroelectric generation and nuclear power plants. (Fig. 2.81 1 quad= 1 quadrillion BTU = 1×10^{15} BTU = 1.055×10^{18} J). Significant difference in carbon emission factors exists, for different fossil fuels, (Table 2.18). Nearly 75 percent more carbon is released per unit of energy when coal is burnt instead of natural gas while the synthetic oil or gas made from coal or shale oil produces about 80% more carbon than coal.

Table 2.18: Carbon emission Factors for Various Fuels

Factor	Natural gas	Conventional oil	Coal	Synthetic fuels			Non fossil fuel
				Oil from shale	Oil from coal	Gas from coal	
106 ton C/Quad	14.5	20.8	25.2	50.2	40.7	42.9	0
Quad/yr	60	120	36	0	0	0	36
Carbon emissions (GtC/yr)	0.9	2.5	2.2	0	0	0	0

The world's reserves of fossil fuels expressed both by energy content and carbon content are presented in Table 2.19 which reveals that coal burning is main source for the increase of CO₂ in the atmosphere and unless we change to solar energy or nuclear power plants the CO₂ levels continue to increase with increase in the usage of coal.

From the data presented in Table 2.19 one can infer that a way to reduce carbon emissions is to switch from coal to oil or natural gas. Thus a gas based power plant emits 42% less carbon than a power plant based on coal.

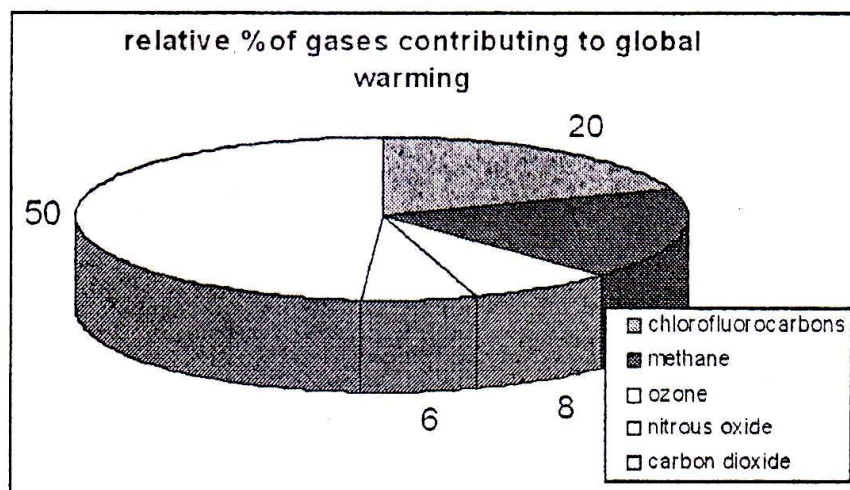


Figure 2.82: Relative contribution to global warming (% of expected climate change) by anthropogenic (human caused) releases of gases into the atmosphere. Notice that while far less methane and chlorofluorocarbons are released than CO₂, they still are very powerful "greenhouse" gases.

Table 2.19: Energy and Carbon content of the worlds Fossil Fuel Reserves and Resources.

Fossil fuel	Gas	Oil	Coal
Reserves GTC 10 ⁹ tons	52	85	550
Resources	145	230	7100
Potential CO ₂ increases	34 ppm CO ₂	54 ppm CO ₂	1675 ppm CO ₂

Carbon dioxide is not the only gas that could cause climate warming. Methane, chlorofluorocarbons (CFCs), nitrous oxide, and other trace gases also absorb infrared radiation and warm atmosphere. Although rarer than CO₂ some of these gases trap heat much more effectively. Methane, for instance, absorbs twenty to thirty times as much molecule for molecule-as CO₂ and CFCs absorbs approximately 20,000 times as much (Fig. 2.82). The past, present and future likely trends of various green house gases are given Table 2.20. Developed countries are the main contributors for green house gases (Fig. 2.83) by human activity and necessary control measures have to be implemented most urgently by these countries.

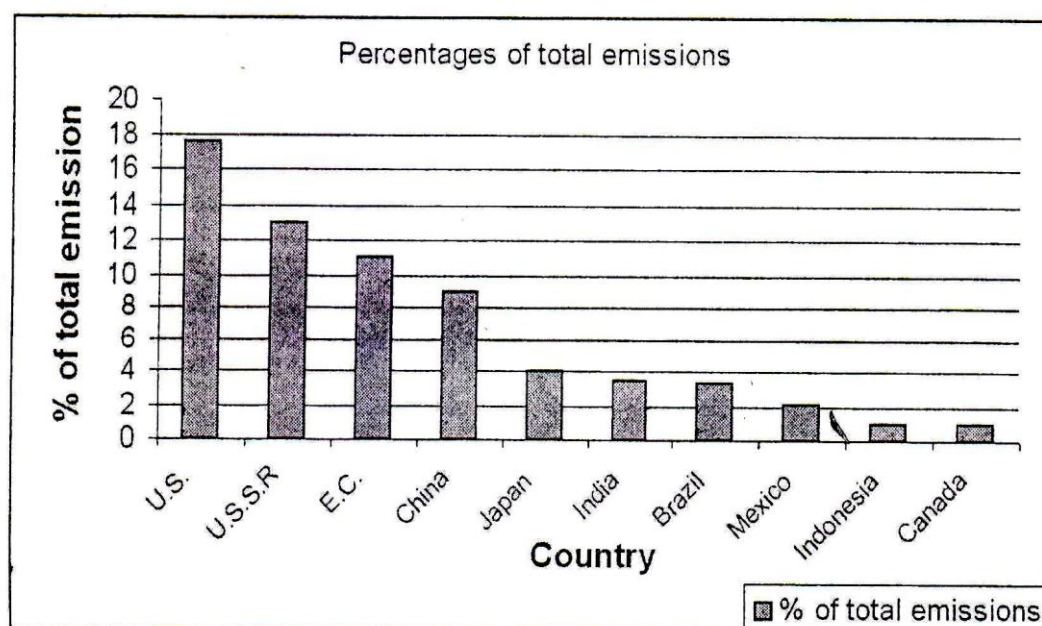


Figure 2.83: Countries with highest green house gas emissions in 1999.

Table 2.20: Past, Present and Future details of important green house gases.

Parameter Cncentration	CO ₂	CH ₄	N ₂ O	CFCS
150	280 pm	1150 ppb	285 ppb	0 ppb
1985	345 ppm	1790 ppb	305 ppb	0.4 ppb
Expected 2075	526 ppm	4402 ppb	478 ppb	3.8 ppb
Annual concentration increases %	0.4	1	0.2	5
Relative greenhouse efficiency CO ₂ ⁻¹	51	25	230	1500
Current greenhouse contribution %	57	12	6	25
Anticipated rate between 1985 & 2075 %	0.57	1.0	0.5	2.5
Equilibrium temperature change 1850 2075 ⁰ C	3.12	0.62	0.28	0.93 = total 4.95 ⁰ C
% total temperature change	63	12	06	1 + 100%
Life time year	100	10	150	100

4. Impacts of Global Warming

The potential effects of global climate change can be considered in terms of ecological systems, sea-level rise, water resources, agriculture, electricity demand, air quality, and health effects. Since climate influences the location and composition of plants and animals in the natural environment, changes in climate have numerous consequences on ecological systems. Shifts in forests in geographic range and composition are likely to occur.

Ecological Impact

Biodiversity is also impacted by climate change, with *diversity* defined as the variety of species in ecosystems and the variability within each species. Examples of impact include an increased extinction of many species; growth or losses in freshwater fish populations depending on geographic location; and mixed effects on migratory birds, with some arctic-nesting herbivores benefiting and continental nesters and shorebirds suffering.

Sea-level rises because increased losses of coastal wetlands, inundation of coastal lowlands, increased erosion of beaches, and increased salinity in estuaries. Coastal wetlands currently total 13,145 sq. mi; with a 1-m rise in sea level, 26 to 66% of these wetlands may be lost.

Impact on Water Resources

The main consequence of climatic changes to inland waters include the following; (a) changes in the global amount of water resources and in the spatial and temporal distribution of these resources; (b) changes in soil moisture; (c) changes in extreme phenomena related to water resource, i.e., floods and droughts; (d) changes in water quality; (e) changes in sedimentation processes; and (f) changes in water demand.

The consequences of climatic change on water quality include possible changes in the precipitation regime and the occurrence of acid rain. Direct consequence of climatic change on water quality occurs. For example, temperature increases can decrease levels of dissolved oxygen in the water. Second, the biochemical oxygen demands (BOD) also increase with temperature. These two effects can decrease the dissolved oxygen concentration in a surface water system. Also, climatic changes can have indirect consequence on water quality since a decrease of river discharges, particularly during the dry season, can increase the concentration of pollutants in water bodies.

Climatic changes influence not only water available but also water demand. For example, water demand irrigation is largely affected by climatic change which conditions evapo transpiration. Water demands for domestic or industrial use are also affected by climatic change, hence water consumption for cooling systems, bathing, washing? And gardening. The simplest way to view the implications of global change

on water resource is to consider the relationship between increasing atmospheric CO₂ and the hydrologic cycle; which may result in the following:

When the atmosphere reaches a new and warmer equilibrium, more precipitation balances faster evaporation. This faster hydrologic cycle is predicted to raise global averages of the up-and-down arrows of precipitation and evaporation by 7 to 10 times. Soil moisture is predicted to fall in some places. Also, precipitation is predicted to increase some seasons and decrease in others. Thus Global climate change caused by the greenhouse effect appears to be a reality although scientific opinion differs as to the rate of change and its impact on water resources.

Impact of Agriculture

Global warming exhibits direct and indirect geographical effects on agricultural productivity. Direct effects occur through changes in the length of the growing season, the frequency of heat waves, and altered patterns of rainfall; while indirect effects result from changes in topsoil management practices. Dry land yields of corn, wheat, and soybeans could decrease in many regions as a result of higher temperatures which shorten a crop's life cycle. In contrast, dry land yields of corn and soybeans could double as warmer temperatures could decrease by 5 to 25%. Irrigation would probably increase in many areas because irrigated yields are more stable than dry-land yields under conditions of increased heat stress and reduced precipitation.

Climate-sensitive electric uses include space heating, cooling to a lesser degree, water heating and refrigeration. Summer cooling electricity demands would increase, while winter heating demands would decrease. As a result of climate change, annual electricity demands are expected to increase by 4 to 6% by the year 2055, additional power plants will be required to meet peak demands.

Impact on Air Quality

Global climate change also has implications for ambient air quality. Increased emissions of SO₂, NO₂, and CO are associated with power plants meeting increased electric demands. Plume rises from stacks would decrease due to higher ambient air temperatures and reduced buoyancy effects; these decreases would be manifested in higher ground level concentrations of air pollutants located closer to their stacks. Air pollutant dispersion is also affected by weather variables such as wind speed and direction, temperature, precipitation patterns, cloud cover, atmospheric water vapor,

and global circulation patterns. Ozone pollution problems in many urban areas would worsen due to higher reaction rates at higher temperatures and lengthened summer seasons.

Impact on Human Health

Human health effects are manifested by changes in morbidity and increases in mortality, particularly for the elderly during hotter and extended summer periods. Geographical patterns in relation to health effects are also expected.

5. Predicted effects of Global warming

- According to greenhouse theory, any warming on Earth should be accompanied by cooling in the stratosphere (the second layer of Earth's atmosphere) and the mesosphere (the layer of the atmosphere above the stratosphere). Some cooling of the stratosphere has been observed, but most of this is probably the result of ozone depletion. Recent measurements indicate a 2°C drop in the temperature of the lower mesosphere.
- To date, any temperature changes possibly caused by an enhanced greenhouse effect have been too small to exceed normal short-term variations in mean atmospheric temperature caused by volcanic eruptions, air pollution, and other climatic factors.
- Mean global temperatures never vary more than a degree-either side of 12°C. Should this change, even by a degree, then the consequences are likely to be considerable. For example, between 6000 and 8000 years ago, a temperature rise of 2°C was responsible for melting the ice sheets spread across both hemisphere and brought about the end of the last ice age.
- Warming or cooling by more than 1°C over a few decades would be disastrous for Earth's ecosystems and for human economic and social systems. Such rapid climate change would alter conditions faster than some species, especially plants, could adapt or migrate. These changes might also shift areas in which it is possible for people to grow food. Many areas might become uninhabitable because of drought, or floods following a rise in average sea levels.
- We don't yet know enough about how Earth works to accurately project the possible effects of our emissions of greenhouse gases on global and regional climates or on the biosphere.

- A warmer troposphere would have different consequences for different peoples and species. Some places would get drier, some wetter. Some would get hotter, others cooler. Here are some possible effects of a warmer global climate.

Mean global temperatures are likely to rise by 1.4°C ($\pm 0.7^{\circ}$) by year 2030, and by 2.1°C ($\pm 0.8^{\circ}\text{C}$) by year 2050 Fig. 2.84. Furthermore, global mean sea level which has risen 10-15 cm in the last century may rise by another 10-20 cm by 2025 and 50-200 cm by 2100. Most of this increase in sea level comes about from an increase in sea volume due to thermal expansion and rather less from the melting of polar ice. These predictions of sea level rise are also less than those of a few years ago but will still cause extensive flooding of low-lying areas in the world, especially during storms. The countries most at risk are the river delta areas of Bangladesh, India, Egypt, Thailand, and China (most vulnerable first) but many small islands will also suffer. The immediate effect of inundation will be crop destruction but more importantly, the surrounding ground waters will become increasingly saline and large areas of productive land rendered permanently useless.

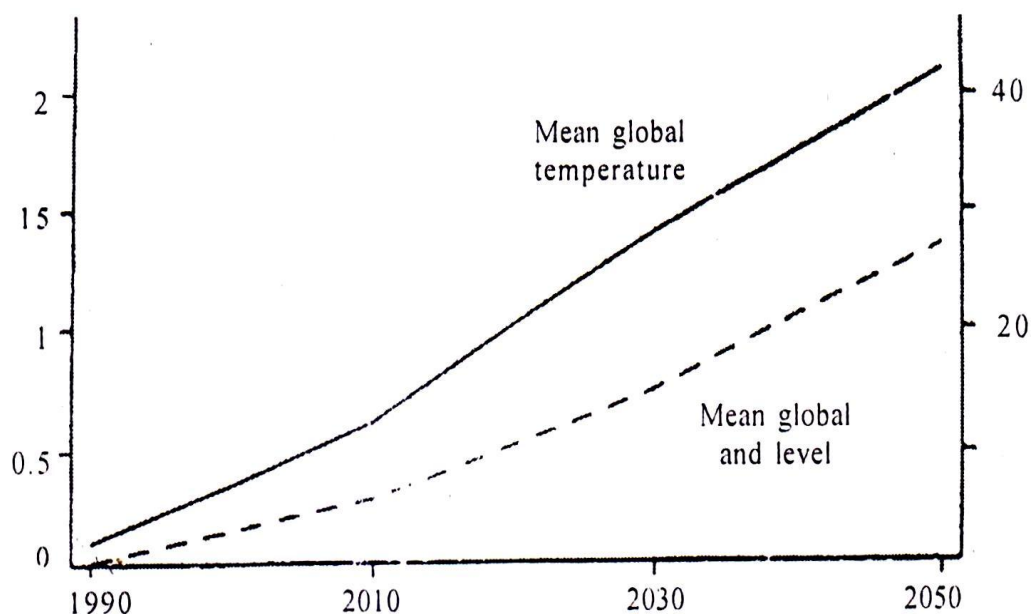


Figure 2.84: Likely changes in mean global temperatures and sea levels (IPCC Predictions)

A 1 meter (3.3 foot) rise in ocean levels by 2035 would cause

The seas to move 30 meters (100 feet) farther inland along many portions of our nation's coasts. Crores of rupees of coastal properties would be lost in USA. The city of

Charleston, South Carolina, alone would suffer \$650 million in damage by the year 2035. Similar flood damage would probably be experienced in Boston, Philadelphia, New York City, Baltimore, Washington, Norfolk, Miami, St. Petersburg, and New Orleans.

1. Twenty percent of the most populated areas of India and Bangladesh would be inundated.
2. Large tracts of agricultural land would be destroyed because of salinization. Changing weather patterns could make huge areas infertile or uninhabitable. The result could well be more massive movements of displaced people than any in the history of this planet.
3. Many of the world's most productive rice-growing areas would be destroyed by flood waters, including the fertile, highly populated deltas of the Indus (Pakistan), Ganges (Bangladesh), and Yang Tze (China) rivers.
4. Many aquifers along the Gulf and Atlantic coasts of the United States, which now serve as a source of drinking water for many American cities, would become contaminated by salt water from the ocean.
5. The increased salinity of many American estuaries, such as the Chesapeake Bay and Delaware River estuaries, would destroy their value as breeding and nursery grounds for many valuable species of game and commercial fish.
6. Many plants and animals would become extinct because of the rapid change in temperature.

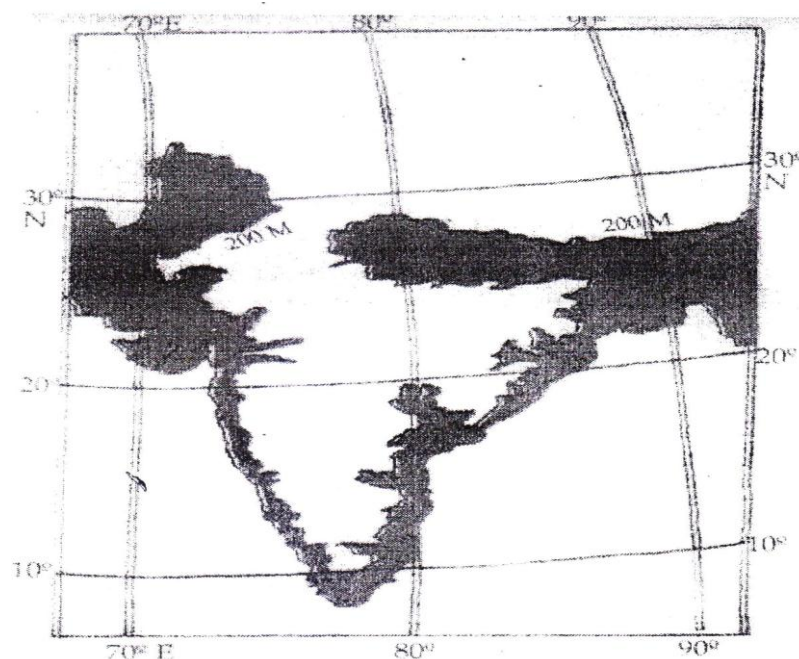


Figure 2.85: The present Indian coast line and the future one if the sea level rises by 2 meters.

A 2 meter rise in the sea level would

1. Severely affect the coastal areas around the globe where about a quarter of the world's population now lives, and that too in poor countries lying in the tropical belt of the earth. Some of the best beaches in the world would be lost forever thus affecting tourism.
2. Maldives, off the West coast of India, Marshall Islands in the Pacific and some islands in West Indies, would disappear from the globe for ever.

The future of the Maldives comprising over 2000 inhabited and 1,000 uninhabited islands about 600 kms towards the "south west from the Indian coastline, is hanging delicately in balance. The sea waters around the capital, Male, have already reached optimum levels. One island in the Maldives has already gone under the Arabian Sea. A 2 -meter rise could wipe out these atolls from the face of the earth, while a 1 meter rise could cause heavy tidal wave activity during storms and cyclones. The 2.45 lakh people there will not know where to go, when the sea devours the islands. They are destined to emerge as the world's first environmental refugees.

Bangladesh, dominated by Ganges-Brahmaputra-Meghna delta, is massively populated and is painfully poor. It is already plagued by floods, with sea level rising by 2 meters, she would lose 16 % of its land area. Egypt will be in similar trouble. It could lose 15 % if the land under farming. The present Indian coastal line and the future coastal areas to be submerged for 2 m rise in sea level generated through the computer model are shown in Fig. 2.85.

- ***Changes in food production;*** Food productivity could increase in some areas and drop in others. Past archeological evidence and computer models indicate that climate belts and thus tolerance ranges of plant species (including crops) would shift northward by 100-150 kilometers (60-90 miles) or 150 meters vertically for each 1° C rise in global temperature. Computer models have projected drops in the global yield of key food crops ranging from 30% to 70%. With current knowledge, we can't predict where changes in crop-growing capacity might occur or how long such changes might last.
- ***Reduction in water supplies:*** Lakes, streams, and aquifers in some areas that have watered ecosystems, croplands, and cities for centuries could shrink or dry up

altogether, forcing entire populations to migrate to areas with adequate water supplies - if they could. We can't say with much certainty where this may happen.

- ***Changes in forests:*** Forests in temperate and sub arctic regions would be forced to move toward the poles or to higher altitudes leaving more grassland and shrub land in their wake. However, tree species can move only through the slow growth of new trees along forest edges-typically about 0.9 kilometer per year or 9 kilometers per decade. If climate belts moved faster than this or if migration were blocked by cities, roads, or other barriers built by people-entire forests of oak, beech and other delicious trees could die and release CO₂ into the atmosphere as they decompose. According to Oregon State University scientists, projected drying from global warming could cause massive fires in up to 90% of habitats and injecting huge amounts of CO₂ into the atmosphere.
- ***Reduction in biodiversity:*** Large scale forest diebacks would also cause extinction of species that couldn't migrate to new areas. And fish would die as temperatures soared in streams and lakes, and as lowered water levels concentrated pesticides. Any shifts in regional climate would threaten many parks, wildlife reserves, wilderness areas, wetlands, and coral reefs, wiping out many current efforts to stem the loss of biodiversity.
- If warming at the poles caused ice sheets and glaciers to melt even partially, global sea level would rise even more. About one-third of the world's population and more than a third of the world's economic infrastructure are concentrated in coastal regions. Thus, even a moderate rise in sea level would flood low-lying areas (many of which contain major cities[^], as well as lowlands and deltas where crops are grown. It would also destroy wetlands and coral reefs and accelerate coastal erosion. Currently, global sea levels are rising a few centimeters per decade. Scientists project that two thirds of this rise is the result of global warming. Recent studies indicate the remaining third may be due to cutting down forests, draining of wet lands, and large scale pumping of ground water.
- ***Weather extremes:*** In a warmer world, prolonged heat waves and droughts would become the norm in many areas. And as the upper layers of seawater warmed,

hurricanes and typhoons would occur more frequently and blow more fiercely.

- **Threats to human health:** A warmer world would disrupt supplies of food and fresh water, displacing millions of people and altering disease patterns in unpredictable ways. The spread of tropical climates from the equator would bring malaria, encephalitis, yellow fever, dengue fever, and other insect-borne diseases to formerly temperate zones. Sea-level rise could spread infectious disease by flooding sewage and sanitation systems in coastal cities.

Destruction of the ozone layer also will speed the global warming process. Ozone protects plankton and other living things from the sun's harmful full ultraviolet rays. As it is depleted and more radiation moves through the atmosphere, the numbers of plankton will decrease substantially.

6 Some observed global features that can be related to global warming

The average global temperature in July 1998 was 16°C; 0.63 °C higher than the long term average for July and 0.22 higher than the previous average up to July in 1997. July 1998 was the hottest July in the history of the world since meteorologists started keeping records more than 118 years ago. It was also the hottest month on record.

Global warming effects in India

According to DR. G.B.Pant, working at the Indian Institute of Tropical Meteorology, Pune, India has also warmed up somewhat in the last 3 decades. While the average temperature had risen by 0.4°C for the better part of the 20th century, the rate has climbed to 0.6 °C per 100 years in the last 30 years. Days are hotter and the nights are the same. This has increased the difference between the maximum and minimum temperatures. So the weather is changing.

Despite the repeated warnings of scientists that the green house effect could eventually have highly adverse effects on human society, the general public, as well as policy makers, were generally unconcerned with the threat until 1998. In 1998 Americans experienced unusual drought, searing heat, floods, and hurricanes - the precise events scientists predicted would occur with increasing frequency and severity as the levels of green house gases rise.

7. Global warming control measures taken

Nevertheless, many steps are being taken around the world to combat the potential of global warming. In the United States, \$ 1 billion were earmarked for global warming research per year since 1991. According to recent studies by the National Academy of Sciences and the Congressional Office of Technology Assessment, the United States could reduce its green house gas emissions by 25 - 35% of 1990 levels using existing technology at low or no net cost, and by 48% at low to moderate cost. A 1993 study estimated that a doubling of current atmospheric levels of greenhouse gases by the middle of the next century could cost the U.S. economy alone about \$60 billion per year and upto\$335 billion per year, assuming temperatures continued to rise.

United States and many other countries have committed to phasing out the production of CFCs, the potent greenhouse gases. In addition, billions of trees will be planted around the world to help combat the excessive production of CO₂, especially since the trees absorb CO₂ in the air. Another important sink is the biomass, viz. living green plants, in which the photosynthesis rate is known to accelerate with increase in the carbon dioxide level.

Stratospheric Ozone Depletion

The second global environmental problem of great concern is the possible destruction of the stratospheric ozone layer. At ground level, ozone, O₃, is a strong eye and respiratory irritant and a major component of photochemical smog. It may also act as a greenhouse gas. In the stratosphere, 10 to 20 km above the earth's surface, is a layer of low-density air containing a 300 to 500 ppb stratospheric ozone layer shielding of solar radiation penetrating into the atmosphere (Fig. 2.86).

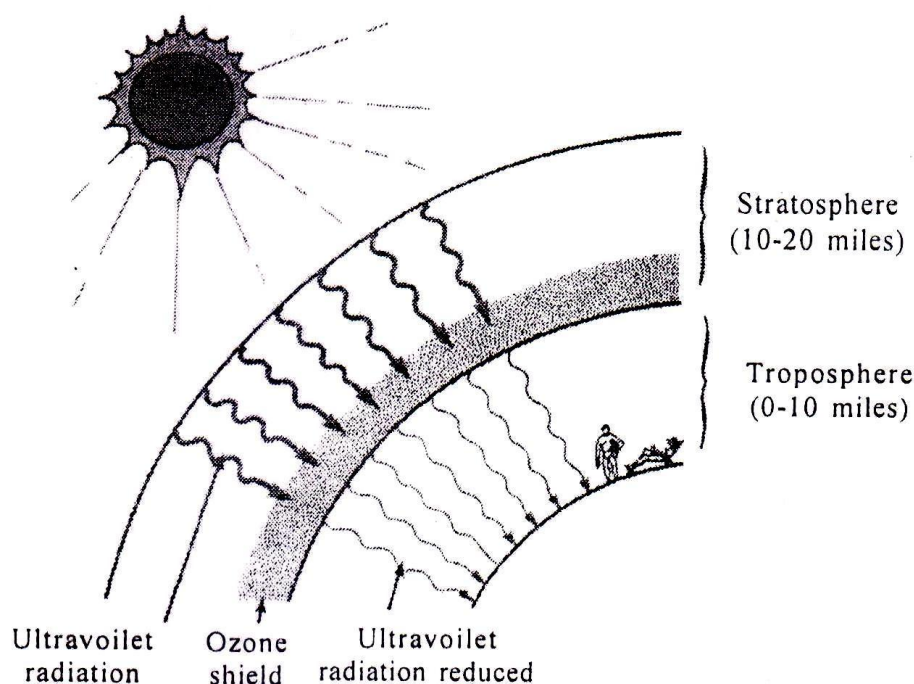


Figure 2.86: The ozone layer in the stratosphere shields the earth from potentially lethal ultraviolet radiation.

As discussed earlier the earth's atmosphere can be divided into a series of spherical layers with distinctive vertical temperature gradient. The troposphere extending upto 0-20 km is heated from below by solar radiation reflected back by earth's surface while the stratosphere (with the lower limit at an altitude of 8-16 km depending on latitude and extending up to 45-50 km height) is heated from above by adsorption of u.v. light by its ozone layer.

1. Ozone Distribution and Temperature Profile in the Atmosphere

The distribution of ozone in the stratosphere will leave profound effect in the outer atmospheric temperature and the strong temperature inversion set in at the stratosphere that makes the air dynamically stable and resistant against vertical mixing. So once the pollutants enter the stratosphere they will have long life times and can build up to globally unacceptable levels. Farry and Dobson are the first scientists who pointed out that ozone occurs in trace quantities throughout the atmosphere with peak concentration in the stratosphere. (20-25 km altitude Fig. 2.87). Observations of the total amount of ozone in a vertical column have established the average column abundance and the general pattern of latitudinal, longitudinal, seasonal, and meteorological variations.

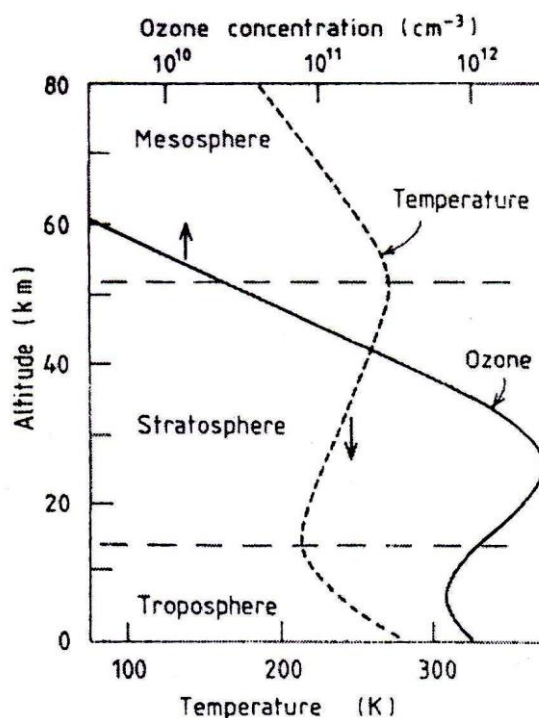
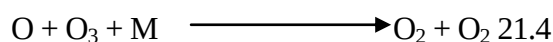
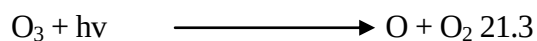
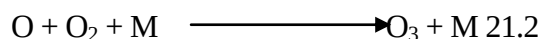
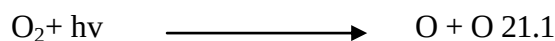


Figure 2.87: Ozone distribution and temperature profile in the atmosphere.

Total ozone is usually stated in Dobson Units or matm cm, related to the thickness of an equivalent layer of pure ozone at standard pressure and temperature. If the ozone in a column at the atmospheric pressure, it would be about 3 mm thick, i.e. the average total amount of ozone is 300 DU. Seasonal and latitude variations at sub-polar latitudes are about $\pm 20\%$ of this value. The annual average total ozone is a minimum of approximately 260 DU at equatorial latitudes and increases poleward in both hemispheres to a maximum at subpolar latitudes of about 400DU. The high latitude maximum results from transport of ozone from the equatorial middle and upper stratosphere, the region of primary production, to the lower stratosphere in pedlar regions. About 90% of all the ozone in the atmosphere resides in the stratosphere.

2 How is this Ozone Produced

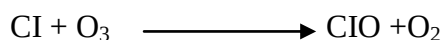
According to Chapman the following reactions are responsible for the dynamic equilibrium of ozone formation.



Thus Ozone is produced by the absorbance of solar ultraviolet radiation by oxygen molecules which then photo-disassociates to form oxygen atoms (O). These O atoms in turn react with O₂, via a three-body reaction to form O₃. The O₃ produced is subsequently photo disassociated by both u.v. and visible light.

Until a few years ago, the ozone layer was in a state of dynamic equilibrium. In other words, ozone-forming and ozone-depleting reactions proceeded at similar rates, and therefore the amount of stratospheric ozone remained fairly constant. It is true, however, that there might be variations in abundance as high as 10 % from year to year. And even in a given year, the amount of ozone in the stratosphere might be two to three times greater in one place than another.

In 1974, F.S. Rowland, of the University of California, reported that the chloro-fluorocarbon gases (CFCs) used to propel deodorants, hair sprays, shaving creams, insecticides from spray cans, and used in refrigerators and air conditioners were accumulating in the stratosphere and causing ozone depletion. The total amount of CFCs released into the global atmosphere is considerable. In 1986, the U.S. used 700 million pounds of CFCs. Destruction of the ozone layer is a complex process. That destruction is mostly caused by elemental chlorine atoms; the mechanism apparently involves two reactions.



Other reactions are going on in the stratosphere that modify and compete with these two, but if we ignore other reactions, add these two reactions, and cancel like terms, we see that the overall reaction is.



with no net consumption of Cl atoms. Thus one Cl atom can convert many ozone molecules to ordinary oxygen molecules. As per one estimate from 10⁴ to 10⁶ O₃ molecules may be destroyed by one Cl atom. (This mechanism is often referred to (as catalytic destruction of ozone, because the chlorine atom acts as a non consumed catalyst for the reaction).

3. Anthropogenic Sources

Mans capability to produce nitrogen and chlorine compounds at levels equalling or exceeding natural sources has led to numerous investigations aimed at assessing the impact of human activities on the ozone layer. Starting about 1900, humans began releasing into the atmosphere synthetic chlorine-containing compounds in significant amounts. Those like methyl chloride that have hydrogen atoms can be attacked in the atmosphere by the OH radical; for this reason most of them do not survive to reach the stratosphere. Carbon tetrachloride, CCl_4 , has no hydrogen; most of it is believed to reach the stratosphere and to participate in the destruction of the ozone layer. Its world production has been more or less constant over the past 60 years.

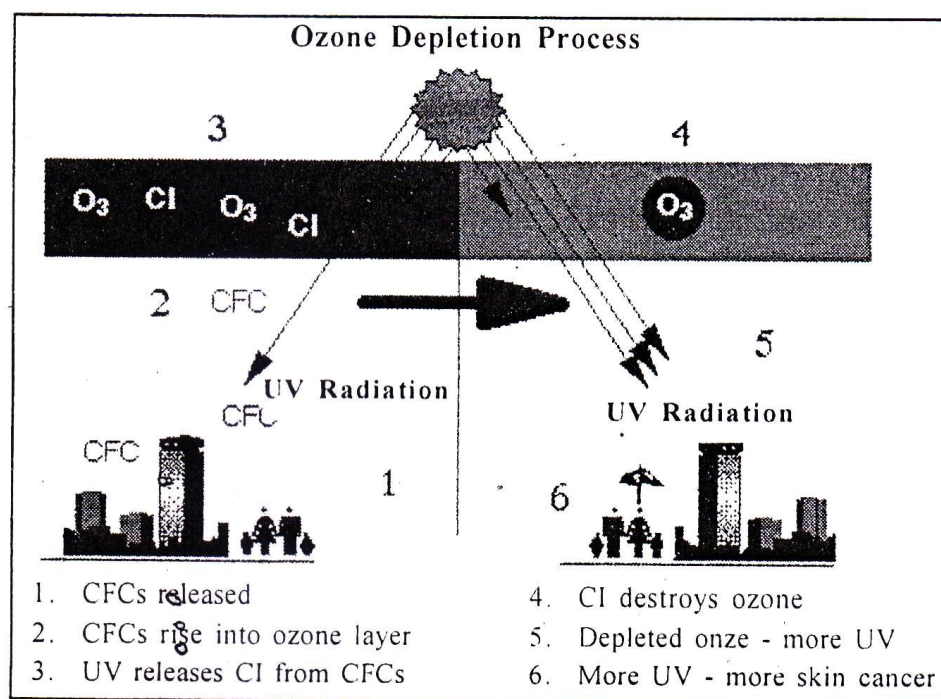


Figure 2.88: Ozone depletion process by CFCs.

CFCs (compounds containing chlorine, fluorine, and carbon, commonly called Freons) were first developed by General Motors for use in household refrigerators. One of their virtues is their chemical inertness; they are non-toxic, non-flammable, invisible, tasteless, odourless, non-almost everything else. They replaced toxic sulphur dioxide and ammonia in household refrigerators. This replacement saved many lives. However, they are found to be active ozone destroying compounds (Fig. 2.88).

The CFCs which have attracted most attention in ozone depletion are CFC-11

(CFC₁₃) and CFC-12 (CF₂Cl₂). The life time of CFC is about 77 years, while that for CFC-12 is 139 years. Hence any reduction in CFC release will have little effect in the immediate future. Model predictions of ozone column changes due to increases in CFC's have varied widely during the last 10 years. If CFC emissions continue at the 1980 rates long enough to obtain a steady-state, 8 ppb of chlorine would result. Calculated changes in column ozone, when chlorine is increased from 1 ppb to 8 ppb, range from approximately 3 to 9%, depending on the model used. In all models, the major decrease occurs in the upper stratosphere, near 40 kms. As chlorine is increased it exceeds a certain threshold where each additional chlorine atom destroys progressively more and more ozone. By increasing chlorine to 15ppb, the models then predict ozone column changes of 9 to 22%.

This nonlinearity for large chlorine perturbations can have significant implications for the interpretation of effects of changing CFC emissions. The most abundant organochlorine compounds in the atmosphere are CCl₂F₂, CCl₃F, CH₃Cl, CCl₄ and CH₃CCl₃. The total atmospheric content of organo chlorine compounds have grown from about 0.8 ppb in 1950 to 1.0 ppb in 1970 and 3.5 ppb in 1987 (WMO-NASA, 1988). The current rate of increase exceeds 1 ppb per decade.

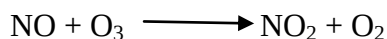
CFCS are not the only ozone-eaters. A few other chemicals can release highly reactive chlorine and bromine atoms if they end up in the stratosphere and are exposed to intense UV radiation, including: 1. bromine- containing compounds called halons and HBFCs (both used in fire extinguishers) and methyl bromide and 2. carbon tetrachloride and methyl chloroform, or 1,1,1, trichloroethane (used as a cleaning solvent for clothes and metals and as a propellant in more than 160 consumer products, such as correction fluid, dry cleaning sprays adhesives, and other aerosols.

Trace amounts of bromine are also reported to efficiently catalyse ozone destruction. The predominant anthropogenic source is CH₃Br and CF₃Br. Some sources, such as CF₂BrCl and C₂H₄Br₂, are entirely man made. CH₃Br is used as soil fumigant and other compounds of bromine are used as fire retardants and fuel additives. An increase in CH₃Br from 20 to 100 ppt would result in a decrease in total ozone of 30%. The largest relative change in ozone occurs around 15 km with a secondary peak at 40km.

Carbon dioxide concentrations are increasing largely as a result of burning fossil fuel. Increased CO₂ leads to lower stratospheric temperatures, and hence a slowing down of temperature dependent (O + O₃, NO + O₃) ozone destruction reactions. This results in a net increase in stratospheric ozone concentrations. Doubling CO₂ concentrations leads to temperature decrease of 7 to 10 K near 40km, and a corresponding increase in ozone between 9 to 19 %. Increase in the total ozone column will be in the range 1.2 to 3.5%.

Increases in total ozone between 0.9 and 3.0 % are also predicted for a doubling of CH₄ concentrations. For such an increase in CH₄, stratospheric OH is predicted to increase by up to 50 % and HO₂ by up to 100%. The resulting increase in HNO₃ and HNO₄ production reduces NO₂ concentrations and a subsequent reduction in the NO_x catalytic cycle. Methane is currently increasing due to the growth in rice paddy farming and cattle farming.

Some other gases can attack the ozone layer, e.g., NO from stratospheric airplanes and relatively inert N₂O, if we release much of it at ground level. NO, released by high flying aircraft, can contribute to ozone depletion by the reaction



Which is swift and practically irreversible? But it is not a catalytic reaction like the chlorine reaction; one NO molecule only destroys one O₃ molecule, so much more NO is needed per unit of damage than Cl.

Nuclear explosions produce copious quantities of NO_x which may be injected into the stratosphere. Early work predicted O₃ reductions of up to 70 % in the Northern Hemisphere. There are two significant sources of N₂O which results from human activity. These are combustion and the use of nitrogenous fertilizers that would enhance biogenic emissions of N₂O. A doubling in N₂O concentrations is predicted to give 10-16% global ozone depletion. The depletions vary with altitude and are greatest at higher altitudes. For a more realistic increase of 20% in N₂O, total ozone decreases range from 1.1 to 2.6%.

Ozone Hole

Antarctic Ozone Depletion Fig. 2.89 (a) - (g)

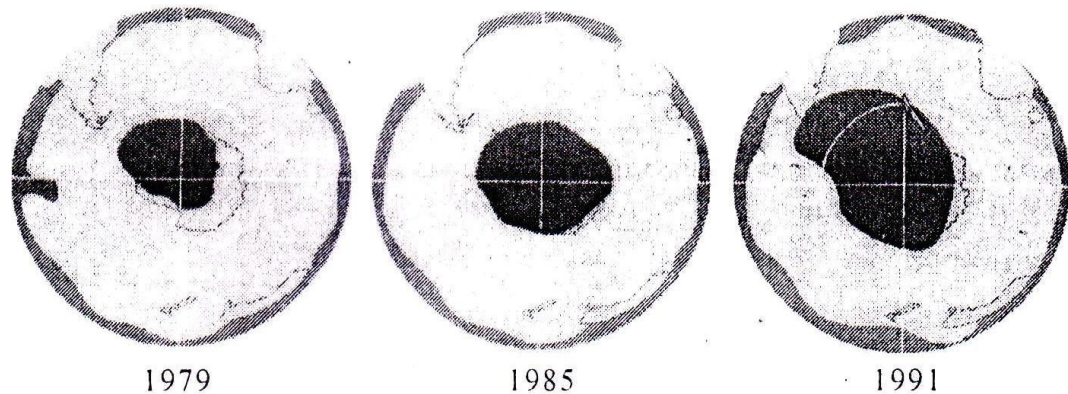


Figure 2.89 a: Seasonal thinning or loss of Ozone.

The protective ozone layer showed a hole over 50% of the area of the Antarctica continent, according to a picture taken by NIMBUS-7 satellite on October 5, 1987. This hole covers approximately 7 million square kilometers. (Fig. 2.89 (a)). It shows the lowest ozone value ever observed according to the officials of the National Science Foundation. Measurements from instruments aboard the Nimbus 7 satellite showed that the region of ozone depletion was larger than the Antarctic continent, while balloon borne, instruments indicated that greatest depletion occurred between 12 and 24 km in altitude. Fig. 2.89 presents the trends in the depletion of ozone in polar and non Polar Regions.

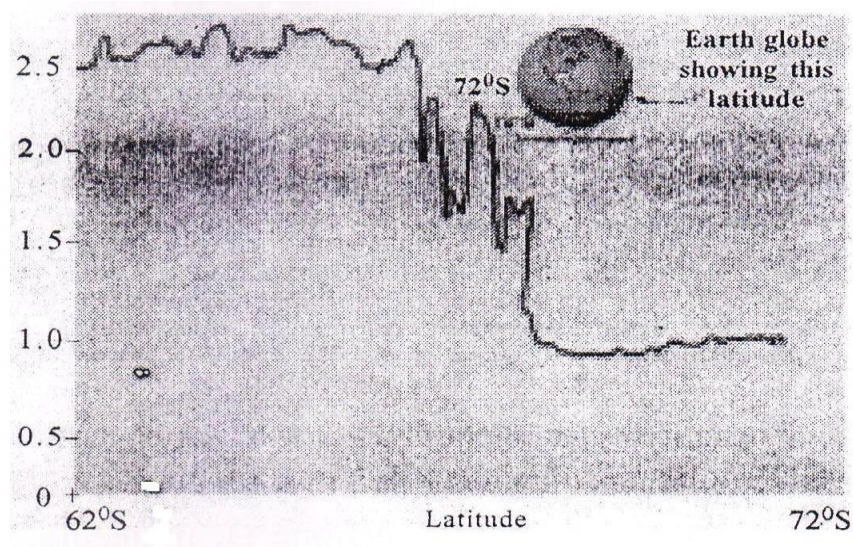


Figure 2.89 b: Ozone hole over Antarctica.

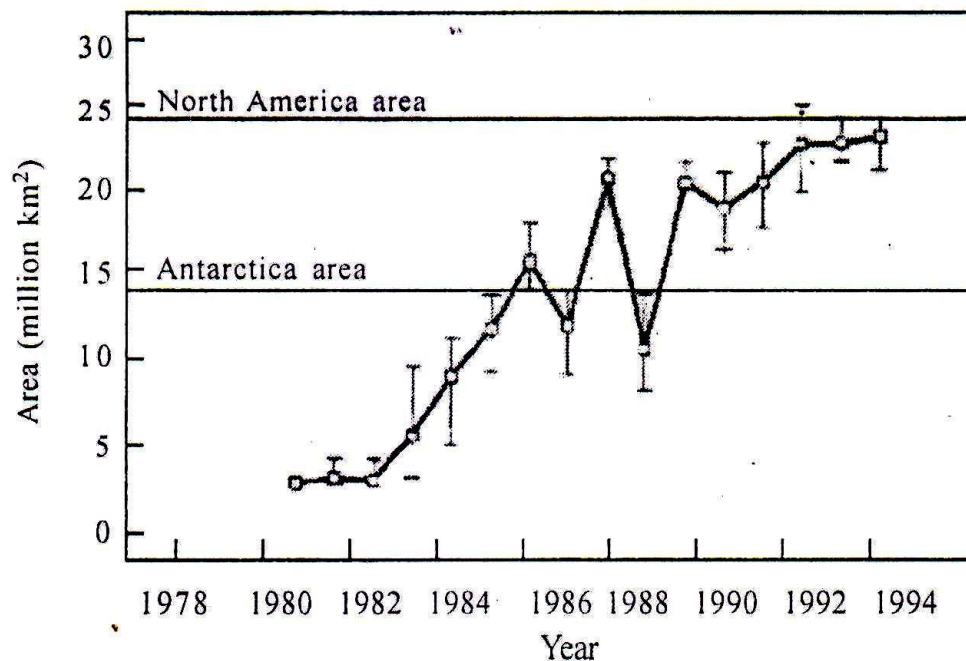


Figure 2.89 c: Variation with year of the size of the ozone hole now about the size of North America.

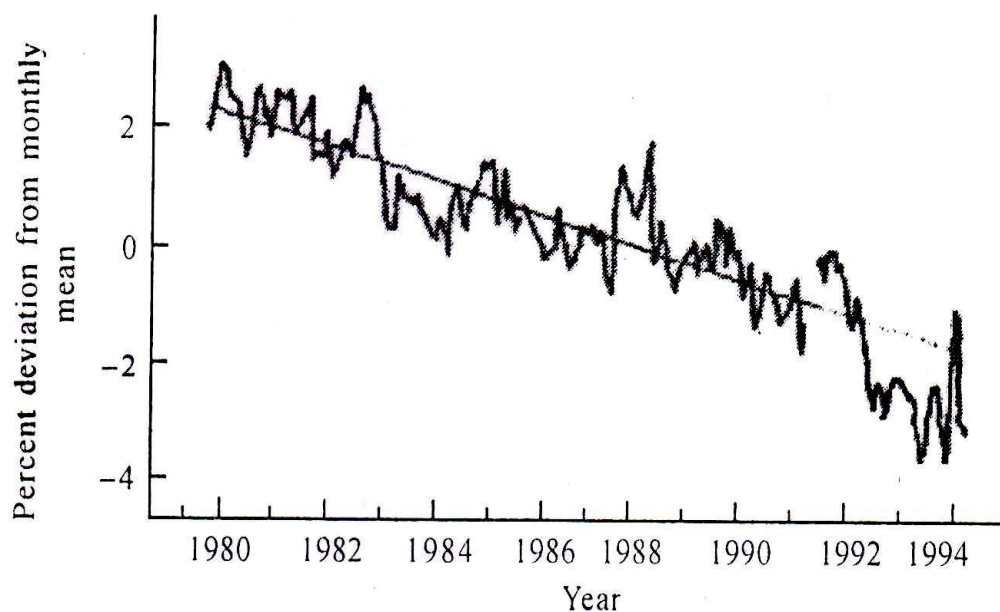


Figure 2.89 d: Overhead O₃ for non Polar Regions (60°N – 60°S) showing some worldwide depletion.

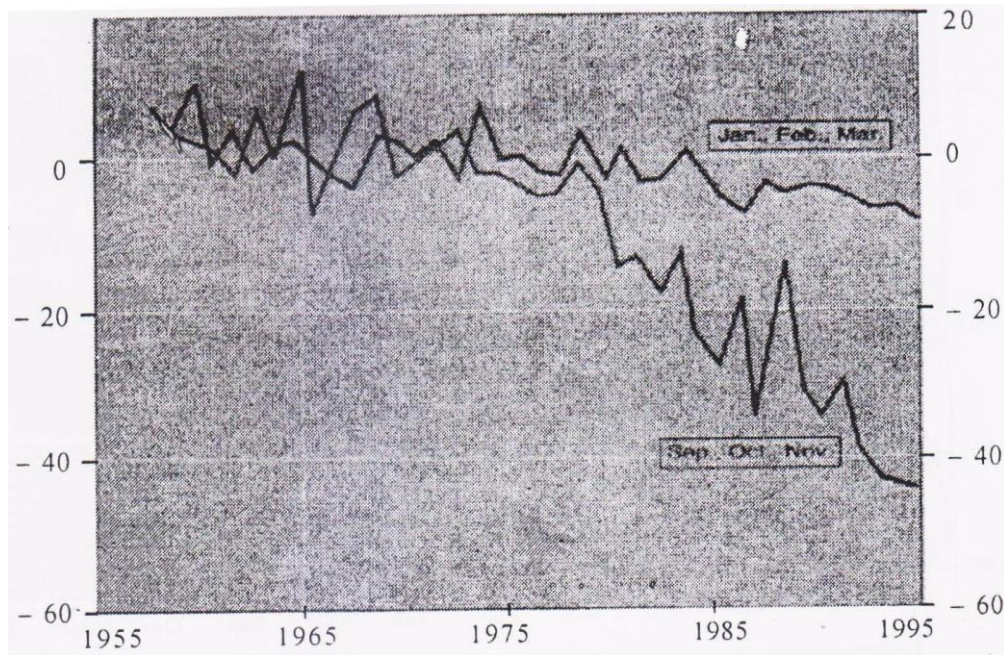


Figure 2.89 e: Ozone hole seasonal variation.

Various theories have been postulated to explain higher ozone depletion including dynamical air motions near the pole, a connection with the 11 year cycle in solar activity, and a chemical mechanism. It is now recognised that the depletion is caused by manmade chlorine pollution of the atmosphere in combination with unique wintertime meteorological conditions. The circulation of the winter stratosphere over Antarctica and the surrounding oceans is dominated by the polar vortex.

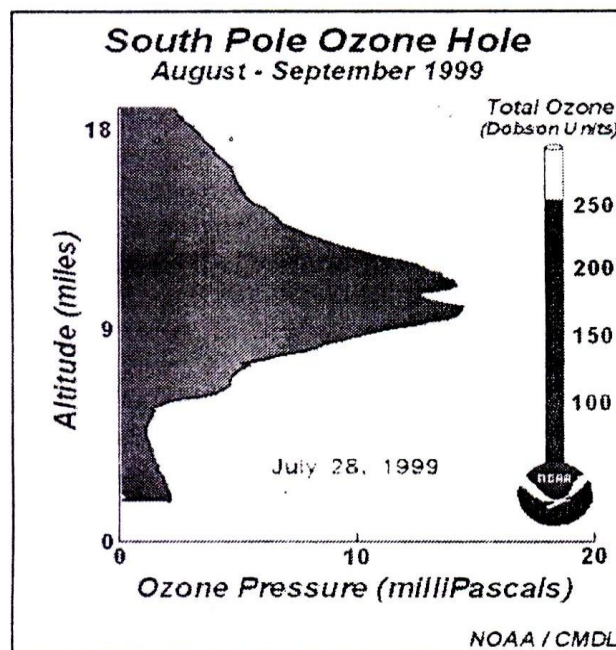


Figure 2.89 f: Extent of ozone distribution in South Pole.

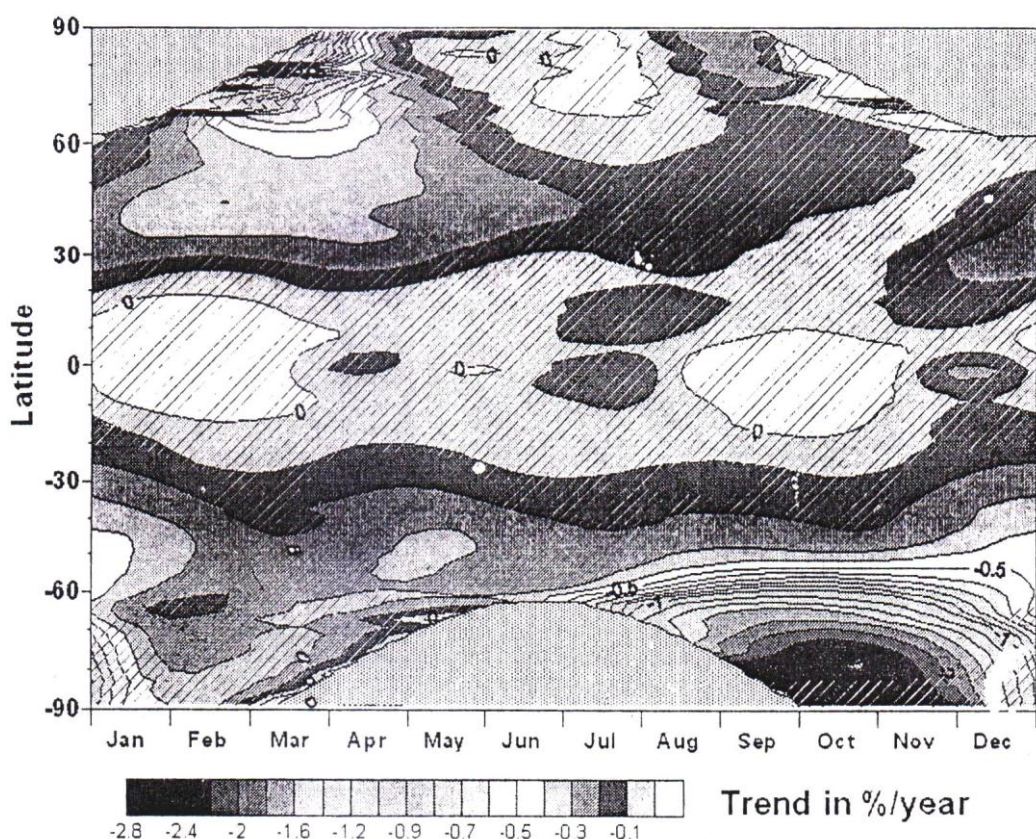


Figure 2.89 g: Global trends in Ozone November 1978 to December 2000.

This is the region of very cold air surrounded by westerly winds which may reach speeds of 100 ms^{-1} or more by the spring. Air within the vortex is sealed off from that at lower latitudes and the vortex acts as a containment vessel in which chemistry may occur in near isolation. Temperatures within the vortex fall below 190 K ; cold enough in the lower half of the stratosphere for polar stratospheric clouds (PSC) to form. These clouds remove active nitrogen from the stratosphere that would otherwise remove active chlorine and also provide surfaces for heterogeneous chemical reactions.

Some scientists have maintained that even if the protective ozone blanket was partially destroyed, the increase of UV radiation would be absorbed by clouds and atmospheric pollution. However, two Canadian scientists reported that the amount of UV radiation in the air over Toronto, Ontario, increased 5% each year from 1989 to 1993, coincident with the annual thinning of the ozone shielding. Some studies indicate that the ozone breakdown is accelerated in the presence of ice crystals and sunlight. Although the greatest amount of ozone thinning has been caused by man-made CFCs sometimes a natural event, such as a volcanic eruption, will contribute to the depletion of ozone. In 1992, volcanic Mt. Pinatubo in the Philippine Islands erupted and injected untold trillions of tiny

sulphate droplets into the atmosphere. It is no coincidence that in the fall of 1993 the ozone hole over Antarctica was the largest ever recorded, according to David J. Hofmann of the National Oceanic and Atmospheric Administration.

More than 70 % of the ozone blanket was destroyed in a 23 million square kilometer area- almost the size of the entire North American continent. Scientists theorised that the trillions of the tiny sulphate droplets injected by the eruption provided the surface on which the ozone depleting reactions could occur. The implications are disturbing. As Rowland stated". There's a distinct worry that what's happening in Antarctica could happen here". In 1994 scientists reported a dramatic worsening of the ozone depletion problem, not only in Polar Regions but over much of the Northern Hemisphere. Rumen Bujkov of the U.N.

International Ozone Commission reported the ominous news at a 1994 meeting of the American Association for the Advancement of Science. According to Bujkov, levels of ozone have dropped 10% globally over the past 25 years. More serious for Americans, however is that this ozone shield over the United States was thinned by 15 % during the winters of 1992 and 1993. On some days the depletion was as high as 45%. Similarly high levels of ozone depletion have been recorded over Europe and Siberia.

Because of the importance and the gravity of the situation, an international conference was held in Montreal, Canada. It was sponsored by the United Nations Environment Program. At this conference, 24 countries signed a milestone accord which promised to cut the production and use of ozone destroying chemicals by 50%, around the year 1999. The chairman of the conference declared, "There has never been an agreement like this on a global scale'. The administrator of the United States Environmental Protection Agency said, 'The signing shows an unprecedented degree of cooperation among nations of the world in balancing economic development and environmental protection".

4. Solutions: Protecting the Ozone Layer

If the model and measurements of ozone depletion and its possible effects are correct, it is highly essential to stop producing any ozone depleting chemicals now. Even after stopping the production of ozone depletion chemicals, the models indicate that we

still will have to wait 50 -100 years for the ozone layer to return to 1985 levels, and another 100-200 years for full recovery. Substitutes are already available for most uses of CFCs, and others are being developed (Table 2.21). CFCs in existing air conditioners, refrigerators, and other products must be recovered and in some cases reused until the substitutes are phased in this will be expensive, but if ozone depletion should become more severe because of our activities, the ecological, health, and financial costs will be much higher.

Table 2.21: CFC substitutes.

Types	Pros	Cons
HCFCs	Breakdown faster (2-20 years). Pose about 90% less danger to ozone layer. Can be used in aerosol sprays, refrigeration, air conditioning, foam, and cleaning agents.	Are greenhouse gases. Will still deplete ozone, especially if used in large quantities. Health effects largely unknown. HCFC - 123 causes benign tumors in the pancreas and testes of male rats and may be banned for use in aerosol sprays, foam, and cleaning agents. May lower energy efficiency of appliances
HFCs	Breakdown faster (2 -20) years. Do not contain ozone destroying chlorine. Can be used in aerosol sprays, refrigeration, air conditioning, and foam.	Are greenhouse gases. Safety questions about flammability and toxicity still unresolved. May lower energy efficiency of appliances. Production of HFC - 134a, a refrigerant substitute, yields an equal amount of methyl chloroform, a serious ozone deplete.
Hydrocarbons	Cheap and readily available. Can be used in aerosol sprays, refrigeration, foam, and cleaning agents	Can be flammable and poisonous. Some increase ground-level pollution.
Ammonia	Simple alternative for refrigerators; widely used before CFCs.	Toxic if inhaled. Must be handled carefully.
Water and steam	Effective for some cleaning operations and for sterilizing medical instruments	Creates polluted water that must be treated. Wastes water unless the used water is cleaned up and reused.
Terpenes	Effective for cleaning electronic parts	None
Helium	Effective coolant for refrigerants, freezers and air conditioners	This rare gas may become scarce if use is widespread, but very little coolant is needed per appliance.

UNEP took up the issue of Ozone depletion in 1976 and adopted a simple but effective approach. It first concentrated on assessment of the problem by convening a

meeting of experts on the Ozone layer in 1977. On the recommendation of this meeting, UNEP set up a Coordinating Committee of the Ozone Layer in cooperation with the World Meteorological Organisation. CCOL consisted of the leading experts of the world on the Ozone layer. Over the next ten years, this committee provided regular assessments of the state of the Ozone layer and coordinated further research. These reports attracted international interest among the people and the governments and UNEP provided the frame work for harnessing this interest to promote international action. It marshalled the information, options and legal expertise needed for decision making.

This process led to the Vienna Convention for the Protection of the Ozone Layer in 1985 and the Montreal Protocol on Substances that Deplete the Ozone Layer in 1987. The trends in the production of halons in developed and developing countries are shown in Fig. 2.90 (a). The effect of Montreal Protocol on the decrease in the stratospheric ozone losses, and resultant skin cancer incident and ratification of Montreal Protocol by various countries are summarized in Fig. 2.90 (b).

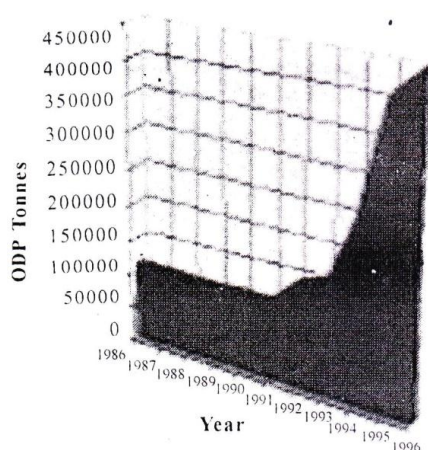
Pollution and Climate Variability

From fundamental studies on weather, it can be deduced that human activity may influence climate in at least three ways:

- i. By changing the radiational properties of the Earth's surface,
- ii. By venting waste heat into the atmosphere and
- iii. By changing the concentration of key gaseous components of the atmosphere.

The Intergovernmental Panel on Climate Change (IPCC) suggests that the chief human influence on the climate is the general warming effect of the buildup of carbon dioxide and other greenhouse gases. Secondly, in many parts of the world including much of Europe and North America, warming has been partly masked by other pollutants—the aerosols of sulphates and soot that form a thin haze which reduces solar heating.

Production of Halons by Developing Countries



Production of CFCs by Developing Countries

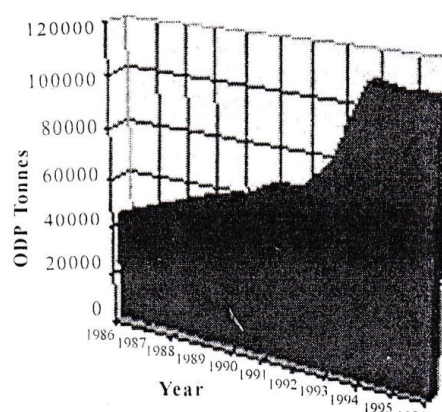


Figure 2.90 a: CFCs and Halons production by developed and developing countries.

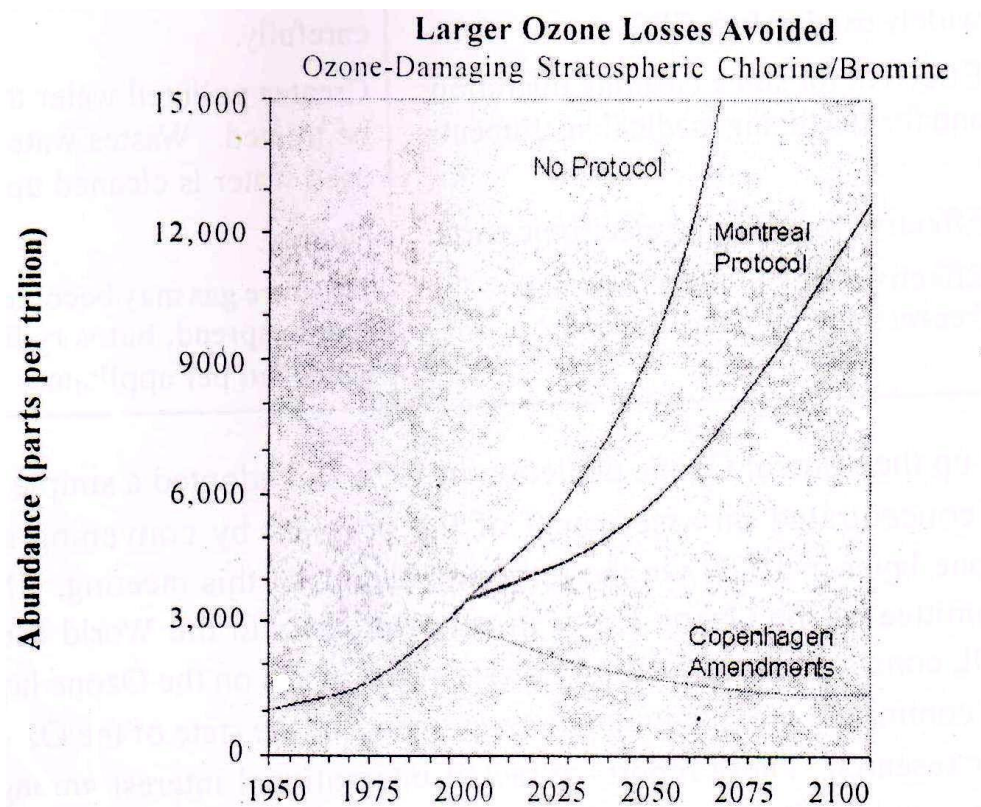


Figure 2.90 b: Larger ozone losses avoided.

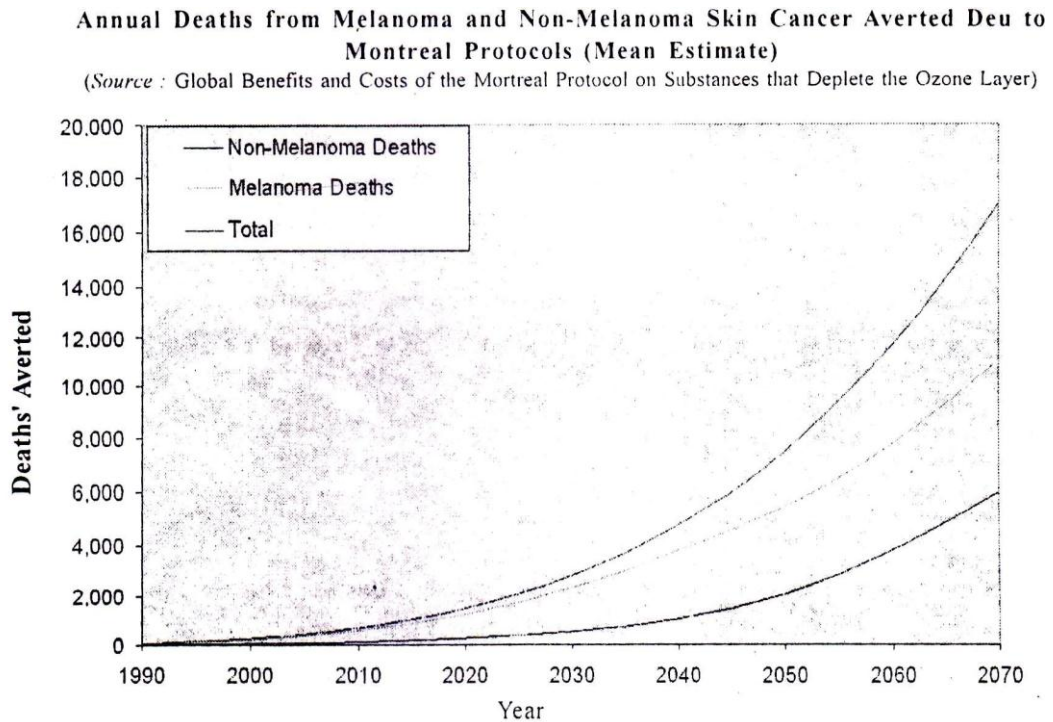


Figure 2.90 c: Annual deaths from Melanoma and non melanoma skin cancer averted due to Montreal Protocols (mean estimate).

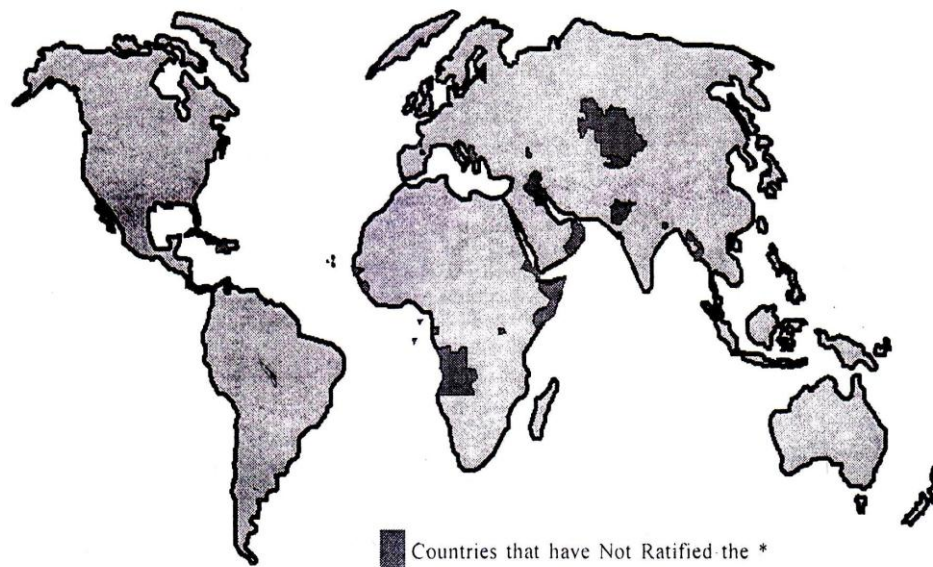


Figure 2.90 d: Ratification status of the Montreal Protocol.

Greenhouse gases (GHG) contribute to major climatic changes in developing countries, where increasing populations will require more and more energy resulting in greater levels of GHG emissions. According to IPCC estimates, 68 per cent of world's GHG emissions are likely to be from developing countries by the year 2025. This suggestion forces one to think that impact of climate change will be more severe

in developing countries like India and China whose economies are largely dependent on agriculture and which are already under stress due to increasing population pressures and associated demands for fresh water, energy and food.

Climate Change and Economy

It is a global policy issue that will force us to consider new approaches on environment, energy, economics, international regulations and competitiveness. The effect of climate change on agriculture is bound to be the most significant. Physiological processes in plants may respond to increased levels of CO₂ in the atmosphere. Some statistics is available on the effects of climate on wheat and rice. Scientists at Indian Agricultural Research Institute, New Delhi suggest that a temperature rise of 3°C will result in a loss of 15—20 per cent in yield of wheat. Malaysian scientists have reported a 19 per cent decline in yields of rice under doubled CO₂ conditions. India has witnessed a 25 per cent increase in CO₂ levels in the atmosphere between 1900 and 1980, and a decrease in the productivity of rice has been reported.

Climate Change and Water

Another important resource likely to be affected by climate change is water. Model projections indicate a decline in monsoon rainfall over the northern and central plains of India in a high CO₂ world. In general, the projected changes in rainfall, soil moisture and surface run-off could have significant impact on our water resources. Preliminary results suggest more frequent rainfall over north-east India in a warmer atmosphere which may cause severe flash floods.

IPCC

The Geneva-based Intergovernmental Panel on Climate Change (IPCC) was set up by UN in 1988. To quantify and assess climate change, various scientific organizations have since been set up. IPCC scientists use data from a number of experiments being conducted across the world, notably the International Geosphere-Biosphere programme, the Global climate observing system and the Global energy and water cycle experiment. Three agencies govern these activities namely— International Council of Scientific Unions, UNESCO and World Meteorological Organization. To understand the problems of climate change and to initiate a mechanism of global action, the 1992 UN Conference on Environment and Development (UNCED)

launched the Framework Convention on Climate Change (FCCC). The first conference of FCCC was held at Berlin, in 1995.

El Nino

El Nino is the term that was applied by Peruvian fishermen to a period of reduced fish-catch due to rise in temperature of the surface of the seacoast of Ecuador and Peru. It typically occurred around the Christmas; therefore, it was called as *Christ Child*. In 1966, Jacob Bjerknes of University of California at Los Angeles demonstrated a relationship between El Nino and weather extremes. In 1982 and 1983, El Nino made new headlines and was blamed for weather extremes in many parts of the world. Heavy rains and flooding in these years plagued normally dry portions of Ecuador and Peru. Some locations that normally receive 10 to 13 centimetres of rain had as much as 3.5 metres of precipitation. At the same time, severe drought besetted Australia, Indonesia and Phillipines. Huge crop losses, property damage and much human suffering were recorded. Farther-north, one of the warmest winters on record was followed by one of the wettest springs for much of the United States. The ferocious storms that struck the California coast brought unprecedented beach erosion, landslides and floods. Excessive rains brought floods to the Gulf States and Cuba.

What is El Nino?

Major El Nino events are intimately related to large scale changes of atmospheric circulation in the Pacific. These circulation anomalies involve both the tropical atmosphere and ocean. Each time the El Nino occurs, the barometric pressure over large portions of the southeastern Pacific drops, whereas across the Pacific, near Indonesia and northern Australia, the pressure rises. Moreover, when the El Nino event ends, the difference in pressures of these two regions swings back in the opposite direction. This sea-saw pattern of atmosphere between the eastern and western Pacific is known as *Southern Oscillation*. Collectively, it is called El Nino/Southern Oscillation (ENSO). It is an inseparable part of the warming that occurs in the central and eastern Pacific every 3 to 10 years.

Typically, Pacific trade winds converge near the equator and move westwards into a semipermanent region of low pressure near Indonesia. This steady westward flow of air drags the water of the warm surface towards the west. The result is the "piling up"

of a thick layer of warm surface water and a higher sea-level in the western Pacific. Meanwhile, strong coastal upwelling of cold water and a lower sea-level characterize the eastern Pacific.

The phenomenon of southern oscillation, which occurs due to unknown reasons, changes the normal situation dramatically. Barometric pressure rises in the Indonesian region, causing the pressure gradient along the equator to weaken. Consequently, easterly winds in the western Pacific diminish and then change the direction. This reversal creates a major change in the equatorial current system, with warm water moving towards the east. With time, the temperature of the water in the eastern Pacific increases and the sea-level rises in the region. These events lead to the development of El Nino (Figure 2.91).



Figure 2.91: A satellite image of the Pacific Ocean taken on June 25, 1997 shows that the weather disrupting phenomenon known as El Nino is getting stronger. The areas 1 and 2 (where El Nino emerges) indicate the abnormal warming up of the ocean. This area is about one and a half times the size of the US. The areas marked 3 indicate normal conditions.

La Nina

Recently, a phenomenon opposite to El Nino has been reported by scientists. Literally, La Nina means "the girl". La Nina features strong trade winds and unusually low temperatures of the sea-surface in the central and eastern tropical Pacific. An intense La Nina may also be linked to weather extremes in mid-latitudes. For

example, the US drought in 1988 coincided with an intense La Nina.

Impacts of El Nino

It is difficult to be precise about the impacts of El Nino although enough historical data in the last 50 years has been gathered to make some intelligent guesses. Direct impacts of El Nino range from storms in the western United States and the disappearance of fish along the Peruvian coast. Storms occur due to warming of the air which rises due to convection causing unsettled weather. Fish stocks decline because a rise in temperature of the surface of the sea disturbs the phenomenon of upwelling, thus changing the ecological conditions in the coastal waters. Peruvian and Chilean coasts are located in the zone of *upwelling*. This means that under normal conditions, the nutrients dissolved in deep waters are continuously brought to the surface. During El Nino, the cycle of upwelling is disturbed causing delicate ecological imbalances.

In 1982-83, El Nino directly affected fish stalks not only in South America but also in the US. There are many indirect effects of El Nino. A severe storm can result in loss of life, destruction of infrastructure and disturbances in regional economics which in turn can affect international economy.

El Nino and Its Effects on Climate

The El Nino event of 1997, first noticed in January, has caused a sensation. Those who love drama have dubbed it as the climate event of the century. Only time will tell if it is an exaggeration. Previous El Nino episodes, for instance in 1982—83, took scientists by surprise. But the El Nino occurrence this year has certainly turned their attention on the relationship between man, natural elements and the place of science in predicting and mitigating the adverse effects of natural disaster.

Causes for the Occurrence of El Nino

In the 19th century, El Nino appeared on an average every seven and a half years, now it comes every five years. Are other factors to blame or is it because of the "greenhouse effect", resulting from human activity, in particular the release of carbon dioxide into the atmosphere? A report in *Nature* (No. 6678, April 23, 1998) argues that the 20th century has been exceptionally warm. Climatologists assert that the Earth's surface has warmed ever since the beginning of the Industrial Revolution and

three of the hottest years in this century were branded together in the nineties—1990, 1995 and 1997.

Scientists of the University of Massachusetts, USA, have taken an artful solution, i.e. a clutch of long-term historical records and matched them with what is termed "proxy" records of past temperatures. Annual variations are preserved in a variety of natural settings such as laminated deposits of polar ice, growth rings of trees, chemical evidence of climatic change contained in tiny marine fossils, seasonal growth patterns of corals along with fossilized pollen in lake sediments. The researchers calibrated these natural variations against historical records so that they could use these natural records to extract meaningful information about temperatures which was then combined with the available thermometric records. Their verdict—the twentieth century has been the warmest in 600 years- and the three warmest years of the nineties were hotter than any other period since the Middle Ages.

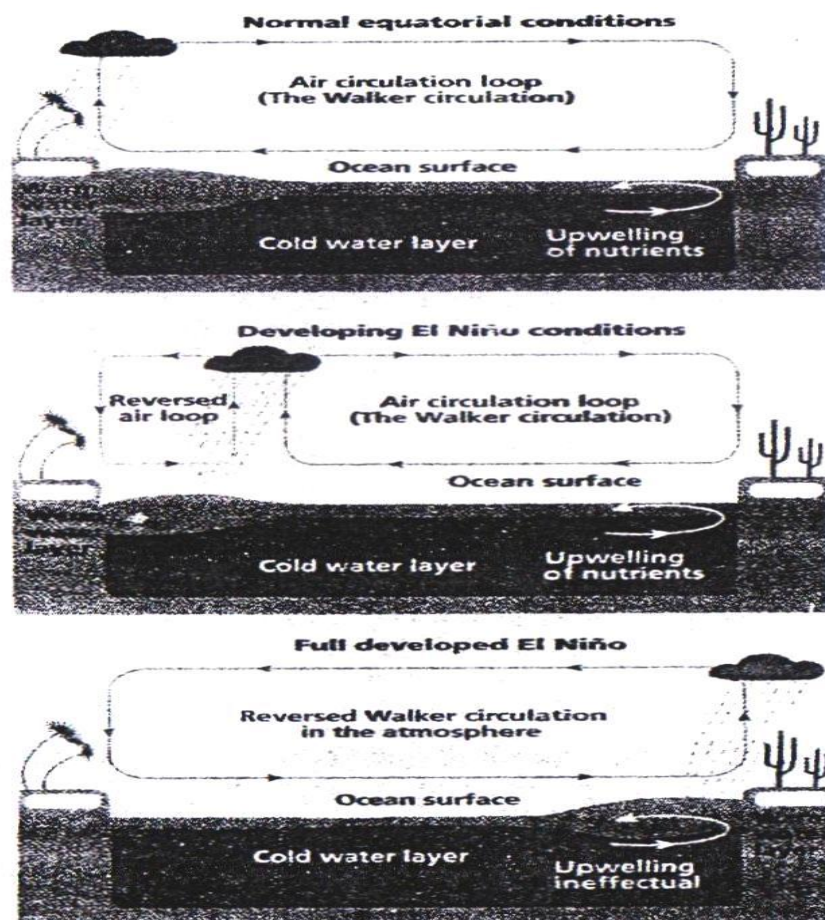


Figure 2.92: Change in the temperature of the ea affects wind patterns which ultimately affect weather globally.

Until the 20th century, they found that a variety of mostly natural factors combined to influence the climate. They cause included changes in solar radiation and volcanic haze, reflecting sunlight and heat trapping greenhouse gases, mainly CO₂, in the atmosphere. But in the 20th century, greenhouse gases—from burning of fossil fuels like coal, oil and natural gas—have been the most dominant factor. Atmospheric concentration of carbon dioxide has risen phenomenally. As generally known, certain level of greenhouse gases in the atmosphere is needed to keep the planet warm enough to sustain life.

But the beneficial natural levels of these gases in the atmosphere are being continuously boosted by human activities, especially the burning of fossil fuels. If these emissions are not curbed, the amount of the greenhouse gases in the atmosphere would become double by the end of the next century compared with pre-industrial revolution levels. "The warming of the past few decades appears to be closely tied to emission of greenhouse gases by humans", said Michael E. Mann, chief author of the report on the new study. Other studies have essentially come to the same conclusion.

The Walker Effect

In the 1920s, Sir Gilbert Walker made the seminal connection between barometer readings of air pressure at sea level at stations on the eastern and western sides of the Pacific Ocean (Tahiti and Darwin, Australia). He observed that when pressure rises in the east, it usually falls in the west and vice versa. Walker and his team sorted through data on weather records till they found some patterns of rainfall in Latin America which could be associated with changes in the temperatures of ocean waters (Figure 2.92).

What robbed Walker of the credit for establishing the vital link between patterns of rainfall in South America and the ocean temperatures was his theory of a connection between monsoons (or the want of it) in India and unusually mild winters in Canada. Walker was criticized for his thesis—how could climatic conditions over such widely separated region be linked?

Case Studies**1. *An Indian summer.***

India experienced the worst summer year in fifty years which left more than 3,000 dead people and millions soaking in sweat. The heat wave took its toll in almost every state of the country—the worst affected being Orissa. According to Indian Meteorological Department, the southeasterly winds from the Bay of Bengal, which usually blow across Orissa in May, were missing this time. These winds normally nullify the effect of the heat wave brought by the surface winds from the north-west plains of the country thereby causing thunderstorms and preventing the temperature from rising further.

Environmentalists, non-governmental organizations as well as some meteorologists attribute the unprecedented heat wave to unchecked deforestation, the El Nino phenomenon and the most importantly global warming.

El Nino at work. The heat and dry weather conditions were not experienced only in India. Climatic swings—droughts or deluges— prevailed in almost every part of the world. The first five months of 1998 were the hottest months of the planet on record, say scientists of the US-based National Oceanographic and Atmospheric Administration. They further stated that the average global temperature from January to May was about 17.2°C, marginally hotter than the previous record set in 1997. The El Nino phenomenon is the main reason behind the mercury ascent.

"Even if it sounds unbelievable, it has actually caused most of the problems", says Majib Latif, a climatologist at the Max Plank Institute for Meteorology at Hamburg. After 1982, this was the second most strong El Nino in one generation, causing damages of over US \$ 10 billion.

2. *North America*

The El Nino caused an extremely violent tornado season in the US in 1998. In Florida and Alabama, hundreds of people lost their homes. The whirlwind left behind a 16 km-long trail of destruction in Georgia. In California, the storms caused floods and landslides. In the first quarter of the year, damages amounted to approximately US \$ 1 billion. The winter in the North American east coast was usually mild but the coast was extremely humid. The insect population was benefitted mostly from the

humidity. Los Angeles suffered an invasion of rats while the flowering plants of California were swamped by the killer bees. America was also inflicted by a wave of allergies, the worst in 40 years. Since, El Nino is now on the decline and its colder sister "La Nina" is due to set in, meteorologists predict an extremely dry season ahead in south and west USA—bringing with it the hazard of uncontrollable forest fires.

3. *Central America*

Mexico recorded only one-tenth of the normal rainfall. Ravaging fires were gobbling the country's last virgin cloud forest—the Chimalapas. The fires ravaging the mystical forests were so huge and remote that authorities could not even count the number of blazes. With the 22 ecosystems and G2 species of reptiles comprising the cloud forest, the firefighters have been unable to employ the most effective methods of dousing the blaze. An estimated 16,800 acres of forestland have been destroyed since the fires started last year.

In Panama, 1997 was the driest year of the century recording 35 per cent less than normal rains. The drought has also disrupted sea traffic which passes through the Panama Canal. Even normal monsoons may not be able to fill Panama's rivers and lakes. As the country gets about 70 per cent of its energy from hydroelectric plants, Panama is suffering a severe energy crisis.

4. *South America*

In Peru and Ecuador, heavy rainfall caused disastrous landslides and floods, destroying roads, bridges and often whole villages. At least 500 people died and 2,50,000 were left homeless. The floods transformed the Sechura desert in north Peru into a 1,000 sq km of lake. The repairs of the roads would cost the two nations US \$ 1.5 billion. Though the Peruvian fishing flock is equipped to combat an El Nino attack, the fishing industry, with exports of US \$ 1 billion annually, suffered huge losses. The warm temperatures in the Pacific forced the large sardine schools to move southwards. This caused about 85 per cent of Peruvian seabirds to starve.

Uninterrupted rains have submerged almost 60,000 sq km of land in Argentina and Paraguay. More than 12,000 people have lost their homes. Brazil, in contrast, is suffering from an unprecedented drought. While droughts in Brazil's northeast are periodic, low rainfall is painting the landscape and fires have destroyed almost 60,000

sq km of rainforests. According to estimates, almost 10 million people are suffering from the effects of drought. Experts fear forest fires may lead to long-term climate changes, mostly dry spells in South America.

5. *Africa*

Violent storms and catastrophic floods were El Nino's Christmas gift to the eastern African region. Floods in Somalia left 1,600 people dead. Kenya measured 10 times more than normal rainfall in October. Bad harvests and high transport costs caused the prices of some vegetables to rise by almost 400 per cent. In Uganda, where 65 per cent of the foreign exchange earnings come from coffee, exports were almost halved. Tanzania has estimated its El Nino damages at US \$ 117 million and has requested the World Bank for US \$ 47 million in aid. Incessant rains brought the danger of an epidemic. In east Africa, at least 17,000 people have suffered from cholera, thyroid or malaria since the rains started.

6. *Australia*

Australia was prepared for the El Nino onslaught. Forest fires had destroyed thousands of houses and taken countless lives in the last El Nino season of 1982. Though this drought caused more fires than the last time, preventive measures reduced damages. The Australian firefighters were better equipped and had already prepared corridors for the fires in advance. Despite this, the bush fires in southeastern Australia destroyed at least 200,000 hectares of meadowland. Bush fires are normally caused by lightening. However, because of the extreme dryness, they spread very rapidly. Two firefighters lost their lives while dousing the blaze.

7. *Monsoon too soon*

The showers that hit Delhi on June 16, 1998 caught everyone, including meteorologists, completely unaware. They heralded the earliest onset of monsoons in 97 years. Expected to arrive by June 29, the rains were 13 days ahead of schedule. After studying the weather patterns, including cloud formation and precipitation, we came to the conclusion that an influx of systems—tropical westerly trough and monsoon circulation—working together, resulted in advanced monsoons in central India. The Arabian Sea cyclone, as it hit the land, also catalyzed the movement of the monsoon. A senior meteorologist was of the view that the early monsoon could have a possible link with the El Nino, which is now on the decline or even the La Nina, the

cold phase which follows an El Nino phenomenon. Does early monsoon mean an early departure? Meteorologists had no answer.

8. Southeast Asia

Indonesia and Malaysia experienced the worst drought in 50 years. Forest fires destroyed two million hectares of forests in just three months of 1997 causing damages of about US \$ 2.5 billion. A haze cloud, the size of western Europe, shrouded Southeast Asia. The main cause of the fires may have been the plantation owners' ritual of clearing forests, by burning them, but the conditions propelled by El Nino aggravated the blaze, making firefighting impossible. At least 70 million people have been affected by the smog, and it is still unclear what long-term effects this will have on their health (Figure 22.10). According to some reports, the smog also contains suspected carcinogens, the effects of which may result in impairing the health of thousands of children permanently.

Programmes Related to El Nino

Since the El Nino of 1982, when a severe drought caught the scientific community unaware, considerable efforts have been made to predict and forecast the effect of the phenomenon. In 1985, the Tropical Ocean Global Atmosphere (TOGA) programme was launched which improved the understanding of the atmosphere-ocean interaction. During 1992, TOPEX/Poseidon satellite was launched into the Earth's orbit. TOPEX measures sea level along the same path every 10 days. This information is used to measure change in sea currents.

The Tropical Atmosphere Ocean (TAO) Programme. It consists of about 70 ATLAS buoys and moorings sites in the tropical Pacific Ocean. They send oceanographic and meteorological data in real-time via the Argos satellite system. TAO has been instrumental in predicting and monitoring the progress of El Nino. TAO is supported by US, France, Japan, Korea and Taiwan. Scientists have developed the capacity of predicting El Nino. They use a combination of historical data and direct observations and numerical models to do so.

Institutions of Climate Change

Intergovernmental Panel on Climate Change (IPCC)

When it comes to understanding climate change, the Intergovernmental Panel on Climate Change (IPCC), established by the UN in late 1988 to address knowledge gaps related to the science, impacts and policy responses to the climate problem, is widely recognized as the final word. The panel has three working groups, including:

- Working group I for scientific assessments,
- Working group II for impacts, adaptation and mitigation and
- Working group III for economic and social dimensions of climate change.

Because of the political sensitivity of the problem, each working group communicates its results to the other two before taking major decisions.

The findings of the *IPCC First Assessment Report* were presented to the second World Climate Change Conference in Geneva, in 1990 and updated for UNCED in 1992. The report related greenhouse gas build-up to economic and technological development and to national and international policies. It reported that global temperature had gone up by 0.5°C over the last century, and Australia had measured a sea-level rise of 1.22 mm. It warned that the coastal areas of many countries, including Japan, Egypt, Bangladesh and the US, would be threatened by rising sea levels. Island states like Maldives, Tuvalu and Kiribati could be inundated. Tropical diseases like malaria would spread to higher latitudes. Droughts would become more serious in many regions. The gravest effects, according to the report, would be from human migration, as millions are uprooted by shoreline erosion, coastal flooding and agricultural disruption.

The *Second Assessment* was finalized in 1995 and published in 1996. It reported a detectable influence of human activities on climate change and called for urgent action at the national and international level. The *Third Assessment Report* was finalized in late 2000 and published in early 2001. Most of the governments view the IPCC process as credible and legitimate and are content with relying on its international review process. A special committee promotes the involvement of developing countries in IPCC activities.

Besides the IPCC, the World Climate Programme (WCP), established in 1979, focuses on climate data, applications and research and impact studies. It is operated by WMO, UNEP, the International Oceanic Commission (IOC) and the International Council of Scientific Unions (ICSU).

The International Geosphere Biosphere Programme (IGBP), operated by ICSU, builds on scientific work by ICSU, especially through its Scientific Committee on Problems of the Environment (SCOPE). The Advisory Group on Greenhouse Gases (AGGG), established jointly by WMO, UNEP and ICSU, complies biennial reviews of international and regional studies related to greenhouse gases, as well as periodic assessments of the rates of increase in their concentration and resulting effects.

Many other multilateral institutions are also involved in scientific research on climate. UNEP participates in IPCC, WCP and AGGG and makes contributions to the World Climate Impact Studies Programme of WCP. WMO is the UN agency responsible for measurements and studies of the global atmosphere. WMO's Climate System Monitoring (CSM) project, part of a World Climate Data Programme, is designed to provide synthesized information on the state of the climate system. WMO also has programmes on Global Atmosphere Watch, a Tropical Cyclone Programme and agriculture-related meteorological activities.

United Nations Convention on Climate Change

Framework Convention on Climate Change (FCCC) was negotiated under the auspices of the United Nations in 1994 countries including the G-7 and OECD countries. Most of the industrialized nations have pledged to reduce greenhouse gas emission at 1990 level by the year 2000. International negotiations are underway to reduce these emissions further. The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a timeframe sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

World Summit on Sustainable Development (WSSD) Johannesburg (September, 2002)

The World Summit on Sustainable Development (WSSD), held at Johannesburg in September 2002, followed the Stockholm Conference (1972) and the Rio Summit (1992). The three-decade long journey from Stockholm to Johannesburg began with the recognition of negative influences of human activities on environment and was followed by a paradigm that sees environment and development inextricably linked. While national and international discussions still keep revolving about 'what are the key concerns to be addressed globally', some experts and organizations have already suggested the following provisions.

GREEN HOUSE EFFECT

Since the beginning of human civilization, mankind has lived in a competitive relationship with nature. His relentless pursuit of progress, comfort and security has resulted in increased stress on environment, particularly since the industrial revolution. Consequently, the life-sustaining environment has been forced to transform more rapidly than ever before. Human tendency to exert a negative influence on ecology has resulted into rapid increase in the greenhouse gases in the atmosphere, large scale deforestation, loss of biodiversity, severe land degradation and environmental pollution. The effects of these problems are global, so we call them global environmental problems. The overall impact of these problems has been observed as climatic changes, depletion of ozone layer, rise in sea level, and changes in agricultural output and loss of biodiversity— ultimately leading to an ecological crisis capable of affecting the entire life and life support systems existing on our planet, the Earth.

In recent past, global observations have provided clear evidence of climatic changes resulting from anthropogenic activities. According to a report from World Watch Institute (1992), the earth's surface was the warmest in 1990. Six of the seven warmest years on record have occurred since 1980. Observations on temperature at many places of the world over the last century show an average increase of about 0.5K. This is supported by paleo-climatic evidence gathered from deep-sea ice-cores from Arctic and Antarctic regions. While the primary cause of an increase in global temperature in the past has been increasing concentration of CO₂, fossil fuel burning,

extensive deforestation, rapid increase in chlorofluorocarbons (CFCs) has further complicated the global environmental problems.

The minor gaseous constituents, commonly known as trace gases or greenhouse gases (GHGs) like CO_2 , ClO_x , CH_4 , N_2O , HO_x , O_3 , CFCs, etc., though occur in traces but play a surprisingly dominant role in regulating the entire earth's atmosphere. These gases act as the glass panes of a greenhouse which allow solar radiations to pass through and heat the surface of the earth but do not allow the heat radiated from the ground to pass through thereby trapping it in the process. This heat trapping phenomenon is known as *greenhouse effect*. Figure 2.93 describes the greenhouse effect.

Sources and Sinks of Greenhouse Gases

There are three main sources of greenhouse gases:

- i. **Solar sources:** Changes in solar constant, XUV region, solar proton events and changes in ozone content generate the trace gases.
- ii. **Volcanic source:** Cl_x and a number of molecular species like CO_2 , H_2 , CH_4 , COs are of greenhouse interest. Mt. Agung alone that erupted in 1963 spewed 3×10^{32} molecules.
- iii. **Biospheric or industrial sources:** CO_2 , N_2O , CH_4 and CFCs are derived from biospheric or industrial sources.

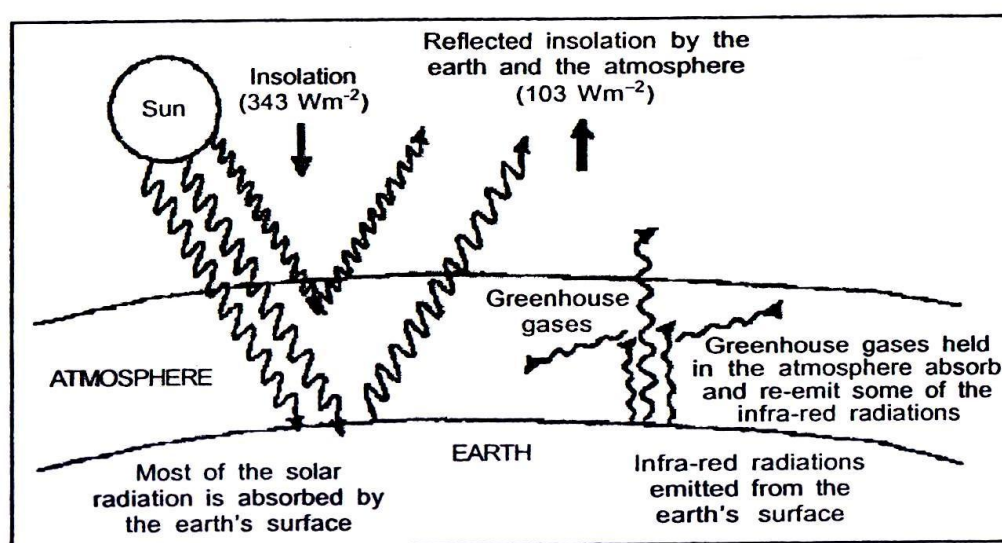


Figure 2.93: Global warming by green house gases; a schematic representation.

Carbon Dioxide—the Most Important Human-Derived Greenhouse Gas

The biosphere annually produces 194 Gt of carbon (1 gigatonne = 1000 million tonnes). Further, the biosphere absorbs small extra volume of carbon supplied from volcanoes. Human interference further adds 6—9 Gt of carbon each year. Six Gt of it come from burning fossil fuels and the rest comes from burning tropical forests. The biosphere is doing its best to cope with the extra burden but can retain only half of this extra carbon. As a result, 1.7 ppmv (parts per million by volume) of CO₂ is added every year. There is no doubt that atmospheric CO₂ levels are arising dramatically and half of this rise has occurred since 1960. Photosynthesis consumes it, and respiration and decomposition release it again (Figure 2.94).

The origin of greenhouse gas emission is an important issue in relation to the need or devising policy to minimize potential global climatic changes and its impacts. The best known of the greenhouse gases is CO₂, which is emitted into the atmosphere in large amounts—the equivalent of more than 6,000 tonnes of carbon per year. The industrialized countries, particularly the US, are largely responsible for the accumulation of greenhouse gases in the atmosphere. An international system for tradeable permits in carbon emissions would break new ground in international trade. But how to allot these permits is a debatable question.

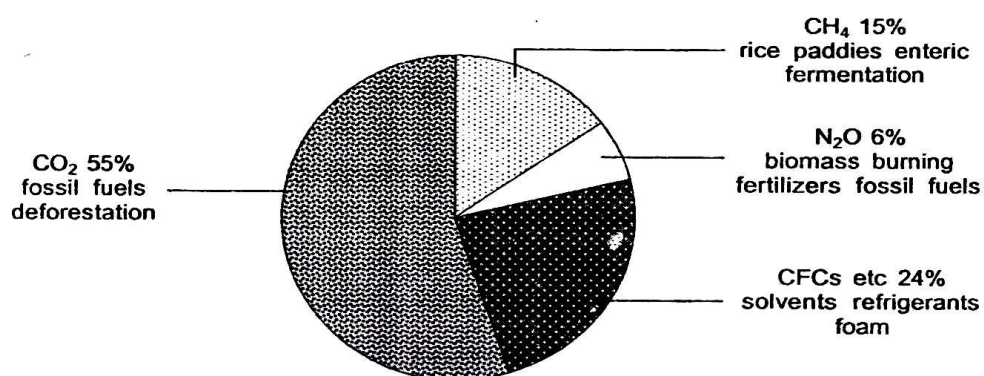


Figure 2.94: The contribution of human derived greenhouse gases to global warming in 1980-1990, with their major sources.

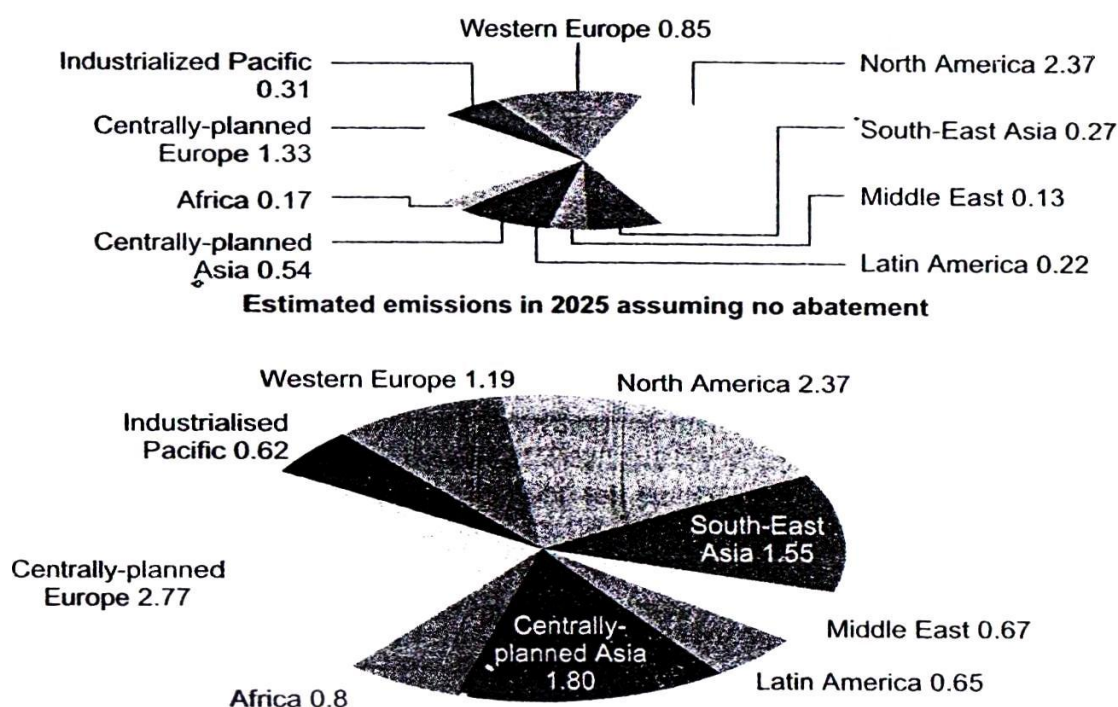


Figure 2.95: Emissions of CO₂ by Region (Giga tonnes carbon)

Data over the last 20,000 years, mainly from the ice-shells of Greenland and the Antarctic, have given a picture of the changing carbon dioxide concentration. About 20,000 years ago, during the last glaciation when the average global surface temperature was 4—5°C cooler than now, carbon dioxide concentration was as low as 200 ppmv. Some 10,000 years back, it reached 280 ppmv. The level continued to about 200 years back when the industrial revolution began. Since then, CO₂ concentration has been increasing at a very rapid rate and has now reached a level of 353 ppmv. Thus, the single most important gaseous constituent responsible for global warming shows a rising trend (Figure 2.95) The contribution made by India to global concentration of CO₂ amounted to 140 million tonnes in 1988—89. In other words, 2.8 per cent global CO₂-warming was caused by India (Figure 2.96).

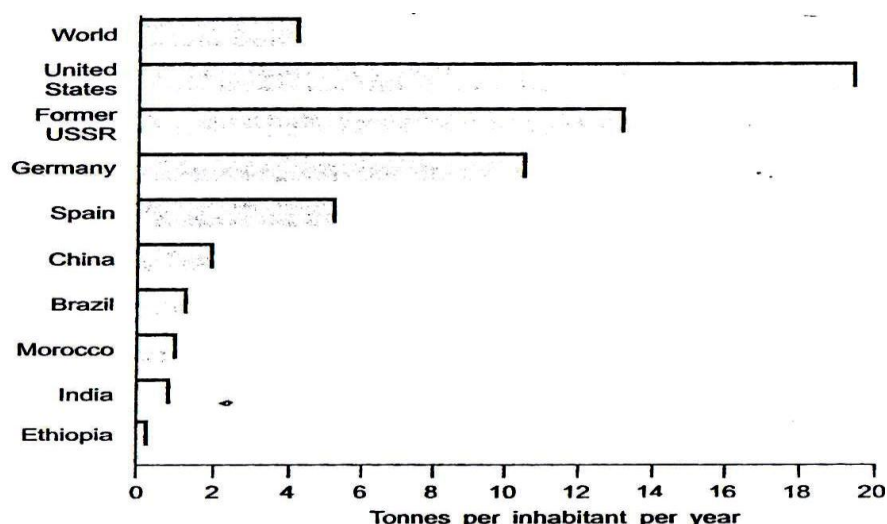


Figure 2.96: Per capita CO₂ emission in affluent countries.

N₂O (Nitrous oxide)

Combustion of coal, oil, biomass and fertilizers, modern waste disposal practices, grasslands, woodlands and tropical and subtropical forests largely contribute to atmospheric N₂O. Total N₂O accounts to about $15.3 \pm 6.7 \times 10^{12}$ gN/year. The main atmospheric sinks occur due to photolysis that equals to $14.0 + 3.5 \times 10^{12} \times 10^{12}$ gN/year. It is increasing at the rate of 0.7 ppb/year.

CH₄ (Methane)

CFCs (Chlorofluorocarbons)

Table 2.22: Greenhouse molecules.

Species	Mixing Ratio			Recent rate of growth (%/yr)	Calculated life time	Ozone depletion potential*	HGWP [@]
	1979	1986	2050 ⁺				
CO ₂	335.5 ppm	344.0	600	0.5	-	-	-
CH ₄	1.62 ppmv	1.70	3.3	1	6.5	-	-
N ₂ O	305 ppbv	310	600	0.25	170	-	-
F11	170 pptv	220	673	5	70	1.0	1.0
F12	290 pptv	390	1325	5	144	0.9	3.4
F22	50 pptv	87	631	11.7	17	0.05	0.35

* Relative to F11

@ Hydrogen global warming potential relative to F11

⁺ Value for 2050 are on the basis of constant atmospheric emissions on Montreal products after 1985, using 1986 production as the atmospheric flux, for other trace gases using a linear rate of charge and for CFC-22 to grow linearly by an additional 76 gN/year after 1985.

According to an estimate total concentration of methane was 1630 ppb in 1984. The main sources are sheep and cattle dung, rice-paddy fields, wetlands, burning of the biomass and mining of coal and mineral oil. CH₄ is 25 times more effective than CO₂ in absorbing the outgoing infrared radiation. The problem from methane arises from its unburnt presence in the atmosphere. Roots of rice plants capture methane from muddy surroundings and transport it through the plant vascular system to the atmosphere. According to an estimate, around 100 million tonnes of methane are released annually. From coal, natural gas and oil industries, almost four times of that level are freshly produced by bacteria, biomass destruction in rice fields and swamps.

Chlorofluorocarbons do not occur naturally and are totally man made. They are used in refrigerators, air conditioners, as aerosol propellants and cleaning agents. India produces about 7000 tonnes of CFCs out of the global annual production of over one million tonnes. Though India and other developing countries consume less than 15 per cent of the global CFC production, USA and the developed countries consume the rest 85 per cent of CFCs. India is one of the signatories of Montreal Protocol. Montreal Protocol calls for a 50 per cent reduction in the use of chlorofluorocarbons by 1998. CFCs halons and other ozone depleters cannot be abandoned without substitutes and those substitutes themselves must be environmentally safe. Industry accepts the need to go farther than the Montreal Protocol and the need for ultimate elimination of ozone depleting chemicals (Table 2.22).

India's case is unique. It is one of the few developing nations that consume as well produces ozone depleting substances (ODS). In fact, after China, it is the largest producer of chlorofluorocarbons (CFCs). It produces most of the other ODS also. The protocol, therefore, hits India's economy twice over—once, when the companies making ODS-based products are forced to phase them out and the second time when the multimillion dollar ODS-manufacturing units have to stop producing these substances. See Table 2.23.

Table 2.23: Phasing out of ozone depleting molecules.

Ozone depleting substances	Producers	Use	Phase out date
Chlorofluoro-carbons	SRF Ltd.	As coolant in refrigeration & air conditioning appliances. As aerosols or sprays in perfumes, shaving foams, insecticides etc. For blowing process in foam-based insulation.	Jan 1, 2010
Halons	Navin Fluorine Industries	As solvent in electronic and precision cleaning, coatings.	Jan 1, 2010
Carbon tetrachloride	Gujarat Alkalies & Chemicals	In fire extinguishers	Jan 1, 2010
Methyl chloroform	Tata Chemicals Ltd.	As solvent in manufacturing and various other processes	Jan 1, 2010
Methyl bromide	SRF Limited	As solvent in electronic and precision cleaning. In coatings.	Jan 1, 2015
Hydro chloro fluoro carbons	Gujarat Fluoro-chemicals Ltd.	As pesticide	Jan 1, 2015
HCFCs	Chemplast Sanmar Fluorine Industries	In large sized coolants and air-conditioning systems	Jan 1, 2040

Human Consequences of These Changes

- i. 5 per cent to 50 per cent increase in drought frequencies,
- ii. 15 per cent destruction of the arable land in countries like Egypt and Bangladesh,
- iii. Overwhelming of whole nations like Maldives and Kiribati by rising sea level,
- iv. Millions of environmental refugees

Ecological Consequences

- i. A warmer globe would change the latitudinal stratification of plant life due to changes in soil moisture,
- ii. Sea level rise due to thermal expansion of water and melting of global ice-sheets,
- iii. Non-adaptability of ecosystems as a whole to sudden changes in the temperature.

However, there are ways through which climate change can be prevented. They include energy efficiency, development of environmentally sound sources of energy, increasing the biospheric sinks of carbon through re-afforestation and other practices.

Estimates of Expected Changes by 2030

Central North America. Warming will vary from 2°C to 4°C in winter and 2°C to 3°C in summer. Precipitation increase will range from 0 to 15 per cent in winter, but there will be decrease of 5 to 10 per cent in summer. Soil moisture will decrease in summer by 15 to 20 per cent.

Southern Asia. Warming will vary from 1°C to 2°C throughout the year. Precipitation will change little in winter and will generally increase throughout the region by 5 to 15 per cent, in summer. Summer soil moisture will increase by 5 to 10 per cent.

Sahel. Warming will range from 1°C to 3°C. Area means precipitation will increase and area mean soil moisture will decrease marginally in summer. However, throughout the region, there will be areas of both increase and decrease in both parameters.

Southern Europe. Warming will be about 2°C in winter and will vary from 2°C to 3°C in summer. There is some indication of increased precipitation in winter, but summer precipitation will decrease by 5 to 15 per cent and summer soil moisture by 15 to 25 per cent.

Australia. Warming will range from 1°C to 2°C in summer and will be about 2°C in winter. Summer precipitation will increase by around 10 per cent, but the models do not produce consistent estimates of the changes in soil moisture.

Environmental Effects of Global Warming

According to Stockholm Environment Institute, all natural ecosystems can tolerate a rise by 0.1°C of temperature per decade. However, further rise in temperature has been calculated to pose serious environmental consequences.

1. Many species, particularly plants, would be unable to migrate to new and somewhat suitable habitats, leading to rapid loss of biological diversity and natural resources of economic importance.
2. The increase in temperature will cause more frequent storms to many parts of the world, including regions that have experienced no such activity earlier.
3. Rainfall and monsoon patterns could shift dramatically as the planet warms. Some of the regions of the world could dry out while others could receive too many

rains—flooding rivers and increasing soil erosion.

4. An increase in temperature will cause the oceans to expand. Rising sea-levels will flood many highly productive areas of the world like Bangladesh, Egypt, Indonesia, China and India.
5. Glaciers and ice-caps will melt contributing further in the rise of sea-level.
6. Rise in sea-level is a threat to the very existence of several island countries in the Pacific, Indian Ocean and Caribbeans.
7. Global warming could seriously disrupt marine ecosystems. The flooding of many coastal wetlands would mean the loss of breeding grounds of fish, shrimps and birds.
8. Groundwater supplies in several parts of the world could become contaminated with seawater.

Ozone Depletion and Global Warming

Global warming is fallout of ozone depletion. Greenhouse gases and the global climatic changes are major problems. The earth's average temperature has not varied by more than 2°C in the past 10,000 years and during the last iceage, the earth probably was about 5°C colder than it is now. Some 5,000 to 7,000 years ago (the Holocene optimum), when the average temperature was perhaps 1°C warmer than it is now, climate then was substantially different from that of today. There was more rainfall in the Indian areas and the Sahara was probably not a desert but a dry Savannah. Yet if some of the principal green house molecules such as CO₂, CH₄ and O₃ continue to increase at the present rate and if many of the current calculations are correct, then the global temperature can rise by 1.5 to 4.5°C in about 50 years.

Differential Greenhouse Effect

There is consensus on the impact of greenhouse effect on the tropical regions—they will be getting hotter. Some experts believe that this tropical warming will cause a cooling effect in the temperate and polar regions. Researchers at Max Planck Institute in West Germany say that more seawater will evaporate in the warmer tropics, which will increase the cloud cover in the temperate zones as the warm, moist air is carried there by the prevailing winds. These clouds will increase rain and reflect the sunrays back into the space, causing cooling below. *This simultaneous[^] warming of one pari of the world and the cooling of another is known as the "differential greenhouse*

effect".

There are also other warming signals. Only nine periods in the past 7,00,000 years has been as warm as is the earth now. The spans of these interglacial periods have been brief—10,000—11,000 years. The current warm spell is about 10,800 years old and may, therefore, be almost over. Equally disturbing is the fact that when a climatic change takes place, it happens quickly. At the start of the last iceage, conditions similar to those of today gave way to tundra within 30 years. According to theory of differential greenhouse effect, the rise of carbon dioxide content of the atmosphere will actually contribute to a global sea level drop and will, therefore, help the low-lying lands of the Asia and Pacific region to expand rather than shrink or vanish.

Ozone Depletion

Ozone (O_3) is a triatomic form of oxygen. It is found largely in the stratosphere that extends from about 6 km at the poles and 17 km at the equator to about 50 km above the earth's surface. It- is present in traces (less than 1 ppm) in the atmosphere. It has a peak concentration (10 mg kg^{-1}) in the stratosphere. Ozone has been the most reactive form of molecular oxygen and the fourth most powerful oxidizing agent. It has a pleasant concentration at about 2 ppm or less, but higher concentration is irritating. It is used as a disinfectant and bleaching agent.

In nature, O_3 are formed in the stratosphere when ultraviolet light strikes an oxygen molecule. A photon splits the oxygen molecule into two highly reactive oxygen atoms (O). These atoms combine quickly with an oxygen molecule to form ozone. Ozone readily absorbs UV light and dissociated into its constituent components.

The Greenhouse Effect

Climate change is caused by emissions of pollutants which increase the so called 'greenhouse effect' by which gases in the atmosphere create a 'blanket' or warming effect by limiting the ability of heat to be radiated out into space. Gases responsible for the greenhouse effect include water vapour, carbon dioxide, methane, ozone and halocarbons, the later four of which have been affected by human activities over the last 300 years. Concentrations of carbon dioxide, methane and ozone in the lower atmosphere have increased greatly over this period. Analysis have shown that global temperature has risen by about 0.6°C since the beginning of the 20th century with

about 0.4° C of this warming occurring since the 1970s. The year 1998 was the warmest in this 142-year record and 2001 was the third warmest. Globally, the decade of the 1990s was the warmest in the last 100 years, and it is likely the last 100 years was the warmest century in the last millennium.

Carbon emissions from the oxidation of fossil fuels have elevated the carbon dioxide concentrations in the atmosphere. Carbon dioxide concentration in the atmosphere fluctuates during different seasons, declining during the northern hemisphere summer and increasing through the winter. When there is spring and summer in northern hemisphere, photosynthesis markedly exceeds the rate of respiration, however in winter, respiration predominates as plants loose foliage and litter decomposition is enhanced. Atmospheric concentrations of other gases like methane (CH₄), chlorofluorocarbons (CFCs) and nitrous oxide (N₂O) have increased. The radiation that reaches the earth is mostly in the visible region of the spectrum (400-700 nm). This short wavelength radiation warms the surface of the earth. Absorption of this radiation in the infra-red region of the spectrum is a property of the greenhouse gases in the atmosphere.

The radiation that these molecules absorb results in higher temperatures. Without these gases in the atmosphere, the mean temperature of the earth would be more than 30° C colder. Earth's atmosphere allows the short wave ultraviolet and visible light, but traps infra-red radiation that is radiated from the earth. This acts as an insulator, trapping heat that would have been lost to space. The concentration of these heat trapping gases in the atmosphere is increasing. An increase in the concentration of any of these gases enhances the capacity of the atmosphere to retain heat. Carbon dioxide is the most important greenhouse gas because of its higher concentration in the atmosphere and its effectiveness as a radiation trap.

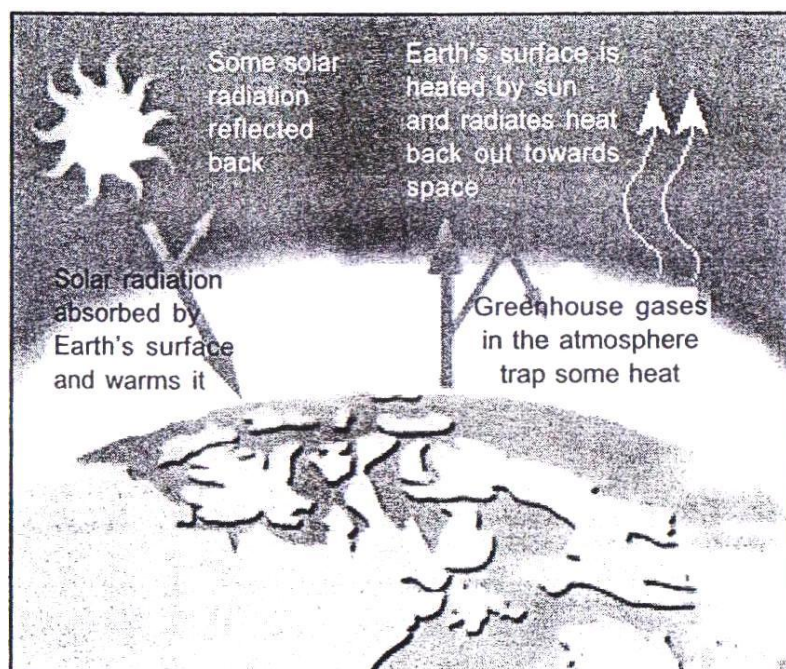


Figure 2.97: Green house effect.

Methane is produced through anaerobic respiration in the stomachs of animals, especially ruminants, in wetlands and during the extraction of oil and natural gas. Most of the methane released is converted to carbon dioxide and some is absorbed by soil bacteria. Methane is around 20 times as potent as carbon dioxide as a greenhouse gas and is responsible for around 15 % of the greenhouse gas effect (Fig. 2.97). CFCs are more potent (10,000 - 30,000 times more than carbon dioxide), however occur in smaller amounts in the atmosphere and trap less heat. CFCs are used as propellants in spray cans and as refrigerants in air-conditioners and refrigerators. These compounds are potent greenhouse gases, but also destroy the earth's protective ozone layer. Ozone is also a greenhouse gas and therefore, its destruction serves to reduce the greenhouse effect. Ozone shields the earth from ultraviolet radiation. Increased ultraviolet light results in increased incidences of skin cancer and damages the photosynthetic apparatus in plants.

Sophisticated computer simulation models show that the global mean temperature is likely to rise by between 1.5 and 5.9° C by 2100. The land is likely to warm more than the ocean and northern high latitudes will warm the most. Global precipitation is likely to increase by about 2 % per degree of warming. However, regional patterns are complicated and not well understood. One major consequence of climate change will be continuing sea level rise, and accompanying increase in the occurrence of extreme

storm surges, changing rainfall patterns are likely to increase soil environment and subsidence and profoundly affect water availability and quality.

Drier soils will change the type and yield of crops, increasing the risk of famine in some areas! Health is likely to be affected, both directly (more summer heat stress but fewer cold deaths in winter) and indirectly (through changes in diseases such as increased food poisoning). Infectious diseases such as malaria are expected to spread. Sea level rise is one of the most certain elements of climate change. Many of the cities are close to coastal areas and will be highly vulnerable to rising sea-level. A rise of 20 cm would threaten coastal settlements, wetlands and low lands.

International Agreements

On the basis of the Vienna Convention, the Montreal Protocol was developed on substances that deplete the ozone layer. This was signed by 185 countries till date. The protocol called for the parties to phase down the use of CFCs, Halons and other man-made ODCs. The protocol includes trade sanctions to achieve the stated goals of a treaty and also offers major incentives for non-signatory nations to sign the agreement. Table 2.24 summarizes the Montreal protocol control measures and the target dates for phasing out the ozone depleting substances.

Table 2.24: Summary of Montreal protocol control measures.

Ozone depleting substances	Developed countries	Developing countries
Chlorofluorocarbons (CFCs)	Phased out end of 1995	Total phase out by 2010
Halons	Phased out end of 1993	Total phase out by 2010
Carbon tetrachloride	Phased out end of 1995	Total phase out by 2010
Methyl chloroform	Phased out end of 1995	Total phase out by 2015
Hydrochlorofluorocarbons (HCFCs)	Freeze from beginning of 1996 35% reduction by 2004 65% reduction by 2010 90% reduction by 2015	Freeze in 2016 In 2015 at base level Total phase out by 2040
Hydrobromofluorocarbons (HBFCs)	Total phase out by 2020 Phased out end of 1995	Phased out end of 1995
Methyl bromide	Freeze in 1995 at 1991 base level 25% reduction by 1999 50% reduction by 2001 79% reduction by 2000 Total phase out by 2005	Freeze in 2002 at average 1995-1998 at base level 20 % reduction by 2005 Total phase out by 2015

Several studies using prediction models have made important findings on the output of greenhouse gases as follows:

- The global mean temperatures around 2050 will be higher than at any time in the last 150 years.
- Within the next century, the rate of change in the global mean temperature will be larger than any seen in the last 10,000 years.
- Will lead to sea level rise caused by the decreases in the density of sea water due to melting of glaciers, flooding of small islands, coastal flood plains and subsiding coastal cities.
- Increased evaporation may cause significant decreases in the levels of important lakes and reservoirs.
- Global warming will be neither temporarily nor spatially uniform. Warming will be severe over land than sea.
- Tropospheric warming will be accompanied by stratospheric cooling.

Impacts of Global Warming on Climate

With the use of computers, scientists have predicted that the mean rise in global temperature rises by 2° C from 1990 to 2100. The warmest years were recorded in the order of 1988 > 1987 > 1983 > 1981 > 1986. In 1990 the phenomenon of El Nino was recorded when the global temperature was the warmest. This is based on the phenomenon of Southern Oscillation which is related to variations in rainfall and sea surface temperatures in equatorial eastern Pacific region. The irregular occurrence of warmer than usual water off the Peruvian coasts is called El Nino. Under normal conditions, the winds and ocean currents of the tropical Pacific travel from east to west producing a large reservoir of warm water around Indonesia. El Nino is a reversal of winds and ocean currents across the Pacific which usually lasts for a year or two and occurs typically every four to five years. Recent El Nino Southern Oscillation (ENSO) events occurred in 1972-73, 1976-77, 1982-83, 1992-93 and 1997-98. The impact of these ENSO events is of global significance with droughts in Southern Africa, Eastern Australia and Brazil, forest fires in Indonesia, storms and wet weather along the American coast from Alaska to Peru and warmer winters in the

American mid-west in 1982-83, ENSO was strongest and induced droughts in Australia, Philippines, Southern India and Southern Africa. It has been predicted that

El Nino events could become more intense with global warming. It is said that warmer the oceans, the greater the potential for El Nino events to develop. It has been shown that the average temperature in Canadian lakes has increased and the extent of sea ice surrounding Antarctica and the Arctic Sea has declined and glaciers throughout the world are receding. In addition to the changes in mean climate figures, global warming may also result in a change in the frequency of extreme events. Some parts of the world are predicted to become drier, others wetter. The impact of even small changes in temperature, total rainfall and the timing of rainfall may be considerable by affecting reproduction, species composition and fire frequency. Species that migrate between the temperate regions and the tropics will have to accommodate the changes in climate across their migratory ranges. This will affect the species that live in the extremities of their current range. Climate change will contribute to rising sea levels and threaten the existence of some small island states and many of the world's great cities. Tropical diseases could become endemic in temperate countries due to temperature rise.

Environmental Impacts of Climate Change

The dramatic impact of global warming is the rise in mean sea level. This results as a result of thermal expansion as water temperature rises. The upper limit of sea level rise is said to be around 1 m which would flood 17% of Bangladesh and 12-15 % of arable land in Egypt and almost entirely destroy the land nations of the Maldives and Kiribati. Coastal flooding will be accompanied by coastline erosion and salinisation of coastal soils and ground water. Changes in sea level will affect the distribution of littoral vegetation (mangroves and sea grasses). Coral species may be affected due to rise in water level. Abnormal high water temperatures affect coral growth through the death of the coral zooanthellae and hence coral growth in warmer areas will be slower.

Climate change can significantly affect agriculture, altering both production and the current range, where particular crops can be grown. In temperate regions, elevated temperature and extended growing season, plant production may increase as a result of global warm in tropical regions, plant production may decline through increased heat and drought stress. The organisms living at extremes of environment will be affected. The vegetation in temperate zones will be more affected than that in the

tropical zones because the increase in temperature is predicted to be greater at temperate latitudes than at those near the equator. Global warming will also result in the expansion of the geographic range of tropical diseases such as malaria, yellow fever and dengue fever. Some tolerant species which have the dispersal capability to keep up with climate change will enter new favourable climatic regime and this will also be facilitated by a smooth, gradual change in climate. Sudden climate change would affect some species which are unable to respond fast enough and may face extirpation or even extinction. In crocodiles and turtles, sex is determined by the temperature at which eggs are incubated. A rise of 2⁰C in sand temperature would result in all green and leatherback turtle hatchlings becoming females. This will have impacts on the population dynamics of these species.

Global Carbon Balance

Nearly 8 billion tonnes of carbon enter the atmosphere each year from fossil fuel burning and as a result of deforestation. Nearly half of this amount remains in the atmosphere, nearly 2 billion tonnes absorbed by the oceans and 0.5 billion tonnes absorbed by northern forests and the fate of balance 1.5 billion tonnes is unclear. The climate change treaty signed by 174 nations in Kyoto, Japan in 1997 agreed that developed countries must produce an assessment of green house gas emissions from all sources and have agreed to reduce these emissions by a certain amount or to increase the amount of carbon stored in forests through afforestation. Countries could trade in carbon credits, e.g. Costa Rica sells carbon credits to countries that have high rates of carbon emissions and Costa Rica guarantee to plant and maintain forests which will provide the sink for the carbon produced by the purchaser of these carbon credits.

Reduction of Greenhouse Gas Emissions

In general, the largest producers of greenhouse gases are those countries with the biggest use of fossil fuels and the populous countries of China and India. Global emission of carbon from fossil fuel burning has increased over the years. Greenhouse gas emissions have reduced a little in developed nations through gains in fuel efficiency; however out rates continue to increase in newly industrialized nations of

South-East Asia and Eastern Europe. While the carbon output in the United States of America grew by 8 % between 1990 and 1996, emissions in Brazil, India and

Indonesia grew by 20 %, 28 % and 40 % respectively over the same period. China is the largest source for carbon emissions in 21st century. Deforestation releases the carbon fixed in the tree biomass to the atmosphere either directly when the wood is burnt or more slowly through decomposition. Deforestation also enhances soil erosion and the humus in the soil is more readily oxidized releasing the carbon to the atmosphere. Brazil and Indonesia are the largest producers of carbon from land-use changes. Reducing fossil fuel use is one way to reduce green house gas emissions. Carbon emissions are related to the growth in human population, economic and technological development. This is given by the formula.

$$\text{Carbon emissions (C)} = P \times A \times T$$

Where P is the size of the human population, A is a measure of the affluence of that human population and can be expressed in terms of the amount of energy used per capita and T assesses the technology or amount of carbon released per unit of energy.

Forests have been continuously destroyed over much of Europe and North America and tropical areas at the rate of 1-2 % per year. We utilize 35 % of the land area to produce crops and raise animals. A human intervention has immense impact on the environment. Nearly 40 % of primary produce is being utilized by human population. This has resulted in the depletion of oceans, draining of wetlands and pollution of water resources. The wastes generated accumulate in landfills, soils, rivers, lakes and the oceans and many species have been affected by the variety of introduced changes.

ACID RAINS

Smokestacks of power plants and a number of industries around the world spew out the basic ingredients of acid-rain, namely, sulfur dioxide (SO₂) and nitrogen oxides (NO_x). Human activities, such as coal burning and use of internal combustion engine and other combustion processes produce sulfur dioxide and oxides of nitrogen (Fig. 2.98). Oxidizing agents such as ozone, hydroxyl ions or hydrogen peroxide, along with water, are necessary to convert the sulfur dioxide or nitrogen oxides to sulfuric acid and nitric acid. Various reactive hydrocarbons (HC) encourage the production of oxidizing agents. The acid forming agents are classified as wet or dry. Wet reactions occur in the atmosphere and come to the earth as some form of precipitation: acid rain. In time, these oxides combine with water vapor in the atmosphere and return to the earth's surface in the form of acid rain. This has been taking place for a number of years, but little has been done about it. The problem is becoming graver with time.

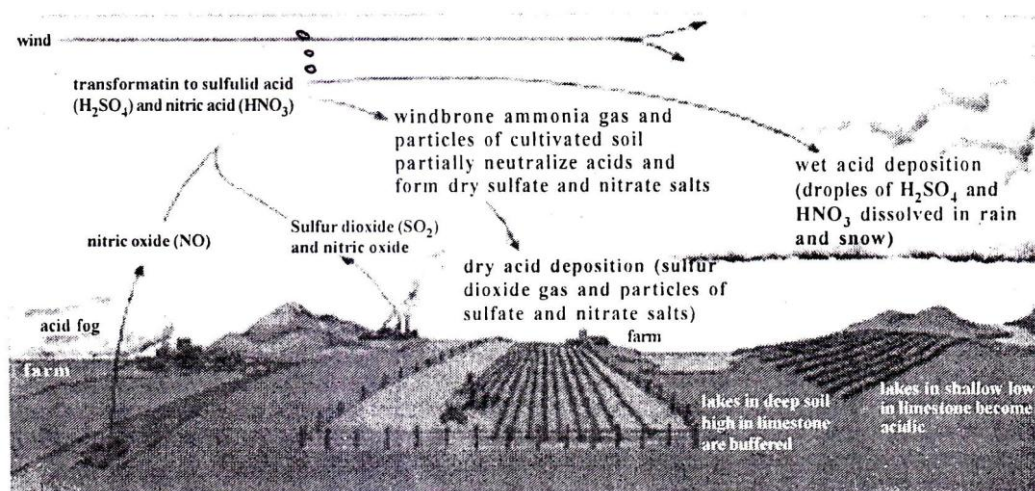


Figure 2.98: Human activities and acid rain.

This problem of acid deposition is primarily related to the use of high-sulphur coal and oil, the combustion of which produces considerable quantities of SO_x , and nitrogen oxides (NO_x). Acid deposition is the accumulation of potential acid-forming particles on the surface. Acids also result from natural causes, such as vegetation, volcanoes, and lightning, and from amongst natural sources of acid rain, other than volcanoes and geysers which contribute SO_x and NO_x , the most significant is formic acid. Biomass burning due to forest fires causes emissions of formic acid ($HCOOH$) and formaldehyde gets oxidized to formic acid in the atmosphere. Millions of metric tons of sulphuric acid and nitric acid fall in rain on earth each year, principally on the United States, Canada and Europe. The concentrations of these acids are too weak to cause burns, but they do produce other severe effects.

Thus acidification results from emission and deposition of airborne primary pollutants such as sulphur dioxide, nitrogen oxides, volatile organic compounds and particulates given off by power plants, industry and vehicles and of ammonia produced by agriculture. Reactions among these can produce secondary pollutants such as nitrogen oxide, formed mainly by a reaction between nitric oxide and oxygen. These primary and secondary pollutants can be converted in the atmosphere, on the surface of buildings, inside plants and animals, or below ground, into sulphuric acid and nitric acids.

Depending on a variety of biological, chemical, and meteorological factors, soils, forests, lakes, rivers, animals, plants and buildings are susceptible in varying degrees

to the effects of these pollutants, acting alone or in conjunction with other factors. Several of these pollutants also contribute to other environmental problems: nitrogen oxides and VOCs are a factor in the creation of ground-level ozone which is harmful to human health, and in threats to the ozone layers; and NO_x also contributes to eutrophication -the harmful build up of nutrients and organic materials in lakes. The mechanism of formation of atmospheric sulphuric acid and nitric acid droplets are shown in Fig. 2.99 & 2.100.

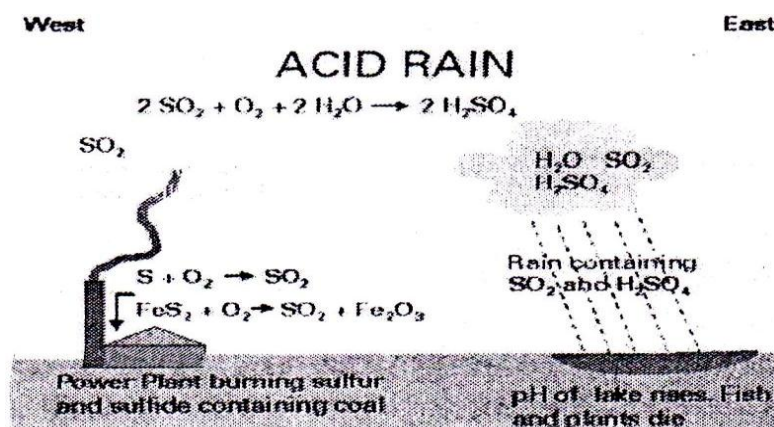


Figure 2.99.

The still and stable air over many south east Asian cities creates ideal conditions for the build-up of pollutants from road traffic and industry, the density of which is increasing rapidly as these countries industrialize more and more. Nitrogen oxides and carbon particles produced by automobiles and other motor vehicles are so plentiful in some large cities that the air is colored by them. Nitrogen oxides also enter the air from the breakdown of agricultural fertilizers. These eventually form nitric acid in moist air. Like sulphuric acid, nitric acid corrodes many metals, and strong concentrations of nitric acid can cause burns on skin.

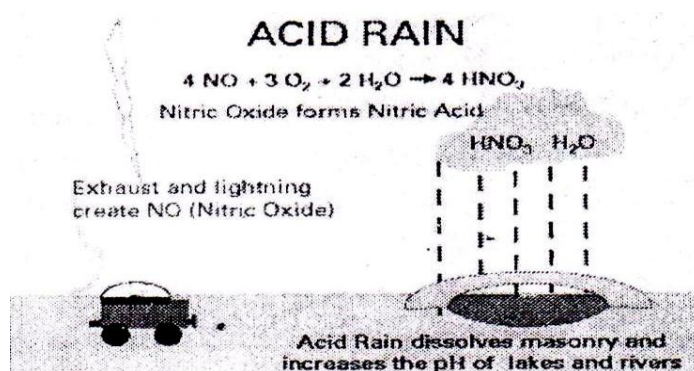


Figure 2.100.

1. Ammonia

The third primary pollutant in acidification - to which more attention has been paid only since the late 1980s is ammonia. A by-product of animal manure and fertilizer use, ammonia is mainly a problem in regions using intensive agricultural techniques, notably Western Europe. It contributes to acidification by causing cloud water to become more alkaline, thereby increasing the rate of conversion of SO_2 and NO_x to acids. It can also be oxidized by microbial activity in soil to form nitric acid. The acids in the atmosphere react with ammonia other cations forming sulphates and nitrates which fall onto the surface of the earth in the form of particulates. It is estimated that about 40%- of the particles present in the atmosphere over the north Polar Regions are in the form of sulphates.

Calculating emissions is difficult, since they depend on a variety of different factors, such as the nitrogen content of animal feed and the conditions under which wastes are spread. Nevertheless, UN figures suggest that Europe produces about 800,000 tonnes of NH_3 emissions every year, hence it is now being taken more seriously by western European policy makers as an element in the broader problem of acidification. This contrasts with the situation in the United States, where ammonia has so far drawn little attention.

2. Volatile Organic Compounds

This is a collective term for a wide range of compounds containing carbon, but is usually taken to include hydrocarbons, oxygenates such as alcohol, and methane, although there is some debate about how to define them. The UN defines VOCs as "all organic compounds of anthropogenic nature other than methane that are capable of producing photochemical oxidants by reaction with nitrogen oxides in sunlight", but a definition as broad as this makes it difficult to measure emissions and to identify trends in the production of VOCs. They come mainly from road vehicles, the chemical and petroleum industries, paints and glues and the use of solvents in industrial processes.

In some situations hydrochloric acid vapour and mists of other acids such as phosphoric acid may also be present responsible for acid rain. These gases dissolve in falling rain making it more acidic than natural rain. Acid fog is formed when chemicals pollutants are dissolved in very moist air. This causes changes in the pH of the air in the same way that acid rain changes the pH of the soil or the water in lakes and rivers. Acid rain

causes serious health problems and brings death to lakes and rivers, along with destruction to structures and the ecosystem as a whole.

Table 2.25: Global SO₂, NO_x, and VOC emissions, 1980-90 (in '000 tonnes)

	1980	1985	1990	1993	% change 1980-90
Sulphur Dioxide					
Europe	40,176	33517	29464	25440	-27
US	23,400	21100	21000	20621(92)	-10
Canada	4643	3704	3800	3042	-18
Russia	12123	11945	10166	-	-16
Other Former USSR	7928	7801	6322	-	-20
China	13370	17260	19990	-	+50
India	2010	2830	3070	-	+53
Japan	1600	1180	1140	-	-29
Other Asia	8525	7599	7372	-	-13
Total	113775	106859	102424	-	+9
Nitrogen Dioxide					
Europe	17584	17226	17550	17757	-0.2
US	20400	19800	19800	18217	-j
Canada	1959	1959	1943	1952	-0.8
Russia	2578	2498	3050	-	+18
Other Former USSR	2908	3172	3679	-	-26
China	4910	6360	7370	-	+50
India	1670	2310	2560	-	+53
Japan	2130	1950	1940	-	-9
Other Asia	3842	4386	4884	-	+27
Total	57981	59661	62776	-	+8
Volatile Organic Compounds					
Europe	-	6639	10411	-	-
US	22300	20000	18500	-	-17
Canada	2099	2315	2256	-	+7
European Russia.	-	6639	10411	-	-
Total	-	-	45160	-	-

3. Acid Rain - Global Scenario

Because fossil fuel consumption is highest in the industrial centres of Europe and North America, the emission of air pollutants is also greatest in these areas, and acidification has - at least until recently-been essentially a Northern hemisphere problem . In industrialized countries, the major sources of SO₂ (Table 2.25) are coal or oil fired power stations, industries that use fossil fuels, metal smelters, oil refineries and heating installations, although the relative contributions of different sources varies from place to place. While power stations account for two-thirds of SO₂ emissions in the

United States and 58 % of emissions in the European Union, they account for only 22 % of emissions in Canada, where smelters play a much bigger role.

Table 2.26: The ten biggest point sources of sulphur in Europe.

Name	Facility	Country	Annual emissions
Maritsa east	Power Station	Bulgaria	350000
Afsin-Elbistan	Power Station	Turkey	288000.
Puentes	Power Station	Spain	271000
Montsegorsk	Smelter	Russia	212000
Nikel	Smelter	Russia	211000
Teruel	Power Statfon	Spain	183000
Belchatow	Power Station	Poland	168000
Janschewalde	Power Station	Germany	157000
Boxberg	Power Station	Germany	149000
Prunerov	Power Station	Czech Republic	137000
Total			2126000

A study on Europe revealed (Table 2.26) that the worst sulphur pollution comes from relatively small number of point sources, mainly power stations. The 100 biggest emitters (one third of them in western Europe) between them accounted for 42% of European SO₂ emissions, with the ten biggest alone accounting for more than two million tonnes of SO₂ emissions each year. However, the balance is changing as industrialized states reduce their consumption and as fossil fuel consumption increases in newly industrializing countries (NICs) such as China, India, Brazil, and South Africa. China for example, relies on fossil fuels for nearly 98 % of its energy needs, and saw its coal consumption grow by 178 % between 1973 and 1993. In the same period, coal consumption grew by 101 % in South Africa, by 193 % in India, by 322 % in Brazil and by nearly 650 % in Taiwan.

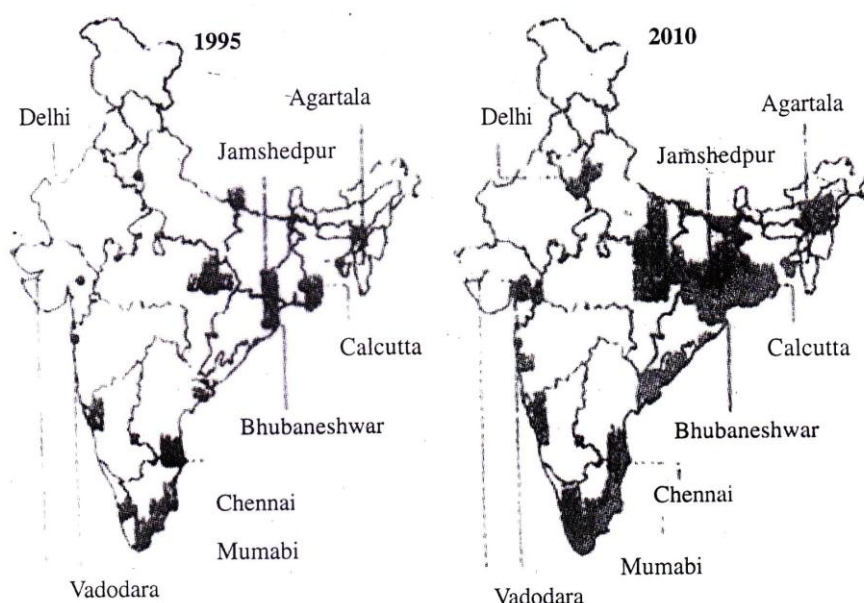


Figure 2.101: Areas at risk (Incidence of acid rain in 1995 and the increase of area affected in India by 2010.

In Asia as well, the situation is about to reach alarming proportions. Given the fact that the two most populous countries of the world - China and India - have substantial reserves of coal, the continent remains a region where coal use is expected to grow substantially in the coming decades. Fortunately, for India, the sulphur content of coal found in the country is consistently low. But this is not the case with China. There are several sources of anthropogenic sulphur dioxide emissions, including power generation and transport and even household energy use for cooking, using a variety of fuels. In fact, the Rains-Asia model indicates the possibility of a 315% increase in SO_2 emissions over present levels in India by the year 2020.

The problem is very real in the sub-continent. India enjoys the dubious distinction of releasing the maximum pollutants in to the atmosphere after China. Total sulphur emissions are expected to rise from 4,400 kilotonnes (kt) in 1990 to 6,500 kt in 2000, 10,900 kt in 2010 and 18,500 in 2020. The areas of risk in India exposed to acid rain in 1995 and predicted increases in area by 2010 are given in Fig. 2.101.

4. Impact of Acid Rain

Damage to Aquatic- Ecosystem

The effects of acid rain on ecosystems are often more difficult to quantify. Intense sulfur dioxide pollution around smelters is known to cause the death of many kinds of trees

and other vegetation. But this is an extreme case and may not be directly comparable to less intense acid rain. However, in many parts of the world, acid rain is suspected of causing the death of many forests and reducing the vigor and rate of growth of others. In central Europe, many forests have declined significantly, resulting in the death of about 6 million hectares of trees. Northeastern North America has also seen significant tree death and reduction in vigor, particularly at higher elevations. Some areas have had 50 % mortality of red spruce trees.

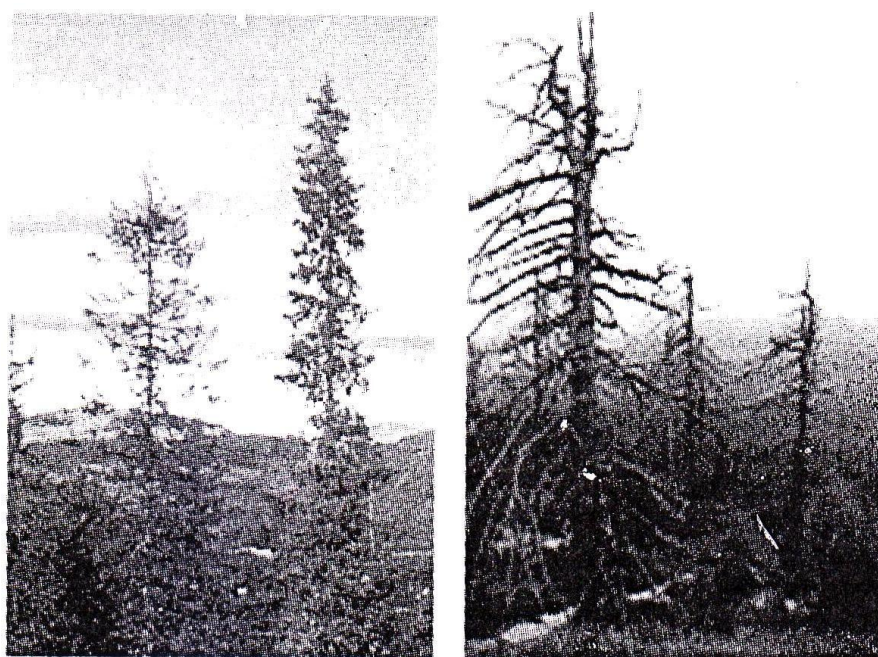


Figure 2.102.

A clear link between the decline of the forests and acid rain were established. Molecules like sulfur dioxide and ozone are known sources of air pollution and cause direct damage to plants. Forest damage due to acid rain was found to be extensive in Europe. In Germany 75% of the forests were found to be affected in 1983. Fig. 2.102.

Freshwater Aquatic Ecosystem

The effect of acid rain on the chemistry of surface water is determined by the geochemistry, geomorphology and hydrodynamics of the watershed and the waterbody. These factors determine the capacity of water to neutralize acids and absorb or release metals (Fig. 2.103).

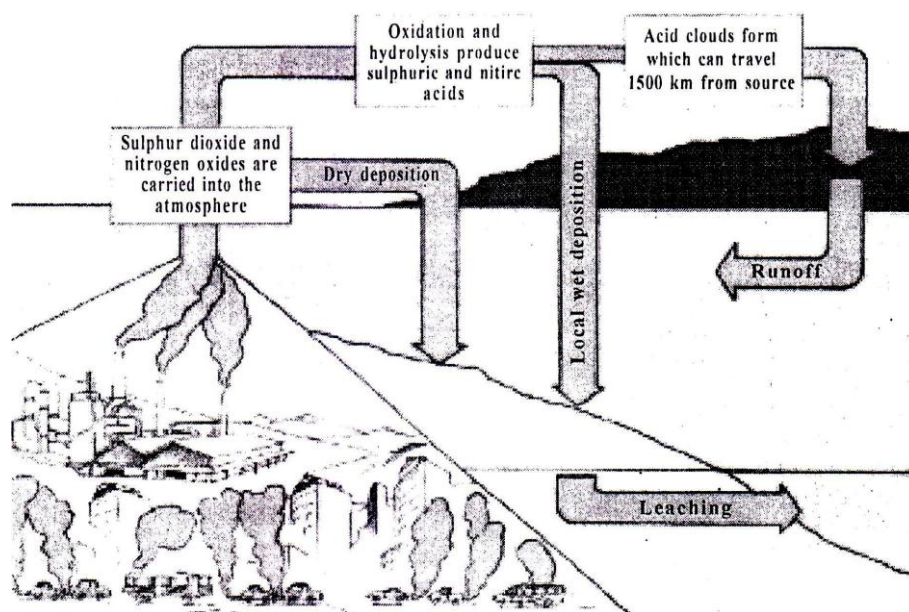


Figure 2.103: Acid rain and the Aquatic environment.

In natural water body's metals such as zinc, cadmium, nickel, manganese, chromium, copper and mercury form complexes with naturally occurring ligands such as fulvic acids and phosphates. In the complexed form the bioavailability, and consequently the toxicity, of these metals is greatly reduced pH also effects the mobility of the metals, present in sediments, towards the overlaying water through direct dissolution; the solubility of most metal compounds in water gets lower as the pH is increased. When a lake gets acidified the metal-fulvic acid complexes are destabilized releasing metal ions. Reduction in pH also increases mobility of the metal compounds from the sediments to the overlaying water. The combined effect of these two phenomena is increase in the concentration of the metals in water. Acidified lakes are most likely to be found in regions where bed rock and soil are low in naturally occurring acid neutralizing materials (Table 2.27).

Table 2.27: Characteristics of naturally acidic lakes and anthropogenically acidified natural lakes.

Naturally Acidic lakes	Anthropogenically acidified lakes
Brown to yellow colour caused by humic substances (peat, tannins etc.)	Very clear water caused by reduced primary productivity (i.e. lack of phytoplankton), precipitation of organic matter by aluminium, and dissolution of iron and manganese colloids. Inorganic acids (particularly sulfuric and nitric acids) predominate in these lakes.
Concentrations of dissolved organic carbon are high while transparency is low	Dissolved organic carbon concentrations are low, (seldom exceeding a few milligrams per liter) where as the transparency is high.
Low pH (below 5) but well buffered; these lakes generally have a greater acid neutralizing capacity (by organic and inorganic buffers and actions of micro organisms). This suggests that brown-water lakes would be less sensitive to the acidifying effects of precipitation.	Poorly buffered: once the alkalinity is exhausted, the pH decreases rapidly, giving little time for the species to adapt.
Abound with aquatic life	Some of the more sensitive taxa, such as blue-green algae, some bacteria, snails, mussels, crustaceans, mayflies, and fish are either reduced or eliminated.
Presence of humic, fulvic, and other organic acids keeps availability of toxic metals in check.	No such cushion available.

Table 2.28: Effects of decreasing pH on aquatic Organisms.

pH	Effect
8.0-6.0	Decreases of less than one-half of a pH unit in the range of 8.0 to 6.0 are likely to alter the biotic composition of lakes and streams to some degree in the long run. However, the significance of these slight changes is not great. Decreases of one-half to one pH unit (a threefold to tenfold increase in acidity) may detectably alter community composition. Some species may be eliminated.
6.0-5.5	Decreasing pH from 6.0 to 5.5 will reduce the number of species in lakes and streams. Among remaining species, significant alterations in the ability to withstand stress may occur. Reproduction of some salamander species is impaired.
5.5-5.0	Below pH 5.5, number and diversity of species will be reduced, reproduction is impaired and many species will be eliminated. Crustaceans, zooplankton, phytoplankton, molluscs, amphipods, most mayfly species, and many stone fly species will begin to be eliminated. In contrast, several invertebrate species tolerant to low pH will become abundant. Overall, invertebrate biomass will be greatly reduced. Certain higher aquatic plants will be eliminated.
5.0-4.5 4.5 & below	Below pH 5.0, decomposition of organic detritus will be impaired severely. Most fish species will be eliminated. In addition to exacerbation of the above changes, many forms of algae will not survive at a pH of less than 4.5

By 1970s in Adirondack Mountains more than 50% of lakes > 600 meters had $\text{pH} < 5$, 90% lakes contained no fish. By 1990s in Sweden 14,000 lakes unable to support lake organisms sensitive to acidic conditions and 2,200 lakes nearly lifeless. In regions where limestone is abundant, acid precipitation gets neutralized easily. Acidification causes adverse effects on all trophic levels of aquatic biota in surface water, from decomposers to fish and amphibians. As lakes become acidified the diversity of phytoplankton species decline due to stresses on acid-sensitive organisms. Molluscs, crustaceans, ephemeroptera and plecoptera appear to be highly sensitive to acidification. Invertebrates in acidic lakes may accumulate toxic trace elements that could then be passed on to vertebrates in the food web. The effect of acidification on aquatic habitat is shown in Fig. 2.104.

Effect of Acidity on Materials: The rate of materials carried on material is effected by three factors namely

- (a) The relative reactivity of the material to acidity: stone and masonry (Fig. 2.105) that contain calcium carbonate or calcium sulphate are particularly susceptible. The pigments in paint can make paintwork susceptible, and humidity encourages metal corrosion.

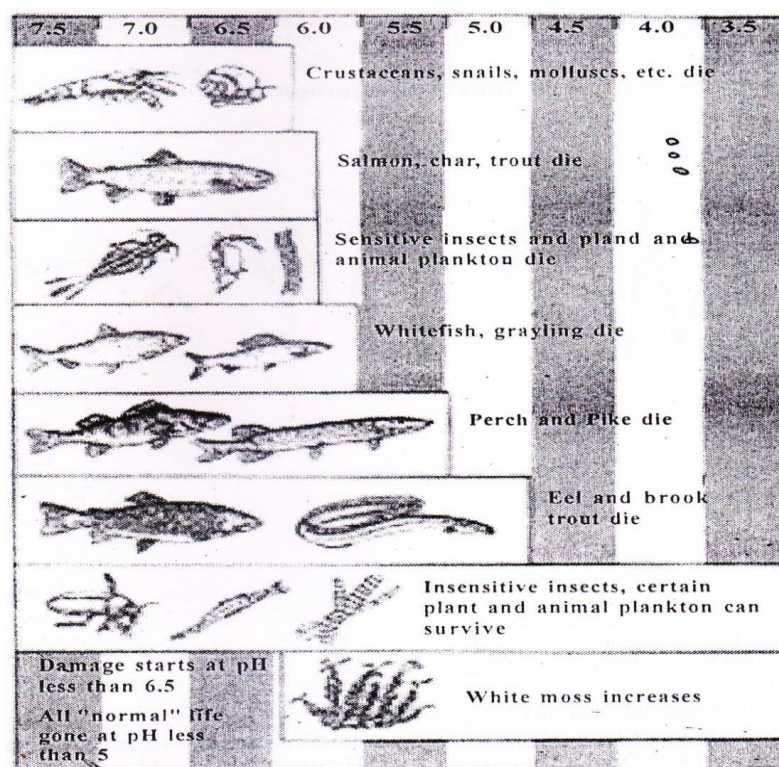


Figure 2.104: Effect of water acidity on aquatic organisms.

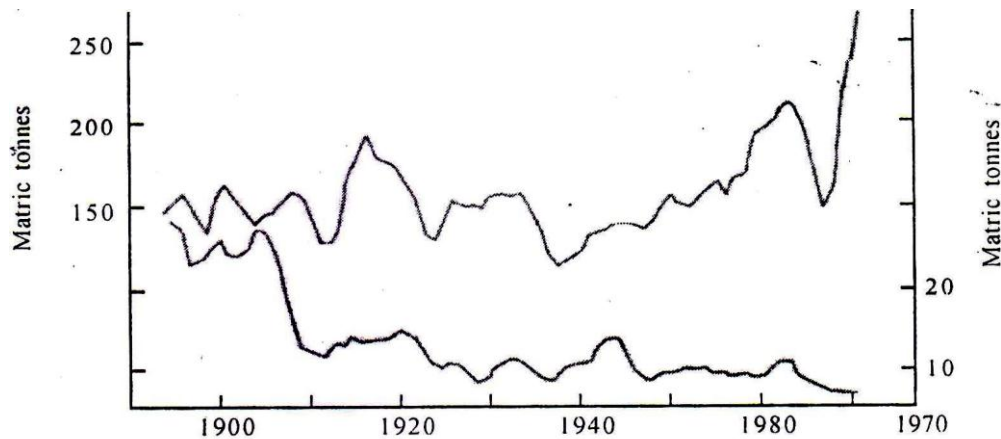


Figure 2.105 a: Effect of water acidity on aquatic organisms.

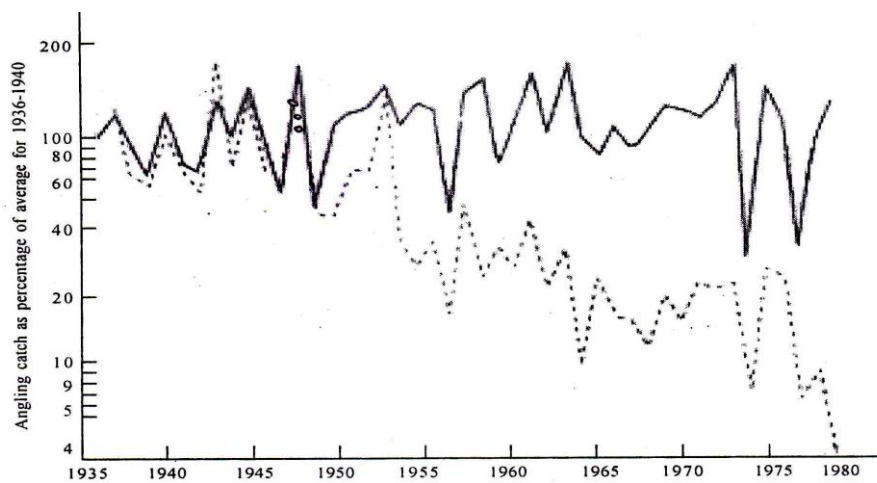


Figure 2.105 b: The catch of Atlantic salmon by sport fishing in Nova Scotia.

Rivers. The data were standardized to facilitate the comparison of acidic and less acidic rivers (-) Mean for 12 rivers with $\text{pH} > 5.0$ (....) mean for 10 rivers with $\text{pH} < 5.0$ (1980).

- Meteorological conditions and physical force of the delivery of pollutants: humidity, air temperature, wind speed, and the intensity, duration and amount of rainfall are all important. Experiments have found that the deposition of SO_2 to marble and limestone increases exponentially with humidity, giving cause for particular concern for buildings in humid tropical and sub-tropical regions.
- The physical location and shape of the stone: the erosion of urban buildings therefore, may be worse at street level because of the greater concentration of pollutants, and stone carved into complex shapes tends to erode more quickly than flat, vertical stone because it retains pollutants longer.

Table 2.29: Acid rain damage to materials.

Materials	Type of impact pollutants	Principal air pollutants	Other environmental factors	Mitigation measures
Metals	Corrosion tarnishing	Sulfur oxides and other acid gases	Moisture, aerosol, particulate matter	Surface plating or coating replacement material, removal to control environment.
Building stone	Surface erosion soiling, black crust formation	Sulfur oxides and other gases	Mechanical erosion, particulate moisture, temperature fluctuations, salts vibration CO ₂ , microorganism	Cleaning, impregnation with resins, removal to controlled environment
Ceramics and glass	Surface erosion soiling, black crust formation	Acid gases, especially fluor-ide containing	Moisture	Protective coating, replacement with more resistant material, removal to controlled atmosphere
Paints and organic coatings	Surface erosion, discoloration, soiling	Sulfur dioxides, hydrogen sulfides	Moisture, sunlight, ozone, particulate matter, mechanical erosion, micro-organisms	Repairing, replacement with more resistance material
Paper	Embrittlement discoloration	Sulfur oxides	Moisture, physical wear, acidic materials introduced in manufacture	Synthetic coatings, strong controlled atmosphere deacidification, encapsulation, impregnation with organic polymers.
Photographic materials	Microblemishes	Sulfur oxides	Particulate matter, moisture	Removal to controlled atmosphere
Textile dyes	Fading, colour change	Nitrogen oxides, ozone	Light temperature	Replacement, use of substitute materials, impregnation with polymers.
Leather	Weakening, powdered surface	Sulfur oxides manufacture	Physical wear, residual acids introduced in manufacture	Removal to a controlled atmosphere consolidated with polymers, or replacements.
Rubber	Cracking	Ozone	Sunlight, physical wear	Add antioxidants to formulation, replace with more resistant materials.

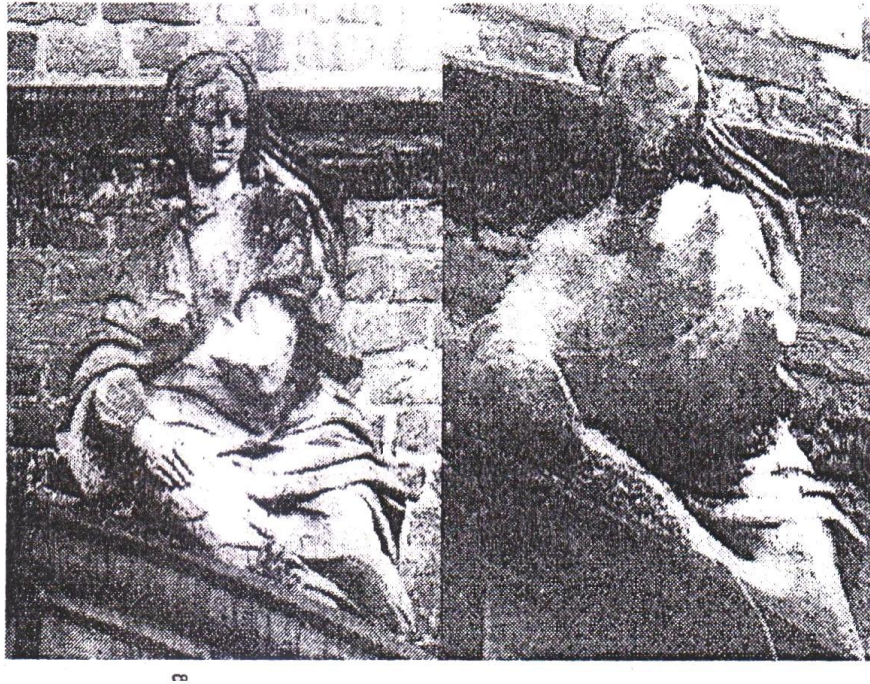


Figure 2.106: Effect of acid rain on monuments.

The effect of principal acid rain causing pollutants on various types of materials and mitigation measures are summarize in Table 2.29. The costs of acid pollution to the world's cultural heritage are causing increasing concern. The end of the cold war and political changes in eastern Europe have drawn new attention to the need to protect the often spectacular architectural heritage of cities such as Crakow in Poland, Prague in the Czech Republic, Bratislava in Slovakia, and Sofia in Bulgaria. There are more than 100,000 stained glass windows in Europe, some of them as much as 1000 years old. There is evidence that much of this glass survived in relatively good condition until the turn of the century, and even survived the second World War, when many stained-glass windows were taken down and stored.

Acid rain affects trees and undergrowth in forests in several ways, causing reduced growth or abnormal growth: The typical growth-decreasing symptoms are:

- a. Discoloration and loss of foliar biomass (yellowing and browning of needles and leaves).
- b. Loss of feeder-root biomass, especially in conifers.
- c. Decreased annual increment (width of growth rings).
- d. Premature senescence (aging) of older needles in confiers.
- e. Increased susceptibility to secondary root and foliar pathogens.

- f. Death of herbaceous vegetation beneath affected trees (all within the drip line from the canopy).
- g. Prodigious production of lichens on affected trees. (All within the drip line from the canopy).
- h. Death of affected trees.

The abnormal growth symptoms are

- a. The active shedding of needles and leaves while still green, with no indication of disease.
- b. Shedding of whole green shoots, especially in spruce.
- c. Formation of stork's nest crown in young white fir.
- d. Altered branching habit and greater than normal production of adventitious (out of place) shoots.
- e. Excessive seed and cone production year after year.
- f. Diseased trees show growth at top, not near bottom with very brittle branches.

In addition water stress symptoms may also be caused:

- a. Altered water balance;
- b. Increased incidence of wet wood disease.

- **Aluminum toxicity:** The natural acidification of fore soils is accelerated by acid, deposition, which mobilizes heavy metals in the soil, notably aluminum. The fine roots of trees are attacked, preventing their roots from taking up enough nutrients or water to survive. Once the roots are damaged the rest of the tree suffers. Support for this theory was offered by the study in the 1980s of sugar maple decline in Ontario, Canada; soils in the region are acidic, and declining maple trees were found to have fine-root systems with higher concentrations than healthy trees. Evidence that forest decline follows dry summers (when soils become more acid and nutrients more scarce) has also lent credence to this theory.

Leaching of Soil Nutrients

Under natural conditions, sulphate is often a major anion in soil water. Faster leaching of sulphate increases the loss of cations like potassium, magnesium and calcium. Similarly, increased input of acidity increases the Exchange between protons and bound potassium, magnesium or calcium ions. This causes the latter to become more available for leaching. Consequently those soils most sensitive to acid rain are

non calcareous sandy soils with a natural pH of around 6 and low in colloidal material through which water percolates easily. However, acid soils with low cation content show the largest loss of nutrient ions even though the pH change is minimal.

Magnesium deficiency: Acid deposition may add nitrogen to soil while leaching out magnesium and calcium from needles and soils. The loss of magnesium may account for the yellowing of spruce needles commonly seen in Germany, since magnesium plays a central role in the structure of the chlorophyll molecule. The loss of magnesium and calcium from the leaves may cause the roots to work overtime to replace these crucial nutrients, and the resulting transfer of these nutrients from the soil increases the hydrogen / calcium ration in the soil, and hence the acidity.

General Stress: Though the concentrations of SO₂, NO_x, oxidants, hydrocarbons and heavy metals are too small individually to cause damage, when combined, however, they, when present together may decrease the production of carbohydrates in plant leaves, thereby decreasing the vitality of roots and leaves. This lowers root production, reducing the ability of trees to withstand attacks from fungi, bacteria, viruses and insects, and making them more susceptible to the stresses of drought, frost and wind.

Excess nutrients or nitrogen: This argues that forest ecosystems have been receiving excessive doses of 16 elements considered essential for plant growth. The increased deposition of nitrogen in particular has encouraged increased growth and excessive demand for nutrients. Nutrient shortages in turn lead to an increased susceptibility to frost and root-disease fungi, changes in root-shoot ratios, and possible nitrogen fixation.

The ammonium hypothesis: Nitrogen in the form of ammonium or nitrate is an important plant nutrient, but most plants have adapted through evolution to exist with very low levels of nitrogen. However, acid deposition may build up nitrogen in soils and plants, leading to oversaturation. If tree growth is accelerated, trees may form large cells that are easily attacked by wind and drought.

Microorganisms

pH determines whether any microbial species can proliferate in a particular environment and the rate at which it can reproduce. Most bacteria and protozoa have

pH optima near neutrality; most fungi prefer an acid environment, most blue green bacteria prefer an alkaline environment.

Wildlife

Acid rain can indirectly affect wildlife by allowing metals bound in soils and sediments to be released into the aquatic environment, where toxic substances may be ingested by wild life, like birds, that feed in such environment. Other indirect effects of acid rain on wildlife are loss or alteration of food and habitat resources. The elimination of fish from a lake, for example may mean that little use of loons or meruansers will occur during the breeding season.

Humans and Buildings

Effects on human health: Fish are not the only organisms that are adversely affected by acid deposition. Humans are vulnerable as well. One of the greatest air pollution disasters the world has known occurred in London in 1952. The killer fog that shrouded the city for 5 days contributed to the death of more than 4,000 people from bronchitis, pneumonia, and heart disease. Although pH measurements of the fog were not recorded at the time, present-day scientists estimate that the fog was a highly diluted sulfuric acid mist with a pH ranging from 1.4 to 1.9! But that was almost four decades ago. According to the Office of Technology Assessment, more than 50,000 premature deaths are caused annually by sulphate-laden air. Acid precursors are the second largest cause of lung disease (after smoking) in the opinion of Dr. Philip J. Landrigan of the Mount Sinai School of Medicine in New York City.

Today more than 40 million people in the United States, or about one in six are drinking water with lead levels above 20ppb - the level considered safe by the EPA. Where did the lead come from? It apparently was leached from galvanized water pipes by the acidic drinking water. Such intake of lead by millions of Americans is cause for considerable concern because medical researchers have shown lead to be one of the factors responsible for high blood pressure and heart attacks in adults and brain damage in children.

There is a wide range of effects on human health. The obvious ones are bad smells, reduced visibility, irritation of the skin, eyes and the respirator)' tract. Some direct effects include chronic bronchitis, pulmonary emphysema and cancer. Some indirect

effects include food poisoning via drinking water and food. Increase in levels of toxic heavy metals like manganese, copper, cadmium, and aluminium also contribute to the detrimental effects on human health.

Some health experts believe that acid rain may also be indirectly responsible for many cases of Alzheimer's disease. This is a disease of the elderly characterized by degradation of the brain and severe loss of memory. Chemical analysis of the brains of people who died from the disease revealed relatively high levels of aluminum. Some researchers believe that aluminum caused the disease. If so, where did it come from? How did it get into the body? The involvement of acid deposition is strongly suggested.

The Green India 2047 project of TERI has estimated that India is already losing between 11 % and 26 % of agricultural output on account of soil degradation. Acid rain would increase this figure significantly. The prospect of increasing consumption of coal in Asia will add insult to injury.

Control Measures

Most effects of acid rain on fish and wild life resources cannot be directly countered without reducing or eliminating the sources of pollution. However, some measures may be taken locally to counter acidification of streams, soil, and rest of the environment. Some of the measures are:

Buffering: The practice of adding a neutralizing agent to the acidified water to increase the pH is one of the important control measures. Usually lime in the form of calcium oxide and calcium carbonate is used.

Breeding of hatchery fish in acidified waters: This practice replenishes fish population that would otherwise decline, thus helping to maintain an ecological balance within acidified lakes.

Prevention of the emission of excess SO and NO from industries: Laws should be formulated by the Government to regulate the emission. Some measures are

- (a) Decreasing emissions of SO₂ from power stations by burning less fossil fuel, using alternate energy sources like tidal, wind, hydropower etc.
- (b) Using low sulphur fuel.

- (c) Desulphurization
- (d) Decrease in emission of NO_x from power stations
- (e) Modification engines.

Acid rain encompasses both wet and dry acidic depositions that occur near and downwind of areas where major emissions of sulphur dioxide and nitrogen oxides result from burning of fossil fuels (Fig. 2.107). Generally, rainfall is slightly acidic as the water reacts with atmospheric carbon to produce weak carbonic acid. Pure rainfall has a pH of about 5.6.

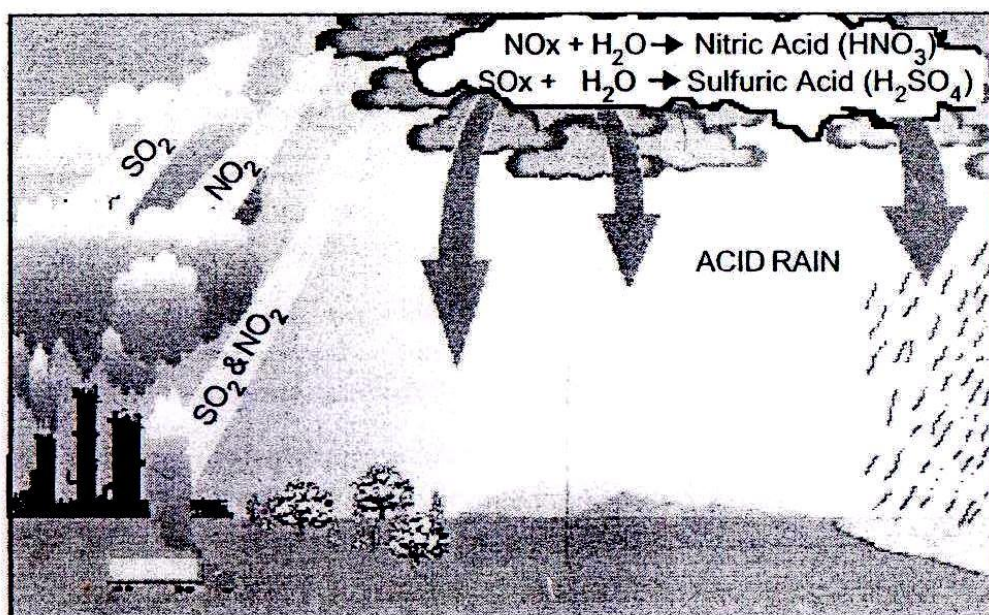
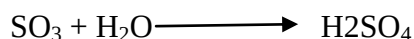
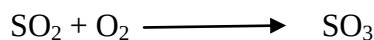


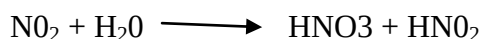
Figure 2.107: Acid rain effect.

Causes of Acid Rain

Sulphur dioxide and nitrogen oxides are transformed by reactions with oxygen and water vapour to form sulphuric and nitric acids. These acids may travel long distances with prevailing winds to be deposited as acid precipitation. Sulphur dioxide is emitted primarily from stationary sources, such as power plants that burn fossil fuels, whereas nitrogen oxides are emitted from both stationary and transport related sources such as automobiles. Coal generally contains between 2-3 % of sulphur and when it is burned, this sulphur is released into the atmosphere. These emissions change into sulphates and nitrates under the influence of sunlight and moisture and get converted into sulphuric acid and nitric acid in the atmosphere.



The oxidation process of aqueous sulphur dioxide by molecular oxygen relies on metal catalyst such as iron and manganese. Sulfur dioxide oxidation is most common in clouds in heavily polluted air where compounds such as ammonia and ozone are in abundance. Some part of the sulphur dioxide is converted into sulphuric acid. Like sulphur dioxide, nitrogen oxides rise in the atmosphere and are oxidized in clouds to form nitric or nitrous acid. These reactions are catalysed in heavily polluted clouds where traces of iron, manganese, ammonia and hydrogen peroxide are present. Nitrogen oxides rise into the atmosphere from automobile exhausts. This reacts with water to form nitric or nitrous acid.



Natural phenomena like volcanic activity, lightning or organic decay also gives rise to an increase in atmospheric pollutants. However, over 90 % of sulphur dioxide emissions and around 95 % of nitrogen oxides released into the air are from manmade sources.

Effects of Acid Rain

Acid deposition influences the environment in several different ways.

1. Effects on Plant Life

Both natural vegetation and crops are affected by acid rain.

- The roots of the plants are damaged by acidic rainfall causing stunted growth or even death.
- Useful microorganisms which release nutrients from decaying organic matter into the soil are killed off resulting in less nutrients being available for the plants.
- Acid rain damages the waxy layer on the leaf surface and makes the plant vulnerable to diseases.
- Plant germination and reproduction are also inhibited by the effects of acid rain.

2. Effects on Soil System

The severity of the impact of acid deposition on vegetation is greatly dependent on the type of soil, the plants grow in. In general, soils that have lime are better at

neutralizing acids than those that are made up of siliceous sand or weathered acidic bedrock. In less buffered soils, vegetation is affected by acid deposition because:

- Increasing acidity results in the leaching of several important plant nutrients including calcium, potassium and magnesium. Reduction in the availability of these nutrients causes a decline in plant growth rate.
- The heavy metal aluminium becomes more mobile in acidified soils. Aluminium can damage roots and interfere with plant uptake of other nutrients such as magnesium and potassium.
- Reduction in soil pH can inhibit the germination of seeds and the growth of young seedlings.
- Many important soil organisms cannot survive in soils below pH 6.0. The death of these organisms can inhibit decomposition and nutrient cycling.
- High concentrations of nitric acid can increase the availability of nitrogen and reduce the availability of other nutrients necessary for plant growth. As a result, the plants become over-fertilized by nitrogen.
- Acid precipitation can cause direct damage to the foliage on plants especially when the precipitation is in the form of fog or cloud water which is up to ten times more acidic than normal rainfall.
- Dry deposition of SO₂ and NO has been found to affect the ability of leaves to retain water when they are under water stress.
- Acidic deposition can leach nutrients from the plant tissues weakening their structure.

3. Effects on Human Health

Acid deposition can influence human health through the following methods:

- Toxic metals such as mercury and aluminium can be released into the environment through the acidification of soils. The toxic metals can then end up in the drinking water, crops, and fish and then ingested by humans through consumption. If ingested in great quantities, these metals can have toxic effects on human health. For example, aluminium is believed to be related to the occurrence of Alzheimer's disease.
- Increased concentrations of sulphur dioxide and oxides of nitrogen have been correlated to increased hospital admissions for respiratory illness.

- Children from areas receiving high amount of acidic pollution show increased frequencies of chest colds, allergies and coughs.

4. *Effects on Aquatic Life*

Acid rain causes a cascade of effects such as:

- Kill or reduce fish population or completely eliminate fish species from water body and decrease biodiversity. For example pH level 4.0-3.5 is lethal to salmonids.
- Reduction in pH and increases aluminium levels which are toxic to fishes.
- Low pH and increased aluminium levels cause chronic stress leading to lower body weight and smaller size thereby reducing their efficiency in competing for food and habitat.
- Change in pH leading to disruption of maintenance of calcium levels of some fishes.
- Input of fertilizer due to land runoff stimulates algal growth.

5. *Effects on Inanimate Objects*

Acid deposition affects a number of buildings and head stones that are constructed with limestone. Paint on cars can react with acid deposition causing fading. Many churches and cathedrals in Europe, Taj Mahal in India, etc., are under attack from the effects of acidic deposition. The Mayan Pyramids, temples, murals and ancient inscriptions are vulnerable to corrosion due to acid deposition. Acid rain causes can affect the carvings and monuments in stones. In limestone, acidic water reacts to form calcium sulfate.



On iron, the acidic water produces an additional proton giving iron a positive charge. When iron reacts with more oxygen, it forms iron oxide (rust).

6. *Measures to Control Acid Rain*

- Controlled burning of fossil fuels to produce electricity.
- Sulphur can also be washed out of smoke by spraying a mixture of water and powdered limestone into the smokestack.
- Cars with catalytic converters can remove toxic pollutants from exhaust gases.

- Alternative sources to produce energy such as hydroelectric and nuclear power can be explored.

UV RADIATION

Relative Penetration of different types of U.V. Radiation from Solar Light

Although largely dependent upon wavelength, certain frequencies of solar radiation penetrate the entire atmosphere and reach the surface of the Earth (Fig. 2.108). Very long radio waves do not get much further down than 50 km above sea level.

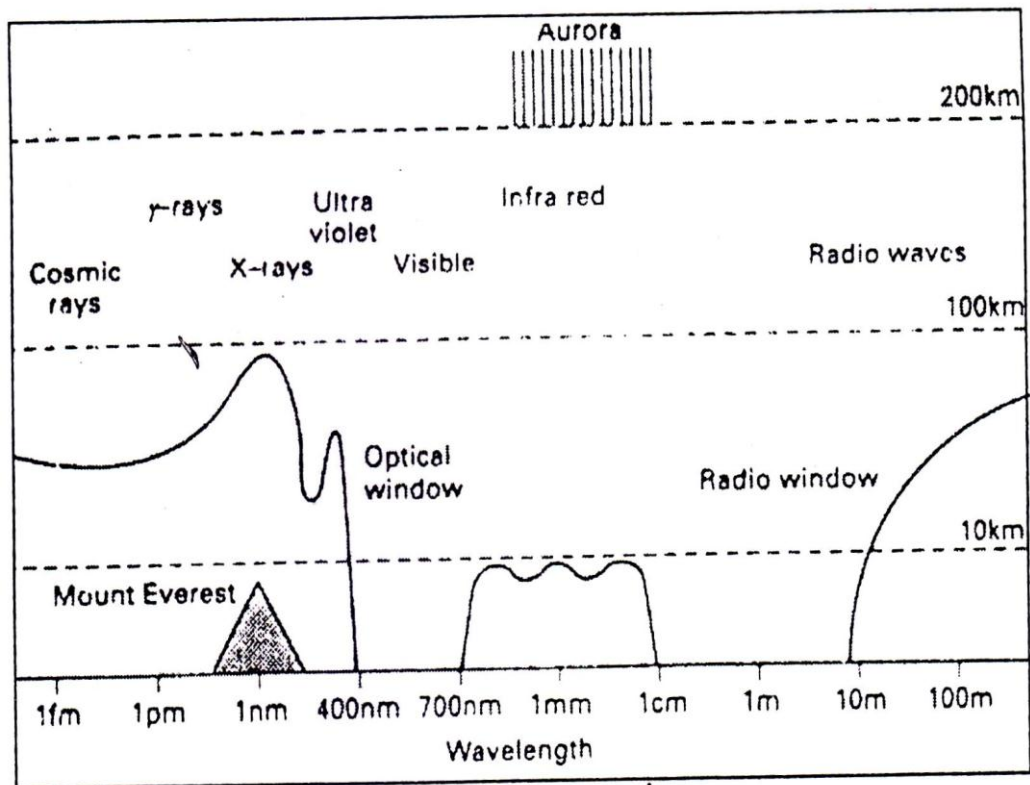


Figure 2.108: The ozone layer in the stratosphere shields the earth from potentially lethal ultraviolet radiation.

Table 2.30: Types of radiation in or near the visible window of the earth's atmosphere.

Wavelength	Type	Remarks
> 13 μm	Long- wave infrared	Between 13 and 17 μm , molecules like CO, and CFCs in the atmosphere absorbs infrared (IR) radiation reflected back from the Earth to provide the blanket or greenhouse effect of global warming.
700 nm -13 μm	Short - wave infrared	13 μm is the upper limit for IR radiation to penetrate to the Earth's surface from the Sun. This IR band heats up surfaces on the planet and also permits reflection of IR of < 13 μm back out into space,
400-700 nm	Visible spectrum	Blue (400 nm) and red (700 nm) components are most important for photosynthesis while vision is most sensitive in green - yellow (500 nm) light.
315 -400 nm	UV-A	Long wave ultraviolet not normally associated with injury to biological systems. Certain photoreceptors of animals and plants operate in this region.
280-315 nm	UV-B	The wavelengths of sunlight likely to cause biological effects. There is some dispute over the upper limit: 315 nm is in the UNEP Report (1991)-others quote 320 nm
<280nm	UV-C	These wavelengths are completely absorbed by the atmosphere before sunlight reaches the surfaces of the Earth. They are more disruptive to biological systems than UV-B and are commonly used for sterilization procedures.

Most incoming infrared radiation is completely absorbed before 10 km up (i.e. just above the height of Mount Everest) but small amounts of short wavelength infrared radiation, all the visible spectrum, and longer wavelength ultraviolet (UV) radiation reach sea level. Shorter wavelength than these (X-rays, γ -rays and most cosmic rays) however, are screened out between 10 to 100 kms above (Fig. 2.109). Conventionally, UV light is subdivided into three categories (Table 2.30) and it is only UV-A and sometimes UV-B that penetrate as far as the surface of the Earth. Fortunately, the biologically more harmful UV-C is filtered out completely.

Atmospheric UV - Penetration Shields

A variety of factors influence the atmospheric penetration of UV-B the solar radiation known to cause most of the adverse effects upon biological systems. The major atmospheric barriers to UV-B penetration are the O_3 molecules in the stratosphere but other environmental factors also affect UV-B fluxes. These include tropospheric pollutants (other than O_3), sunspot activity on the Sun (which may increase stratospheric O_3 levels by nearly 2%) and reflections of UV-B from surfaces, clouds and aerosols. All are highly

variable and account for the fact that long-term records of UV-B fluxes vary and often conflict. These large variations have prevented the establishment of a reliable global model to predict trends in UV-B flux.

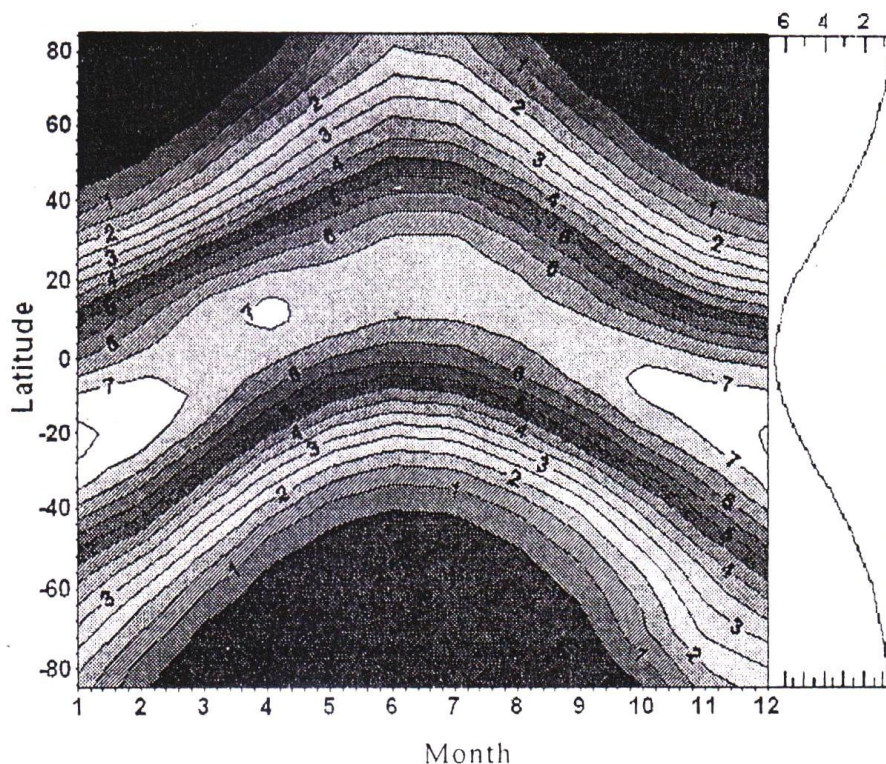


Figure 2.109: Factors affecting UV light penetration in the clear sky. Factors affecting UV in order of decreasing importance are solar elevation, Clouds, Ozone, Aerosols, Sun-Earth distance, Altitude.

Indeed, networks of UV-B monitors usually placed in urban areas for convenience, often record decreases of UV-B due to increases in tropospheric pollutants and cloudiness. The only consistent trends of enhanced fluxes of UV-B due to stratospheric O_3 depletion have been recorded by instruments in Polar Regions.

Effects of Ozone Depletion

The ozone layer reduces the amount of UV-B reaching the earth's surface; and thinning of this layer increase the U.V- B light penetration. Increases in UV-B can be related to adverse effects on human health, terrestrial and aquatic plants, and a degradation of materials. The biological response to increased ultraviolet radiation is often represented by an action spectrum. The relative ability of various wavelengths to cause biological harm can be understood from the action spectrum of DNA molecule

(Fig. 2.110). DNA is highly sensitive to shorter wavelengths of UV, and this part of the light is effectively shielded by ozone. For longer wavelengths in the UV-B portion of the spectrum, the ozone shield is less effective, but DNA is correspondingly less sensitive. However, the intermediate range of wavelengths, (300 to 315 nm) which are less shielded by ozone cause greatest damage to DNA.

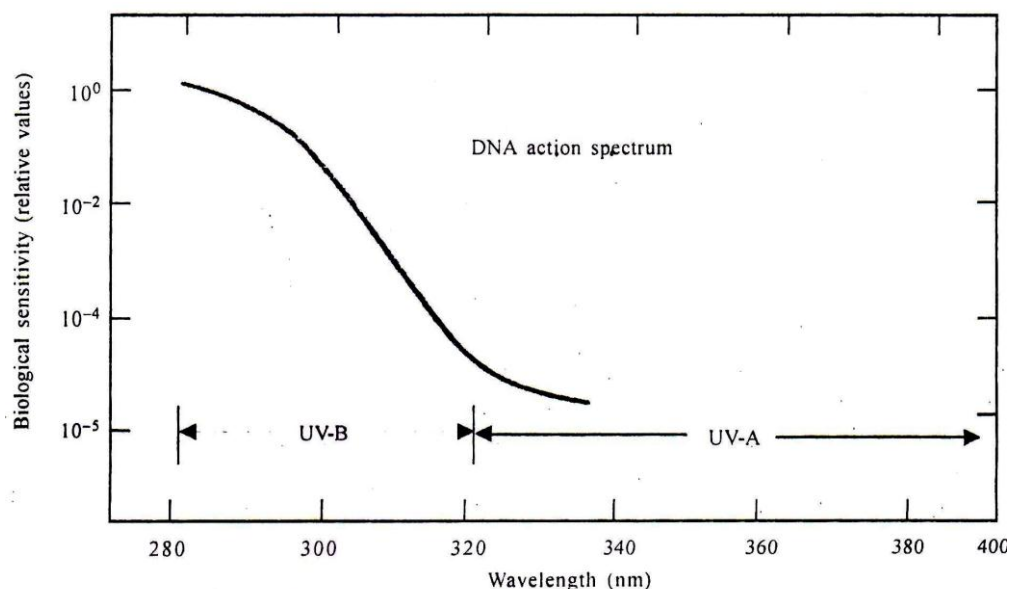


Figure 2.110: Action spectrum for damage to the DNA molecule. The vertical scale is a relative measure of biological sensitivity to radiation at each wavelength.



Figure 2.111: Consequences of ozone depletion.

UV-induced changes in DNA, are found to be responsible for skin cancer which may be either the more common nonmelanoma (basal cell or squamous cell carcinomas), or the much more life threatening malignant melanoma (Fig. 2.111). Non melanoma skin cancer is more prevalent among people with fair complexion, is most likely to

occur on areas of the skin habitually receiving greatest exposure to the sun, and is associated with areas of the world having the greatest amount of sunshine. Though it is rarely fatal, it often causes disfigurement. In the United States, there are about 400 000 new cases of non melanoma each year, with a fatality rate of about 1 percent.

It was observed that at higher latitudes there is less surface level UV-B, and non melanoma rates decrease by roughly a factor of 2 for each 10° increase in latitude. Based on these observations it was predicted that for every 1-percent decrease in ozone, the added UV-B exposure would cause the incidence rate of non melanoma to increase by approximately 2-3 percent. By simply moving 100 miles closer to the equator, UV-B exposure is expected to increase by an amount comparable to what would be expected by a 5% thinning of the ozone layer. The various health problems known to be induced by enhanced UV-B radiation are presented in Table 2.31.

Non melanoma and malignant melanoma skin cancers the relation between malignant melanoma and sunlight is also evident from the fact established that in the case for non melanoma. Malignant melanoma death rates among whites in the United States have been increasing by about 2-3% annually for the past two decades in spite of improved survival rates among those who receive treatment. Ocular damage (cataracts and retinal degeneration) and immune system suppression are some of the other health problems supposed to have relation with U.V. light emission. It is also observed that crops and terrestrial ecosystems would be adversely affected by increasing UV exposure.

UV-B radiation deleteriously affected crop yield and quality. Aquatic ecosystems would be affected as well. Various experiments, for example, have shown that UV-B radiation damages fish, shrimps, and crab larvae, as well as copepods. and plants essential to the marine food web. Scientists have estimated that if the release of CFCs into the atmosphere continues at the present rate, by the year 2025 there will be 1.4 million additional cases of skin cancer worldwide (Fig. 2.112 a). The atmospheric concentration of various chlorine compounds in between 1977 and 1997 are shown in Fig. 2.112 (b). There will also be increased frequency of cataracts-a clouding of the lens of the eye those results in blurred vision. Exposure of laboratory animals to increased UV radiation reduces their ability to fight off bacterial infections it is probable that humans suffer similar effects. Scientists estimate that

the increased UV levels now experienced in the United States will reduce cotton production by 3% and will decrease corn and wheat yields as well.

Table 2.31: Medical conditions known to be induced by enhanced UV-B and their likelihood of increase with further stratospheric O₃ depletion.

Area affected	Condition or agent	Individual types	Radiation Amplification Factor*
Skin	Erythema sunburn		1.7
	Non-melanomatous cancer	Basal cell carcinoma Squamous cell carcinoma Lip cancer Salivary gland cancer Superficial spreading Lentigo maligna (Hutchinson's freckle)	1.4
	Melanoma (cutaneous malignant)	Nodular Unclassified (conditioned worsened)	1.6
	Xeroderma pigmentosa Skin ageing	Elastosis	1.2
Eye	Corneal damage Lens Abnormalities Other effects	Acute Photokeratitis (snow-blindness) Nuclear cataracts Posterior subcapsular Cataracts Cortical cataracts Presbyopia (reading glasses required earlier) Intraocular melanoma	1.1 0.7
Infections	Viruses Protozoa Bacteria Fungi	Measles Chicken pox Herpes simplex HIV-I activation Leishmaniasis Malaria Tuberculosis Leprosy Candidiasis	0.8

Australian television stations now broadcast daily UV levels and warnings for fair skinned Australians - with the world's highest rate of skin cancer - to stay inside during bad spells and to protect themselves from the sun's rays with hats, clothing, and sunscreens when they go out during the daytime - required by law for school children.

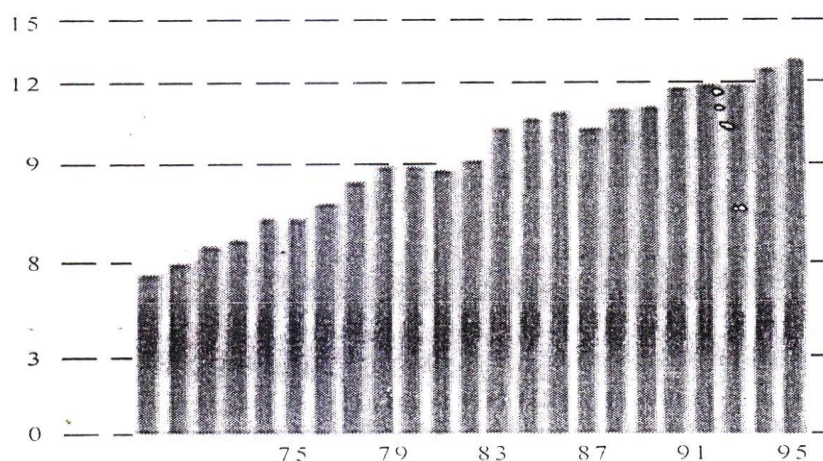


Figure 2.112 a: Red skin cancer data.

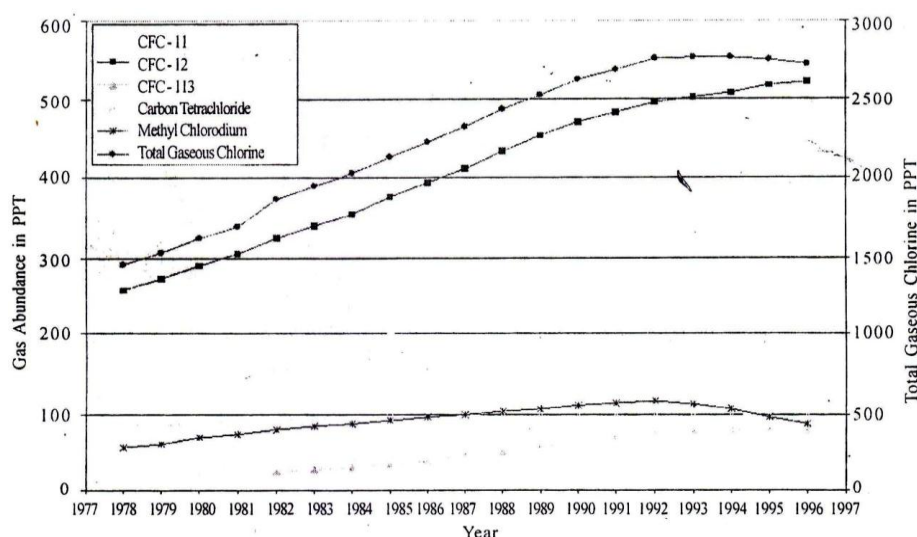


Figure 2.112 b: Atmospheric Concentrations of CFC-11, CFC-12, CFC-113, Carbon Tetrachloride, Methyl Chloroform and Total Gaseous Chlorine.

Chile, the only populous country located under the Antarctic ozone hole, experienced a fourfold increase in malignant melanoma since 1980. Levels of skin cancer and cataracts are also increasing rapidly in the United States, presumably mostly from increased exposure to the sun.

Anthropogenic Damage to the Ozone Layer

While most of the source gases are of natural origin, others have been introduced in nature by the man. It was, thus, realized that there is a growing probability of damage to ozone layer by human activities. In early seventies, supersonic transport was the chief cause of NO_2 radical output into the stratosphere. After the discovery of CFC problem in mid-seventies, ozone destruction by active chlorine (C_{10}_x) has become a

dominating question. Considering all other changes in trace gas system, e.g. N_2O , CH_4 and CO_2 , cooling of the stratosphere has been forecasted leading to less loss of total ozone.

It was found that the hole, commonly known as "*Antarctic Ozone hole*", was formed each year after the return of the sun at the end of polar night. Development of the phenomenon occurred parallel to the increase of the atmospheric chlorine content produced by the emission of CFCs. The ozone-destroying processes in that region influence the whole southern hemisphere.

Since the early seventies, when CFCs came into market, a large quantity has been injected into the atmosphere. The present level of injection is about 7,00,000 tonnes/year for CFC-11 (CFC1_3) and CFC-12 ($\text{CF}_2\text{C1}_2$) taken together. Production of CFCs in India is around 5,000 tonnes/year. CFCs released up to 1987 amount to 15 million tonnes. The developed countries account for 1.2 kg per annum *per capita* of CFCs as against less than 0.006 kg per annum of the developing countries. Global consumption of CFCs estimated in 1995 accounts to 1.2 million tonnes per year. Since the life of these molecules is around 100 years, even with the adoption of protocols put forward at Montreal and London which were further refined at Copenhagen to make them acceptable to all the countries, the ozone layer is not likely to make a significant recovery until the middle of century. For the ozone layer to return to its natural state, the chlorine loading which is presently 3 ppbv has to be brought down to a level below 2 ppbv.

Health Effects of Ozone Depletion and Increased Uv-B Radiation

An increase in the CFC levels in the stratosphere has decreased the ozone levels but increased the UV-B radiation (290-320 nm) reaching the earth's surface. Though overall consequences of UV-B radiation on human health cannot be predicted in a straight forward manner, increased incidences of diseases like skin cancer, cataracts, suppression of the immune system which may affect the herpes viruses, leishmaniasis, malaria, bacterial and fungal infections, tuberculosis and respiratory problems have been recorded. A few examples are discussed below.

Ocular effects: The World Health Organization estimates that cataract is responsible for 17 million cases of avoidable blindness in 1985. By reducing 1 per cent of the

ozone level, there would be 1,00,000 to 1,50,000 additional cases of cataract-induced blindness.

Skin cancer: Increased UV-B levels are expected to cause increase in cancer-related skin disorders, including melanoma skin cancer (MSC), non-melanoma skin cancer (NMSC) and pre-cancerous lesions. The number of patients will increase more sharply than the rate of decrease in ozone layer.

Immunological effects: Ultraviolet radiation has profound effects on the immune system, particularly that of the skin. All the diseases that affect skin at a stage like measles, malaria, leishmaniasis, tuberculosis and leprosy are known to be caused by UV-B induced immune-suppression.

Respiratory problems: Respiratory problems are caused by a variety of air pollutants. These problems are magnified with ozone depletion. Ozone depletion in stratosphere will result in increased levels of ozone in troposphere. The individuals who are sensitive to ozone and are exposed to air pollution also will face serious respiratory problems, i.e. bronchitis, asthma, etc. According to an estimate, about 50,000 cases of lung diseases caused by ozone were reported in Mumbai alone.

Animal health: UV-B radiation will cause squamous cell cancer of the eye in cattle. Most of the animals are not likely to suffer from the immunosuppressive effects of UV radiation, because of their heavy coats but global warming may change the patterns of animal diseases via changes in the prevalence and distribution of insect vectors.

Crop yield: Increase in ozone concentration influences crop yields. It enters the levels through stomata and reduces the yield and quality of the plant products. It was reported that ozone depletion caused 50 per cent crop losses in several European countries—mainly affecting the potato, spinach, clover, alfalfa, beans, poplar, etc.

In 1984, researchers analyzing satellite data discovered that 40-50% of the ozone in the upper stratosphere over Antarctica was being destroyed during the Antarctic spring and early summer (September-December), especially since 1976 (Figure 2.113). Figure 2.114 shows the seasonal variation of ozone with altitude over Antarctica during 2002. The observed seasonal loss during the summer above

Antarctica has been incorrectly called an *ozone hole*. A more accurate term is *ozone thinning* because the ozone depletion varies with altitude (Figure 2.114) and location. The total area of the atmosphere above Antarctica that suffers from ozone thinning during the peak season varies from year to year. In 2000, seasonal ozone thinning above Antarctica was the largest ever and covered an area three times the size of the continental United States. However, in 2001 and 2002 its size decreased somewhat. Measurements and models indicate that CFCs are the primary culprits.

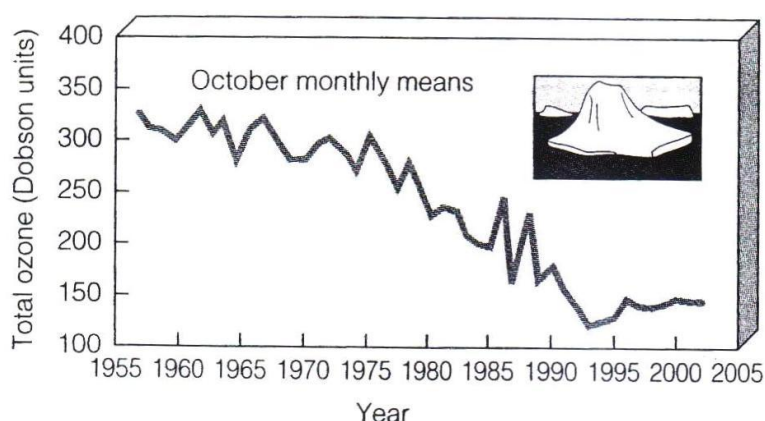


Figure 2.113: Mean total level of ozone for October over the Halley Bay measuring station in Antarctica, 1956-2002.

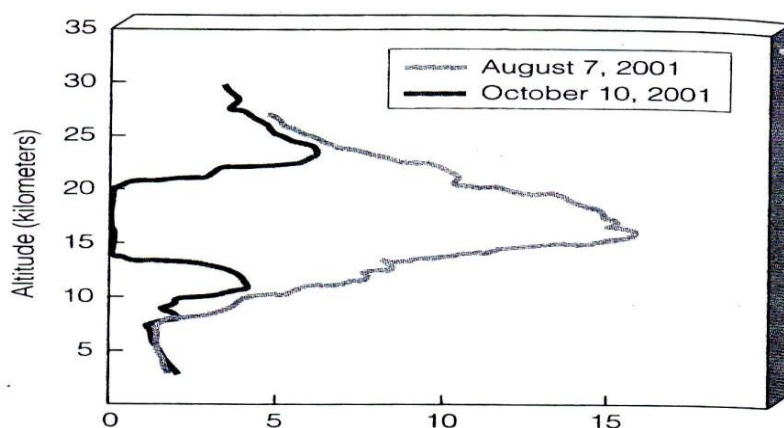


Figure 2.114: Seasonal variation of ozone level with altitude over Antarctica during 2002. Note the severe depletion of ozone during October (during the Antarctic summer, red line) and its return to more normal levels in August (during the Antarctic winter, green line).

After a dark winter, sunlight returns to Antarctica. This sets into motion reactions that release large numbers of Cl atoms that initiate the catalytic chlorine cycle. Within

weeks, this typically destroys 40-50% of the ozone above Antarctica (and 100% in some places). Huge masses of ozone-depleted air above Antarctica then flow northward and linger for a few weeks over parts of Australia, New Zealand, South America, and South Africa. This raises biologically damaging UV-B levels in these areas by 3-10% and in some years by as much as 20%.

In 1988, scientists discovered that similar but usually less severe ozone thinning occurs over the Arctic during the arctic spring and early summer (February-June), with a seasonal ozone loss of 11-38% (compared to a typical 50% loss above Antarctica). When this mass of air above the Arctic breaks up each spring, large masses of ozone-depleted air flow south to linger over parts of Europe, North America, and Asia. Some *good news* is that in 2002 models indicate that the Arctic is unlikely to develop the large-scale ozone thinning found over the Antarctic. According to a 1998 model developed by scientists NASA's Goddard Institute for Space Studies, ozone depletion over the Antarctic and Arctic will be at its worst between 2010 and 2019.

Why Should We Be Worried about Ozone Depletion? Life in the Ultraviolet Zone Why should we care about ozone loss? From a human standpoint the answer is that with less ozone in the stratosphere, more biologically damaging UV-A and UV-B radiation will reach the earth's surface. This will give humans worse sunburns, more eye cataracts (a clouding of the eye's lens that reduces vision and can cause blindness if not corrected), and more skin cancers (Figure 2.115).

Humans can make cultural adaptations to increased UV-B radiation by staying out of the sun, protecting their skin with clothing, and applying sunscreens. However, UV-sensitive plants and animals that help support us and other forms of life cannot make such changes except through the long process of biological evolution.

Connections: What Cancer Are You Most Likely to Get? Research indicates that year of exposure to UV-B ionizing radiation in sunlight is the primary cause of *squamous cell* (Figure 2.115, left) and *basal cell* (Figure 2.115, center) *skin cancers*. Together these two types make up 95% of all skin cancers. Typically there is a 15- to 40-year lag between excessive exposure to UV-B and development of these cancers. Caucasian children and adolescents who get only-one severe sunburn double their

chances of getting these two types of cancers. Some 90-95% of these types of skin cancer can be cured if detected early enough, although their removal may leave disfiguring scars. These cancers kill 1-2% of their victims, which amounts to about 2,300 deaths in the United States each year.

A third type of skin cancer, *malignant melanoma* (Figure 2.115, right), occurs in pigmented areas such as moles anywhere on the body. Within a few months, this type of cancer can spread to other organs. It kills about one-fourth of its victims (most under age 40) within 5 years, despite surgery, chemotherapy, and radiation treatments. Each year it kills about 100,000 people (including more than 7,400 Americans), mostly Caucasians. It can be cured if detected early enough, but recent studies show that some melanoma survivors have a recurrence more than 15 years later.

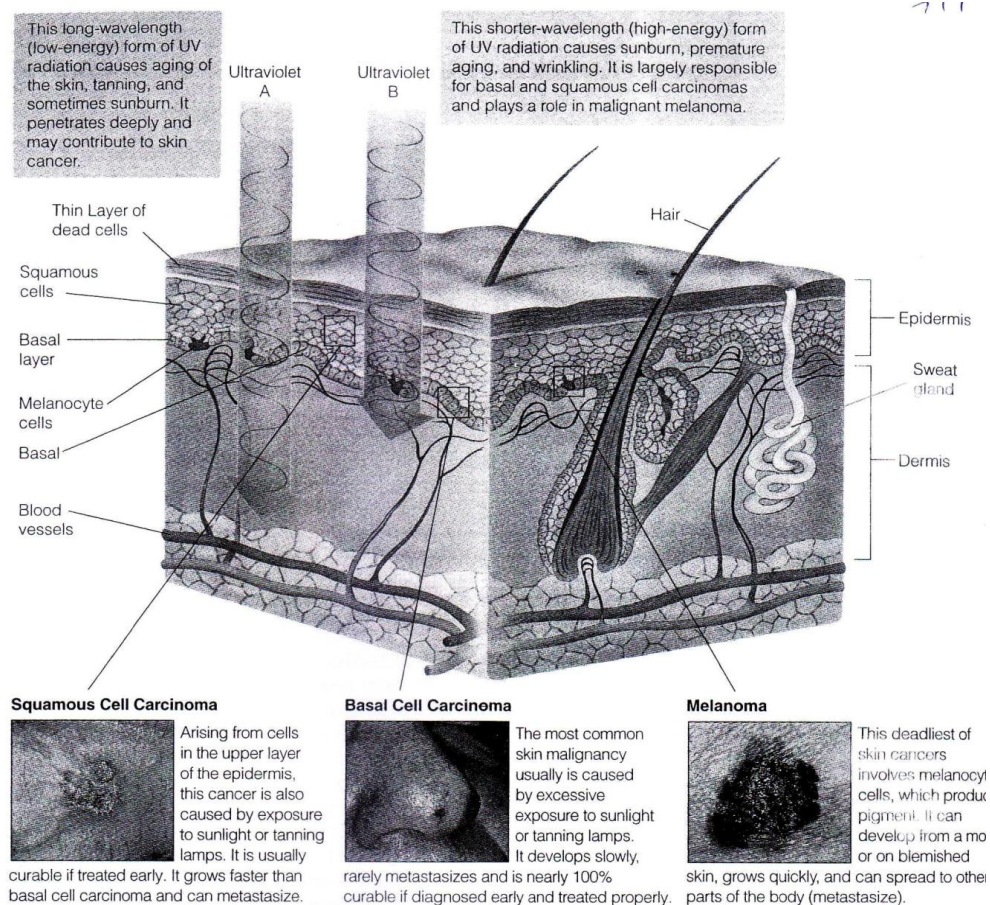


Figure 2.115: Structure of the human skin and the relationships between ultraviolet (UV-A and UV-B) radiation and the three types of skin cancer. The incidence of these types of cancer is rising, mostly because more fair-skinned people have increased their exposure to sunlight by moving to areas with sunnier

climates and spending more of their leisure time exposed to sunlight. If ozone-destroying chemicals continue to reduce stratospheric ozone levels, incidence of these types of cancers is expected to rise. (The Skin Cancer Foundation)

Recent evidence suggests that about 90% of sunlight's melanoma-causing effect may come from exposure to UV-A (which is not blocked by window glass) and 10% from UV-B. Some sunscreens do not protect from UV-A, and tanning booth lights and sunlamps emit mostly UV-A. Evidence indicates that people (especially Caucasians) who get three or more blistering sunburn before age 20 are five times more likely to develop malignant melanoma than those who have never had severe sunburns. About 10% of those who get malignant melanoma have an inherited gene that makes them especially susceptible to the disease.

To protect yourself, the safest course is to stay out of the sun (especially between 10 A.M. and 3 P.M., when UV levels are highest) and do not use tanning parlors or sunlamps. When you are in the sun, wear tightly woven, protective clothing, a wide-brimmed hat, and sunglasses that protect against UV-A and UV-B radiation (ordinary sunglasses may actually harm your eyes by dilating your pupils so more UV radiation strikes the retina). Because UV rays can penetrate clouds, overcast skies do not protect you; neither does shade, because UV rays can reflect off sand, snow, water, or patio floors. People who take antibiotics and women who take birth control pills are more susceptible to UV damage.

Use a sunscreen that offers protection against both UV-A and UV-B and has a protection factor of 15 or more (25 if you have light skin). Apply to all exposed skin (including lips) and reapply sunscreens about every 2 hours or immediately after swimming or excessive perspiration. Most people do not realize that protection factors for sunscreens are based on use of one full ounce of the product—about enough to fill shot glass. Some people also increase their risk of skin cancer by falsely assuming that sunscreens allow them to spend more time in the sun.

Children who use a sunscreen with a protection factor of 15 every time they are in the sun from age 1 to 18 decrease their chance of getting skin cancer. Babies under a year old should not be exposed to the sun at all and should not have sunscreens applied until they are at least 6 months old. Become familiar with your moles and thoroughly

examine your skin and scalp at least once a month. Warning signs of skin cancer are a change in the size, shape, or color of a mole or wart (the major sign of malignant melanoma, which must be treated quickly), sudden appearance of dark spots on the skin, or a sore that keeps oozing, bleeding, and crusting over but does not heal. Be alert for precancerous growths (reddish-brown spots with a scaly crust). If you observe any of these signs, consult a doctor immediately.

CHAPTER III

BIOREMEDIATION AND CURRENT STRATEGIES

Biotechnology has emerged as an applied discipline of biological research with its applications in agriculture, forestry, industry, as well as medicine. An equally important area of global concern that has emerged only recently is the environmental applications of biotechnology. In the chapter on Environmental Pollution and Public Health in this book an account of various pollutants entering our environment and the ways for the prevention and control of pollution has been given. Two things should become evident from this account. Firstly, the disposal, removal and treatment of various pollutants of air, water, and land may not be acceptable due to cost-benefit and other limitations. Secondly, some of the environmental pollutants that are resistant to biodegradation (recalcitrant) lead to problem of biomagnification. Moreover, there are situations where one feels helpless. For example, when there are oil spills in marine waters and when underground storage tanks of petrol begin to discharge hydrocarbons to subsoil and groundwater due to leakage.

It has only been recognised quite recently that biological systems, primarily of microbial origin could prove potential means of degrading some such complex environmental pollutants as well as preventing pollution through waste treatment (solid as well as liquid). Such recent environmental applications of biotechnology emerged into a new area of research and development, bioremediation. In this chapter we would briefly consider the technologies being evolved for use of living organisms (primarily microorganisms) in the cleanup of environment and prevention of pollution caused due to normally non-biodegradable pollutants.

What is Bioremediation?

Bioremediation is "the use of living organisms (primarily microorganisms) to degrade environmental pollutants or to prevent pollution through waste treatment." Bioremediation is emerging as most ideal alternative technology for removing pollutants from the environment, restoring contaminated sites, and preventing further pollution. This environment friendly technology is expanding range of organisms to be used to clean up pollution, and forms a vital component of the so-called green movement of maintaining the nature's overall ecological balance, an issue at present being top priority of environmental awareness and public policy.

Need and Scope of Bioremediation

Application of bioremediation - the use of living organisms to degrade environmental pollutants or to treat waste streams to control pollution- is expanding world over. The OECD (Organisation for Economic Cooperation and Development) in a report entitled Biotechnology for a Clean Environment, issued in 1994 estimated that world market potential for all environmental biotechnologies would nearly double in the 1990s, rising from, \$40 billion in 1990 to \$75 billion by 2000. Bioremediation is needed because certain chemicals accumulate in the environment to levels that threaten human health or environmental quality. It was in fact in mid-1960s, when DDT accumulation changed the old belief (that microbes were able to degrade all compounds entering the environment) that serious efforts were begun to exploit the natural capacity of microorganisms to degrade complex compounds.

OECD has been sponsoring meetings of scientists and government representatives from U.S.A., Canada, Japan and West European countries since 1991 to consider the environmental applications of biotechnology. At such meetings, besides other areas, representatives have examined the state of the art of bioremediation and how governments could extend aid to its research and development. At a recent meeting of OECD workshop, held in November 1994 in Tokyo, participants recognised that bioremediation can have local, regional, and global applications and that both indigenous and genetically engineered microbes may play important roles.

Environmental Applications of Bioremediation

Research projects are being modified to expand the range of microorganisms used for bioremediation. There is search for naturally occurring microbes that have better pollutant degradation kinetics, attack a wider range of pollutant compounds, and do so over a wider range of microbial growth conditions. There is also search for microbes that could grow under extreme environmental conditions, such as tolerance to organic solvents, growth under extremely alkaline substrates, or high temperatures. This information would widen the scope of bioremediation even to non aqueous pollutants and those found in the environmental conditions unfavourable to growth of most microorganisms.

Researchers have also been using genetic engineering to develop new microbial strains with novel biodegradative capabilities. For instance modified microbes may be

produced through genetic coding for the attack of complex chlorinated hydrocarbons such as dioxins which are non-degradable by naturally occurring microorganisms. Adding genes that code for enzymes that breakdown toxic chemicals to microbes able to survive and grow in much disturbed and harsh environments would greatly extend the range of compounds that might be treated with bioremediation. For example, in Japan a research team has already isolated a species of *Pseudomonas* that can grow in solvents containing more than 50% toluene, a condition that kills most organisms through disruption of cell membrane. Adding appropriate genes for catabolic enzymes to this strain has great potential for expanding the range of bioconversions into nonaqueous solvents.

Three different foci of R & D for bioremediation research are emerging worldwide. While Europeans are expanding their traditional waste and water treatment systems to cope with specific chemical pollutants, the U.S.A focuses on site-specific cleanup of soil and water contaminated with petroleum and xenobiotics, and the Japanese take aim at global environmental problems. Each of the three emerging technologies of bioremediation in environmental cleanup will be considered in somewhat detail below.

I. European upgrading of traditional waste and water treatment systems

Several European countries, particularly Germany, the Netherlands, Belgium, Austria and Italy have programmes to foster R&D in environmental biotechnology. German government agencies promote technology transfer and co-operative research between government-sponsored research institutes and private industry. In the Netherlands, the most developed country in environmental biotechnology, the government supports an innovative programme in bioremediation R&D and subsidies industries participating in the programme. For example, long back in 1978, the Dutch Nuisance & Air Pollution Act took advantage of the development of biofilters, a modification of traditional trickling filters, permitting installation of these biofilters to meet air quality standards. Following are examples of the developments made in the waste and water systems in some European countries.

1. Biogas (energy) from solid wastes and refuse. It could be recognized by some newly developed European waste treatment systems that some microbial degradation or transformation occur only in the absence of oxygen, and such a process could be

important in environmental biotechnology. Under anaerobic conditions, microorganisms growing on wastes can sometimes produce valuable fuels. The dry anaerobic composting (Dranco) process converts the organic fraction of biodegradable organic solid waste and refuse into energy in the form of biogas (methane and carbon dioxide) and a humus-like material. The biogas is produced by a consortium of anaerobic bacteria that includes methanogens (methane-producing archaeobacteria).

Full-scale installations using Dranco process are in operation at Brecht, Belgium and Salzburg, Austria. The systems treat source-separated plant residue and paper from municipal waste. In Salzburg, Austria both anaerobic and aerobic microbes are used. The first phase of treatment, anaerobic digestion takes place in a large tank lasting for about three weeks. The digested material then moves for aerobic maturation which takes about two weeks. The process is shown in Fig. 2.116. The facility built by Organic Waste System of Ghent, Belgium can treat 20,000 tons of bio waste every year. Such contained aerobic and anaerobic treatment systems replace the traditional landfills for disposal of solid wastes. These new systems produce biogas that is about 55% methane, which is burnt to produce electricity.

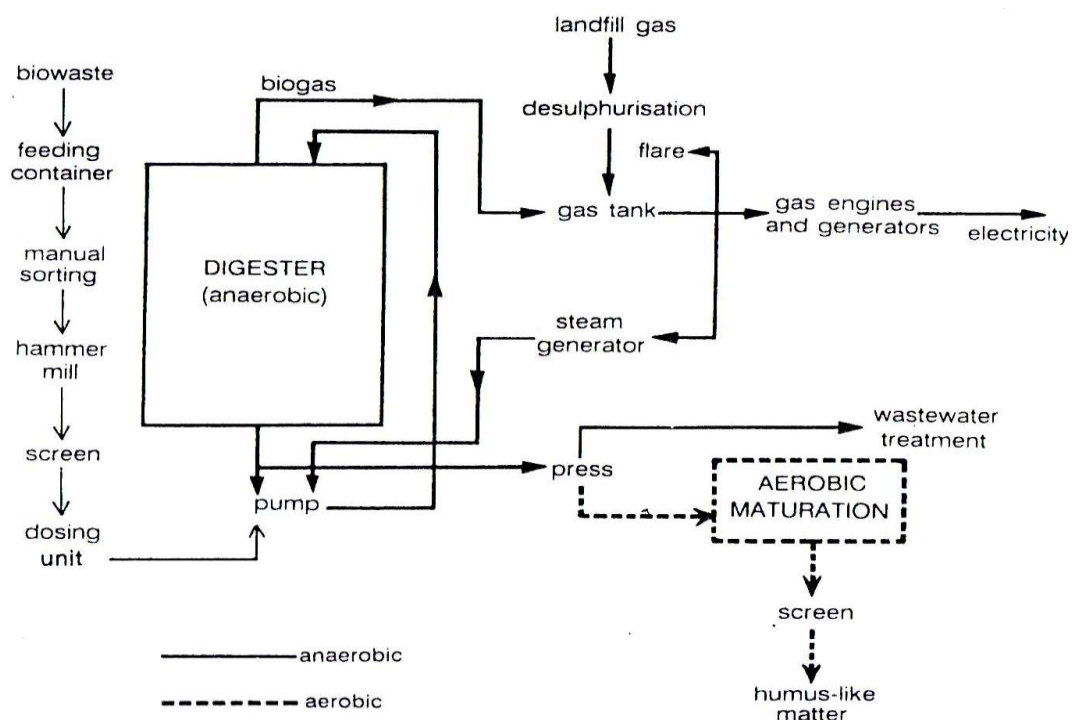


Figure 2.116: Various steps of treatment facility of municipal waste by using both, anaerobic and aerobic microorganisms.

2. Removal of inorganic compounds. Some wastewater systems, originally designed only to remove organic compounds from water aerobically to reduce BOD, have been modified to include anaerobic zones to remove inorganic compounds as well. One such system, a pilot-scaled fluidized bed reactor that removes nitrate from water, has been tested at the municipal water treatment facility in Blankaaart, Belgium. The removal of nitrate from wastewater helps prevent eutrophication of the waterways receiving the treated water. At Blankaaart, nitrate concentration was reduced from 75.0 mg per L to 0.1 mg per L when water was passed through bioreactor. The reactor contains the methylotrophic bacteria, such as *Methylophilus methylotrophus* that carry out denitrification. Methanol is first added to bioreactor to support the growth of methylotrophs and later removed by trickling filters and granular activated carbon filters before the water is discharged for use. The bacteria convert nitrate to nitrite and then to molecular nitrogen, which is released into the atmosphere.

3. Removal of toxic chemicals from industrial wastewater. New waste treatment systems can also maintain populations of desired specific microorganisms that can biodegrade toxic compounds like hydrocarbons and chlorinated solvents found in industrial plant wastewater. These compounds generally escape biodegradation in traditional wastewater treatment systems. Bacteria like *Pseudomonas cepacia* are able to biodegrade chlorinated hydrocarbons present in the effluents of pesticide industries manufacturing DDT, heptachlor, chlordane etc. In Matera, Italy, the wastewater is treated anaerobically in a bioreactor in a factory that produces epoxy resins from epichlorohydrin and phenolics. Besides alkaline hydrolysis and subsequent chloride removal, effluents containing unreacted toxic compounds are also treated with specific microbes. These acclimatized anaerobic microorganisms in the waste treatment digester are able to tolerate the concentration of epichlorohydrin and glycidol in the waste stream, and degrade these and other chlorinated organic so that the detoxified water can be released safely into the environment.

Textile and dye industries in Hong Kong are using the bacterium, *Acetobacter liquefaciens* S-1 to treat their wastewater. This bacterium is able to consume bright coloured azo dyes (agar plate containing 100 ppm methyl red) in culture.

4. Biological gas treatment systems (biofilters, biofilms, bioscrubbers, biotrickling filers). Traditional water treatment systems, particularly aerobic trickling filters, have

been modified to treat air pollutants. In bioscrubbers and biotrickling filters, multiple microbial communities grow on solid surfaces to produce multilayered complexes called biofilms. When gas streams (coming out of water treatment plant) containing organic pollutants are passed through these systems, the pollutants are degraded. Several companies in the Netherlands and Germany have taken the lead in developing such biological gas treatment systems. Since 1978 when Nuisance & Air Pollution Act was enacted in the Netherlands more than 200 biofilters have been installed and this biotechnology is now in widespread use in that country to remove organic contaminants from air. Biofiltration has been used since 1989 to treat gases given off by soybean toasters in Hengelo, the Netherlands. The gases pass through a column packed with a proprietary solid support. A biofilm growing on this support biodegrades more than 95% of the organic compounds in the gases. This biofilter, covering an area of 240 sq. meters can process 300 cubic meters of gas per cu m of packing per hour. A cattle feed extrusion plant in Zwolle, the Netherlands, also uses biofiltration to remove more than 99% of the foul gases from its emissions. The facility handles 600 cu m of gas per cu m of packing per hour.

Air treatment bioreactors are in use in the Netherlands to remove formaldehyde from air released from plywood production facilities and phenols from resin producers. Similar biofiltration systems are being tested to remove solvents from indoor air at point production facilities. Some fungi are being exploited in biofilters for the treatment of volatile organic compounds in air. Some fungi like *Candida tropicalis* are able to assimilate styrene - a fragrant liquid unsaturated hydrocarbon used chiefly in making synthetic rubber, resins and plastics and in improving drying oils. In laboratory tests, such styrene - assimilating fungi are grown on a ceramic support. The mycelium of the fungi gives the biofilters a large surface area and greater capacity to eliminate pollutant than the conventional compost biofilters. In addition to styrene the biofilters can remove toluene, xylenes, α -methylstyrene and propene from test gases. The technique is being scaled up and marketed by TNO Institute for Experimental Sciences in Delft, the Netherlands in collaboration with four Dutch companies.

A German animal rendering plant treats 214,000 cu m of gas per hour using a biofilter filled with peat and heather that has a volume of 3,240 cu m. Odours are reduced 94 to 99%. A ceramics factory in Southern Germany uses biofilters to remove more than

99% of the ethanol and isopropyl alcohol released into the, air from drying ceramics. The alcohols (90% ethanol and¹10% isopropyl alcohol) are released at a concentration of 230 ppm organic carbon and a flow rate of 30,000 cu m per hour. A simple biofilter with a volume of 200 cu m removes them.

II. American focus on site-specific cleanup

In the United States, bioremediation is mostly being used to clean up sites contaminated by toxic chemical spills or polluted from disposal of chemical wastes (primarily mixtures of nonaqueous chemicals). Federal and State Governments have enforced legally the cleanup of several highly contaminated sites that pose threats to human health, particularly where the pollutants are gradually seeping through soil into aquifers used for drinking water. The so-called superfund sites - the sites of highest priority in the list of EPA (The Environmental Protection Agency) - includes more than 1200 locations.

Superfund sites contaminated with multiple pollutants and leaking underground storage tanks, numbering in the hundreds of thousands are being cleaned up through bioremediation with federal funding of about \$20 million since 1990. The Federal government supported research on the potential for bioremediation of sites contaminated with heavy fossil fuels, creosote, munitions (such as TNT and other nitroaromatics), and chlorinated compounds, among others. This funding comes particularly from the Departments of Energy and Defense to clean up contaminated sites on federal lands. Several companies have also taken up bioremediation as cost-effective measure of restoring environmental quality.

Bioremediation appears to be an attractive alternative to the physical removal and subsequent disposal/destruction of pollutants. The cost of moving and incinerating of polluted matters is at least 10 times that of biological treatment, especially if the latter is carried out in situ (in situ bioremediation). Several large chemical producers like DuPont, and other manufacturers like General Electric and General Motors are seeking ways to clean up trichloroethylene (TCE) and polychlorinated biphenyls (PCBs). TCE, once a widely used cleaning solvent, is also the most prevalent ground water pollutant of interest to the Departments of Energy and Defense.

1. Complex organic pollutants including petroleum products in oil spills

Heavy fossil fuels, related compounds as well as chlorinated compounds pollute sites both, in water and land.

(a) Bioremediation of sites in water. Pollutants are often mixtures of complex chemicals. Crude oil, for example contains thousands of hydrocarbons with different structures; refined oils have hundreds of different components; PCB_s have dozens of congeners; and some pollutants are undefined combinations of oils, pesticides, other organic compounds and inorganics such as heavy metals.

Oil spills on ocean waters caused alarming threats to biodiversity and human health. The world first woke up to the disaster of an oil spill when on 18 March 1967 a Liberian tanker, Terry Canyon, ran ground on the southwest coast of Great Britain, near the entrance to the English Channel, spilling 60,000 tons of crude oil into the sea. Oil splattered on to 160 km. of coastline killing fish and birds. In January 1969 occurred the Second major oil spill off the coast of Santa Barbara in U.S.A. discharging oil at the rate of 1000 gallons per hour. In 1978, Amoco Cadiz disaster dumped 68 million gallons of oil along the French coast. On March 24, 1989 the Supertanker Exxon Valdez belonging to the Exxon Corporation, plied on to a reef off the coasts of Alaska, U.S.A. spilling over 11 million gallons of oil into the clean waters of Alaska's Prince William Sound.

As the oil hit 1930 km of shoreline, 100,000 seabirds died including 150 rare species of bald eagles. Many dead seals sank to the bottom of the ocean and at least 1000 sea otters perished. Indian coasts have also suffered from tanker disasters. In July, 1973, 3000 tons of oil washed on to the Gujarat coast when an oil tanker, Cosmos Pioneer ran aground. In 1974, an American oil tanker, Transhuron collided with one of the atolls of the Laccadives, spilling 5000 tons of special furnace oil. In June 1989, a Maltese tanker, M.T. Puppy collided with a British vessel, spilling over 5500 tons of furnace oil into the open seas off Bombay. The massive oil slick in the Gulf in 1991 has been the largest so far, spreading over 700 sq. km. This oil slick made history, spilling more than 330 million gallons of oil, roughly 30 times more than the quantity spilled by the Exxon Valdez on the shores of Alaska. The oil slick stretched over an area of more than 80 km long and 20 km wide moving south at a speed of 20 km a day. It hit Saudi, Bahrain, Qatar and the U.A.E. shores.

Spills can be dealt with more easily if they are confined to a small area on the water surface. For this mechanical booms or barriers are spread around an oil slick to check its progress and prevent it from hitting the shoreline. The spilled oil can also be treated with dispersants, which are sprayed from aircrafts or ships. Dispersants cause the oil to spread farther and disperse in a way similar to the manner soap removes oil from our hands, allowing the oil to be emulsified and washed away with water. A dispersant contains a surfactant, a solvent, and a stabiliser. Absorbents are also used to facilitate the cleanup of oil spills. Natural materials like peat moss, straw, sawdust and pine bark can be used. Synthetic absorbents include polyethylene, polystyrene, polypropylene, and polyurethane. Of all these, polyurethane is the most promising.

By far the safest way of treating an oil slick is bioremediation- the use of biological agents for degrading oil. These microbial surfactants are sprayed from the air. They mix with the oil, emulsify it and disperse it throughout the water body so thinly that it no longer remains hazardous. Bacteria and yeasts can grow on several fractions of hydrocarbons as heptane, decane, hexadecane etc. However, not every clean-up method can clear up all oil spills. Clean-up methods are chosen on a case-by-case basis. Professor Ananda M. Chakrabarty a hydrocarbon biotechnologist, working at the University of Illinois Medical Centre, Chicago, and U.S.A has developed many a new strain of oil-eating bacteria. He could develop a very efficient oil-eating "superbug" using species of *Pseudomonas* through recombinant DNA technology.

Indigenous versus introduced microorganisms. Several hundred U.S. companies sell microorganisms for environmental cleanup. But many of these microbial products are however, of dubious value and are little more than snake oil. Often, naturally occurring (indigenous) microbes at a contaminated site are already biodegrading the pollutant, and addition of introduced microbial products is of no help. Most cultures sold to biodegrade hydrocarbons in contaminated soil and water do not enhance the rates of biodegradation above those carried by indigenous microbes. Efforts have, therefore been made to modify the environment of the given site to enhance the activity of naturally occurring microorganisms, present already at the contaminated site.

Monitoring the persistence and activity of specific microorganisms. It is necessary to maintain specific, complex microbial populations having necessary biodegradative

capacities in order to treat the pollutants. It is difficult to ensure the persistence of these specific populations. A novel method has been developed using reporter genes. These genes produce an easily monitored effect when microbial activities are occurring at the site.

The method has been developed and demonstrated by Gary S. Sayler at the University of Tennessee, Knoxville, U.S.A. Sayler uses expression of the lux gene, which codes for bioluminescence, to monitor degradation. The fermenter vessel glows from light emitted by the aerobic bacterium, *Pseudomonas fluorescent* strain HK44 when naphthalene is present as the carbon and energy source and oxygen as the electron acceptor, expressing biodegradative activity of the bacterium (naphthalene degradation). Strain HK44 was engineered to contain both, the nah gene, which codes for an enzyme that catabolises naphthalene, and the lux gene for bioluminescence; both genes being under the control of the same promoter.

Some examples of bioremediation. The largest bioremediation project in the U.S. so far - the treatment of the Exxon Valdez Alaskan oil spill - highlights the benefits of environmental modification approach to bioremediation. Here site cleanup is achieved by enhancing the activity of naturally occurring oil-eating microbes through modification of the environment. A massive cleanup involving 11000 workers attempted to remove oil from more than 1000 miles of shoreline. Physical cleanup of the oil, using high-pressure water to wash the rocks, cost Exxon over \$ 1 million per day and the treatment was slow and also left subsurface oil that recontaminated shorelines.

Bioremediation through simple addition of nitrogen-containing fertilisers to the contaminated shorelines stimulated the metabolism of indigenous hydrogen-degrading microorganisms and degraded both surface and subsurface oil three to five times faster than occurred at untreated test sites. Natural hydrocarbon degrading microbes were already abundant in the water of Prince William Sound and tidal flux aerated the shorelines making bioremediation a viable treatment. The cost of remediating hundreds of miles of contaminated shoreline was less than \$ 1 million and could complete within a couple of year contrary to more than a decade in un-fertilised condition. Though rates of hydrocarbon degradation were stimulated, it did not lead

to complete removal of the hydrocarbons. Residual hydrocarbons were contained in asphalt-like materials that are insoluble in water and should affect biodiversity.

(b) Bioremediation of contaminated sites on land. Petroleum hydrocarbons can also be successfully removed from land-based sites using environment moderation, as demonstrated more than 20 years ago in tests on the cleanup of a gasoline-contaminated aquifer in Amber, Philadelphia. In 1972 in this test, hydrocarbons were removed by adding fertilisers and using forced aeration to stimulate the growth of indigenous hydrocarbon-utilising microorganisms in the groundwater.

Soil microbes in aquifers are responsible for a significant portion of the degradation of aromatic compounds when land sites are contaminated. These microbes degrade benzene, toluene, ethyl benzene, and xylenes. Most subsoil indigenous microbes biodegrade low levels of these compounds if there is enough dissolved oxygen in the groundwater.

Leaking underground storage tanks in the U.S. have contaminated soil and groundwater with low molecular weight aromatics that can threaten human health, when these hydrocarbons get into drinking water supplies. Bioremediation can treat both soil and groundwater in one step. The cleanup of pollutants from leaking underground storage tanks at bus maintenance and fueling facility in Denver is an example of such a treatment. Gasoline, diesel fuel, and lubricating oil contaminated the soil and underlying groundwater near the leaking tanks. Beginning in 1993, the polluting hydrocarbons were removed by air sparging (physical transfer to the atmosphere) and bioventing in which, the contaminated water was pumped to the surface and reinjected. Oxygen introduced into the water in this way supported the biodegradative metabolism of indigenous microorganisms.

The dissolved concentration in the petroleum-contaminated groundwater was as high as 2.8 mg per L and natural bacteria are able to consume fuel residues at a rate of about 4.2 g of hydrocarbon degradation per L of water per year. In 1993, the Air Force completed a full-scale soil bioventing project to clean up a 27000- gal jet-fuel spill at Hill Air Force Base in Utah. During this 18 month project, jet-fuel residues in soil were reduced from an average total petroleum hydrocarbon concentration of about 900 mg per kg to less than 10 mg per kg. In this process 60% of the hydrocarbons

removed from the soil volatilised directly into the atmosphere and the remaining 40% was biodegraded to carbon dioxide and water.

Bioreactors are being tested by the Department of Energy at its Savannah River site in South Carolina as well as by companies such as Envirogen in Lawrenceville, N.J. to treat volatile compounds. TCE and other organic contaminants can be removed from soil and groundwater by simultaneous use of in situ thermal catalytic oxidation and bioremediation. In such a faster cleanup of contaminants (Fig.2.117), concentrations of volatile organics can be quickly reduced from the soil above the water table by vacuum extraction. These contaminants are then converted to carbon dioxide and hydrochloric acid by catalytic oxidation treatment at the surface. The Savannah River system uses a proprietary-metal catalyst and operates at about 425°C. Bioremediation accomplished by encouraging indigenous methane-oxidising microorganisms, removes contaminants from water-saturated soils as well as much of the residual contamination after volatilisation.

Methane, oxygen, and nutrient gases that supply phosphorus and nitrogen are pumped into the contaminated soil to encourage indigenous microbes which convert the contaminants to carbon dioxide and hydrochloric acid through the action of the enzyme, methane monooxygenase. The system can degrade more than 250 organic compounds, reducing TCE concentration to less than 5 ppb-low enough to meet drinking water standards. Genetically - engineered bacteria like *Pseudomonas fluorescens* strain HK44 are being used to treat naphthalene- contaminated soil in field tests at Oak Ridge National Laboratory, E/Tennessee, U.S.A. In the tests, underground steel tanks, called lysimeters (Fig. 2.118) surround a central sampling core. Each lysimeter is about 8 feet in diameter and 10 feet deep. It is fitted with a cover, sampling ports, and sprinklers to stimulate rainfall.

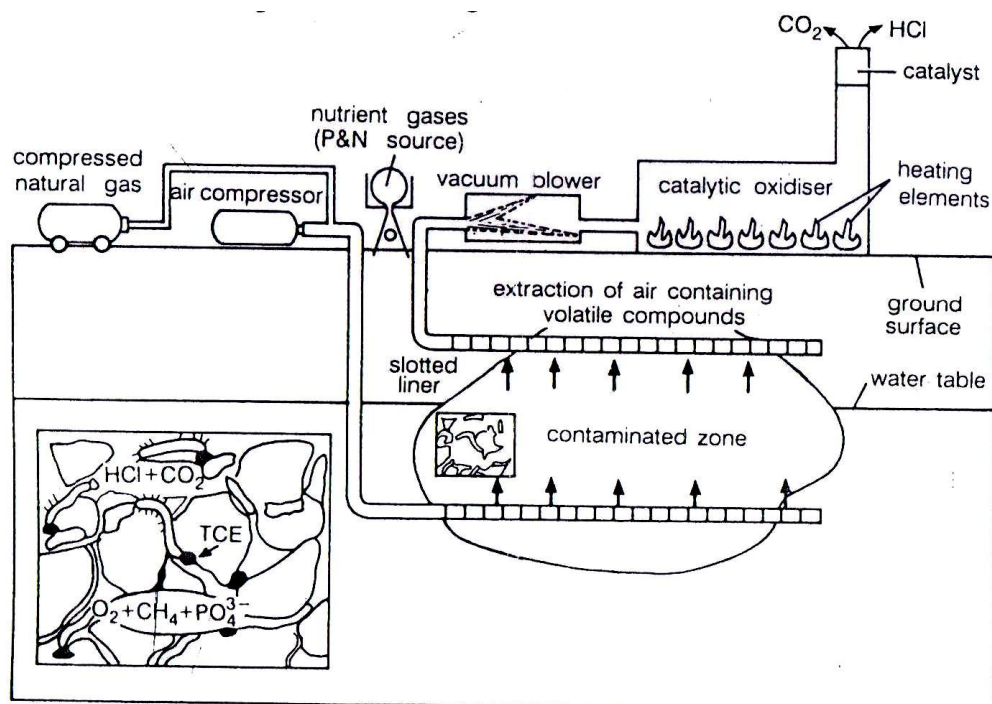


Figure 2.117: A schematic of a full-scale demonstration facility developed for simultaneous use of in situ bioremediation and thermal catalytic oxidation for a faster cleanup of trichloroethylen (TCE) and other organic pollutants of soil and groundwater.

The lysimeters are loaded with contaminated soil and *Pseudomonas fluorescens* HK44 and monitored for the parameters such as colonisation, gene transfer, bioluminescence, and naphthalene degradation. Bioremediation has been only occasionally used in Europe to clean up sites contaminated with petroleum spills. The situation may change over times as Eastern European countries are beginning to face such problems severely soon. Many sites in Czech Republic, Lithuania, Latvia, Ukraine and Russia are at least as polluted as the super fund sites in U.S.A.

2. Heavy metal-polluted sites

Besides organic compounds bioremediation can be used to treat sites contaminated with heavy metals or radionuclides. Microbes-algae, bacteria and fungi as well as higher plants have capabilities to uptake these pollutants. After uptake, these either accumulate or are assimilated by them. Accumulated heavy metals are recovered for recycling or disposal. For example, *Zoogaea ramigera* adsorbs copper and cadmium up to the levels of 300 and 100 mg of metal per g dry wt. respectively. *Pseudomonas putida*, *Arthrobacter viscosus* and *Citrobacter* spp remove several toxic heavy metals

from industrial effluents. Radioactive metals as uranium and thorium are removed by *Rhizopus arrhizus*, and *Penicillium chrysogenum* can accumulate radium. The yeast, *Saccharomyces cerevisiae* accumulates uranium from dilute solution.

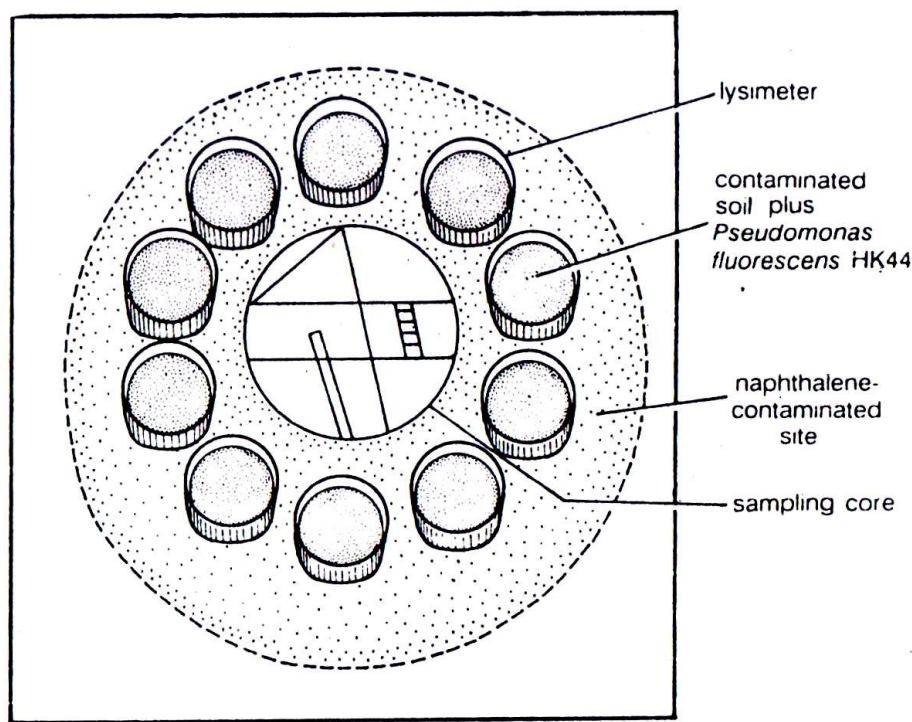


Figure 2.118: An experimental site showing a schematic of field tests to monitor the activity of naphthalene degrading bacterium.

The bacteria, like *Thiobacillus thiooxidans* bring about bioleaching of zinc, cobalt and nickel from sulphide rocks. Fungi belonging to the genera, *Trichoderma*, *Aspergillus*, *Aureobasidium*, *Ophiostoma* and *Rhodotorula* are shown to have biosorption ability of heavy metals and these seem to play important role in detoxification of industrial effluents. The Royal Dutch Shell uses sulphate-reducing bacteria to immobilise metals at an old zinc refining site at Budelco, the Netherlands. The groundwater at this site was heavily contaminated with zinc and cadmium. For bioremediation, groundwater is pumped through a bioreactor to which ethanol, ammonia and phosphate are added to support the growth of sulphate-reducing bacteria. These bacteria convert the sulphate in the groundwater to hydrogen sulphide, which reacts with heavy metals to form insoluble metal sulphides. A flocculent is used to retain the precipitated sulphides.

Green plants are also able to remove heavy metals from contaminated soil and groundwater. Some strains of *Brassica juncea* accumulate heavy metals like chromium when growing in metal-contaminated soils. Tests are being made at Rutgers University Centre for Agricultural Molecular Biology modified *Brassica juncea* growing in chromium-contaminated soil. Small amount of chromium was taken up by the plants and removed from the soil. Some plants can also accumulate lead. The plants can then be harvested and the metals recovered for recycling or disposal. The use of these plants is being developed by Burt D. Ensley at Phytotech. Corp, Monmouth Junction, N.J, U.S.A. in conjunction with scientists at Rutgers University, New Brunswick, N.J., U.S.A. Such a process of toxic removal by using plants is also called phytoremediation.

Some of the limitations of bioremediation can be overcome through genetic engineering. One can produce strains of microbes that are resistant to heavy metals, have greater degradative capabilities and able to grow in more than one kind of environments. The first patent for a genetically engineered organism was granted in the U.S. in 1981 for a bacterium that degrades hydrocarbons. This has never been a candidate for cleaning up oil spills, as it was engineered to degrade low molecular weight hydrocarbons such as toluene and octane that evaporate rapidly. Efforts to engineer genetically modified microbes that can degrade specific pollutants in situ have yet to meet with great success. In most countries environmental regulations greatly restrict the release of these microbes into the environment for in situ bioremediation. The real benefits of genetically modified microbes for bioremediation are likely to be in contained bioreactors.

III. Japanese global applications of bioremediation technology

In Japan, academic, industrial and government research is coordinated by the Ministry of International Trade & Industry (MITI). Developing long-term global applications of environmental biotechnology is one of the R&D priorities of this agency. Japanese bioremediation research focuses on ways to reverse environmental degradation in the 21st century. The research agenda of MITI places great emphasis on global problems such as climate change and desertification rather than on site-specific cleanup.

Japanese are therefore concentrating on much broader issues. Following are the ways in which they plan to handle environmental problems through bioremediation at global scale.

1. Replacement for petrochemicals (hydrogen fuel)

There has been a search for the microbes that produce some substances that can act as replacement for petrochemicals. Biotechnology research for producing hydrogen for use as automotive fuel that will not contribute **to global climate change** is of particular interest. One thrust of the work of Japanese researchers is use of microbes to produce such Fuels and materials (as hydrogen) that do not emit carbon dioxide and thus reducing air pollution. Researchers at several institutions including the National Institute of Bioscience and Human Technology and the National Institute for Resources and the Environment, both in Tsukuba, are seeking hydrogen-producing algae as sources of this clean-burning fuel.

2. Reversal of global warming

Even more far-reaching is the Japanese effort to reverse global warming. Besides looking for hydrogen and other fuels that would not contribute to global climate change there are also simultaneous efforts to develop bioremediation system to remove carbon dioxide already emitted into the atmosphere from the burning of carbon-based fossil fuels. This removal of the "extra" carbon dioxide polluting the atmosphere due to fossil fuel burning would be an extremely dramatic demonstration of bioremediation. The "extra" carbon dioxide contributes to global warming. Microbes can remove enough of this greenhouse gas and some of them convert carbon dioxide to various organic compounds.

The recombinant DNA technology should be of much use in such efforts to produce new strains of microbes that would theoretically do so more efficiently. At the Marine Biotechnology Laboratory at Kamaishi, Japan algae have been isolated that convert carbon dioxide to carbohydrates 10 times faster at 40°C than terrestrial green plants. Such algae could be grown in bioreactors near power plants where they would remove carbon dioxide from the air as it is released by fossil fuel burning at power plant. However, the organic compounds produced by assimilation of this greenhouse gas are likely to be subsequently biodegraded to carbon dioxide and water releasing this gas back to air. A successful bioremediation programme using such algae and other

microbes should therefore depend on finding such microbes that produce lignin or other polymeric compounds resistant to biodegradation as the original fossil fuels were. Such conversions would immobilise carbon, reducing the buildup of carbon dioxide in the atmosphere.

Japanese researchers have been growing some algae in bioreactors at the Marine Biotechnology Laboratory, Kamaishi. The alga, *Chlorococcum litorale*, isolated from Kamaishi Bay and grown successfully in laboratory could tolerate high levels of carbon dioxide, converting it to polysaccharides. Another alga being studied in the same laboratory, *Prasinococcus capsulatus* produces large amounts of extracellular mucilaginous polysaccharide. This alga is being studied for its potential to remove carbon dioxide from the atmosphere and for commercial applications of the polysaccharide.

Another group of microbes, the marine foraminifera, can also convert carbon from carbon dioxide into calcium carbonate. This process, occurring in coral reef formation, removes carbon from the usual biogeochemical carbon cycle that circulates carbon between organic compounds and carbon dioxide. Such a treatment would consume enormous quantities of calcium, creating its own impact on the environment. Despite these limitations the efforts may succeed in attacking global pollution problems. Such Japanese strategies if developed would raise the need for international understanding in the uses of biotechnology.

3. Biodegradable plastics

Biodegradable plastics made of microbially produced polyhydroxybutyrate have already been developed and being marketed by ICI in the U.K. These ICI's biodegradable plastics are used worldwide in trash bags that biodegrade in landfills. In Japan and elsewhere studies are being made on microorganisms that produce such biodegradable polymers that form solid wastes. Researchers under the guidance of Yoshiharu Doi in the polymer chemistry division of the Institute of Physical and Chemical Research (the Riken Institute) in Saitama have isolated a strain of the bacterium, *Alcaligenes eutrophus* that produces a copolyester of 3- and 4-hydroxybutyrate. The cells of this bacterium produce 80% of their biomass as this polymer, when grown on 1, 4- butanediol or γ - butyrolactone.

4. Biodesulphurisation

Japanese have also developed microbial systems to remove inorganic sulphur from industrial air emissions. The Bio-SR system developed by Dowa Mining has been put to commercial use. Industrial exhaust gas containing hydrogen sulphide passes through an acidic, ferric sulphate solution which oxidises the sulphide to elemental sulphur while reducing the ferric ion to ferrous ion.

An iron- and sulphur -oxidising bacterium, *Thiobacillus ferrooxidans* regenerates the ferric sulphate solution. The bacterium is grown in a bioreactor at a pH between 2 and 3. At a commercial facility of NKK Corporation, Tokyo, concentrations of hydrogen sulphide in an effluent gas are reduced from a range of 400 to 2000 ppm to less than 10 ppm. Thus 99% of the sulphide that would have otherwise gone to the atmosphere is captured as sulphur.

In the U.S. also, the Energy Biosystems in Woodlands, Texas have been developing similar systems to remove organic sulphur-containing compounds from fossil fuels. The bacterium *Rhodococcus* biodegrades dibenzothiophenes and other organosulphur compounds in the fuel. Biodesulphurisation produces a cleaner fuel that does not produce sulphur oxide emissions when it burns. The process may be used to produce low-sulphur diesel fuel that can meet the sulphur dioxide air emission standards of the Clean Air Act.

Japan's official policy for the development of its biochemical industry since 1990 has required the industry to work to preserve the global environment, treat wastes, and conserve natural resources. The policy calls for the biochemical industry to use the sophisticated functions of microorganisms that make them friendly to the environment. Under this policy MITI has initiated research projects at several national laboratories to work in collaboration with industry and Universities. These projects include work to develop biotechnology systems to combat global environmental changes.

5. Reversal of desert formation

At present, 4.5 million sq km (35% of the total land area of the planet) is threatened by desertification due to loss of water from various soils. Efforts are being made to develop microbes that could help reverse desert formation. Such biological systems

produce products like biopolymers that retain water reversing the phenomenon on large landscapes. In Japan, a MITI - supported programme initiated the use of the bacterium, *Alcaligenes latus* to produce a super bio absorbent, a polysaccharide composed of glucose and glucuronic acid that can absorb and hold more than a thousand times its own weight in water. This ability is yet to be tested in the field.

Future Outlook

The above account shows that bioremediation has promising future with several potential applications to clean up the polluted environments and treat wastes. Compared to physical cleanup methods, in situ bioremediation is much less expensive and causes less environmental perturbation. It may alter manufacturing practices, fuel production and composition, the way of individual's disposal of wastes, cost of products, and environmental quality.

However, employing bioremediation effectively in many applications requires both further R&D and clarification of government policies, particularly in release of genetically- engineered organisms, a controversial issue, scientifically as well as politically . Most European countries as well as the U.S. and Japan have regulations that ban the deliberate release of genetically engineered microorganisms. However, it may be possible to use them in contained bioreactors. Most successful applications of bioremediation, such as the treatment of the shorelines contaminated by the Exxon Valdez oil spill, have relied on indigenous microorganisms and simple environmental modifications such as nutrient applications and aeration.

The current and emerging applications of bioremediation are different in Europe and Japan than they are in U.S.A. Research in U.S.A. promises to contribute to the development of cost-effective solutions for bioremediation of contaminated sites. This new biotechnology will enable contaminated soils and waters to be cleaned up for reuse. In several European countries existing biological waste treatment technologies are to be extended to new areas for removal of harmful toxicants from air \and industrial waste streams. If current trends continue, the Netherlands and Germany are likely to become worldwide leaders in biotreatment of wastes by the end of the century.

Japanese research could aptly combine a quest for improved global environmental quality with a drive for energy self-sufficiency. Their efforts to reduce global warming, if successful, will have far-reaching effects. Japanese programmes to replace petroleum with biologically produced hydrogen and to replace gasoline-powered automobiles with cars that burn hydrogen would greatly reduce future buildup of carbon dioxide in the atmosphere. A change to hydrogen fuel produced by microbes would be a major new use of bioremediation for pollution prevention that would revolutionise not only the petrochemical and automotive industries but the worldwide economy.

Phytoremediation - Biotechnology of Cleaning Up the Environment by Plants

The ability of microorganisms to uptake and accumulate heavy metals such as Co, Cd, Zn, Mn, Cu, Pb, Ni, Hg, Ag, etc. is very well known. Different bacteria; fungi (yeasts, dimorphic as well as filamentous) such as species of *Saccharomyces*, *Rhodotorula*, *Aureobasidium*, *Ophiostoma*, *Aspergillus*, *Rhizopus* and *Trichoderma*; some algae, and diatoms such as *Thalass'osira pseudonana* have such an ability and being studied for their biotechnological potential as agents of effluent detoxification. This has already been elaborated earlier in this chapter under bioremediation.

Among vascular plants, some aquatic weeds such as species of *Salvinia*, *Lemna*, *Azolla*, *Eichhomia*; sedges and even tree species are also known to tolerate, uptake and even accumulate heavy metals and other toxicants in their cells. Besides microorganisms plants are also being studied for their potential of environmental cleanup. Green plants are not only the lungs of nature with unique ability of purifying impure air by photosynthesis releasing oxygen to sustain aerobic life in the biosphere, but it has also been only quite recently demonstrated that they could also be very useful in cleaning up the hazardous waste sites. Vegetation can filter contaminated runoff and may someday be used in the treatment of hazardous industrial and other waste sites.

Though phytoremediation has a long history but its industrial application is quite recent. Plants are being tested for their ability to clean up contaminated soil, and even genetically engineered varieties are on the horizon. "The process of recovery of hazardous substances from soil or groundwater contaminated with municipal or industrial wastes etc. by using plants is called phytoremediation." Some examples of

experimental field tests on removal of toxicants from soil and industrial wastes by using plant systems are given below.

a. Recovery of heavy metals from soil

It has already been briefly described earlier Under bioremediation that green plants such as specific strains of Indian mustard (*Brassica juncea*) can accumulate heavy metals when grown in chromium-contaminated soils. Modified strains of this plant have been shown to accumulate up to 40% of their biomass as heavy metals, such as lead and chromium. Researchers in the State of New Jersey in U.S.A. carried out field trials in 1994 and demonstrated that the plants could be safely grown in chromium contaminated soil at a site adjacent to Liberty State Park, N. J. A small amount of chromium was taken up by the plants and removed from the soil. The plants were then harvested and the metal recovered for recycling or disposal. The use of these Indian mustard plants is being developed by Burt D. Ensley at Phytotech. Corporation, Manmouth Junction, N.J., U.S.A. in collaboration with Ilya Raskin and coworkers at Rutgers University, New Brunswick, N.J., U.S.A. Tests to optimise metal uptake by such modified Brassicas are already in progress at these research centres. It is quite possible that in near future such plant systems could be effectively used for cleanup of metal contaminated soils at various sites.

Another such study is being made by Scott Cunningham, a senior researcher at DuPont. He has already undertaken field tests for such study on plants to remove lead contamination from DuPont facilities. These include manufacturing sites for alkyl lead, Remington lead-based bullets and lead-based explosives as well as lead paint and lead pipes. According to him lead is "sticky" and difficult to coax into a plant, and "using plants as waste treatment systems is in its infancy". Experimental possibilities, according to Cunningham, include genetically engineering the plants to include genes for enzymes from microbes or animal livers to things that breakdown molecular bonds. The lead uptake in the field tests conducted by him has not reached amounts that would promise a site cleanup. He hopes to achieve 20 tons of plants per acre with 1 to 3% metal content. He claimed to have got there. But for the time being, the plants are being used "as a guardian, for in situ stabilisation, so that the site looks like a field, not a concrete block".

While microorganisms breakdown the organic bonds, the plants themselves take up the metals through their root system and sequester the contaminants in their cells. Useful plants can be found growing on ore outcroppings or contaminated areas. One variety of plant came from the lot of a convenience store. For instance, a variety of tree, *Sebertia acuminata* (Sapotaceae), a native of New Caledonia accumulates an astonishing 20-25% of its body dry weight of nickel. The plant bleeds bluish green latex (sap).

i. Treatment of municipal wastewater and industrial wastes

Plants as such may not be able to sequester toxic pollutants from wastes. Roots and rhizomes of some plants provide an ideal habitat for the growth of different kinds of microorganisms, chiefly bacteria and fungi. These microbes are very effective in remediation of contaminated wastewater and industrial wastes containing chlorides, bromides, sulphates etc. The microbes remain active even in extreme conditions through frosts and surface freezing and the hot summer, as well as highly extreme pH and anaerobic reducing conditions. Each plant on earth harbours its own microbes around the roots and the microbes are able to adapt themselves with growing roots.

In U.S.A. suitable species of plants are being grown in artificially designed experimental marsh systems to study the potential of plants in treatment of wastewater. One such plant's wastewater system, the newest tourist attraction is the one designed for treatment of wastewater of Albemarle's two bromine plants in Magnolia. At Albemarle's Magnolia South Bromine Facility in Arkansas, tourists do not come to see the chemicals being manufactured but for this wastewater treatment system using marshy plants. The South unit of wastewater system is a 54-acre artificial marsh populated by sedge plants such as *Scirpus lacustris*, maiden cane and *Typha latifolia*. Each marsh unit is 2000 feet long, 180 feet wide and 12 to 18 inches deep with 40,000 plants. A 30 acre storm water impoundment basin is used for heavy rainfall. The marsh designed by a former National Aeronautics & Space Administration (NASA), U.S.A. scientist treats the facility's rainwater runoff and noncontact process water.

The marsh does what a mechanical wastewater treatment plant would do, but with a smaller outlay of less than \$ 2 million and for lower operating costs. A mechanical system would have required as much electricity as an entire town, whereas the marsh

requires only monitoring equipment demanding as much energy as a single hair dryer. Bill Wolverton, former NASA research *Mti4* and founder of Wolverton Environmental Services, Picayune, Missouri, U.S.A designed this Albemarle's two marsh systems. He also helped build a rock reed filter marsh at Degussa's Theodore, Alaska, U.S.A. plant in the late 1980s. Wolverton, who retired from NASA in 1989 designs plant systems for treatment of indoor air, municipal wastewater and industrial waste? This technology is being used in biotreatment of wastes.

Wolverton has also been consultant to Biosphere 2 earlier in which people were sealed into a closed environment. Phytoremediation is most exciting and challenging in indoor air treatment dealing with problems of sick building syndrome, and in the industrial area. Albemarle's first marsh at the South plant has been filtering and cleaning-rainwater runoff and noncorrosive process water since 1993. The system was the cheapest alternative for dealing with increasing demands of the Clean Water Act in U.S.A. Based on the success of the South plant; a second unit was built in the beginning of 1995 at Albemarle's Magnolia West Facility. This second unit, about one-fourth the size of the first one, started operating in early October in 1995.

Each of the marsh systems consists of three areas. Runoff and cooling water enter a lagoon, where pH and temperature fluctuations are equalised. The lagoon releases water to two parallel marshes. The storm water impoundment basin is used for heavy rainfall. The marshes are the heart of the biotreatment process of phytoremediation. The plants, bulrush (*Scirpus* spp), maiden cane, and cattails (*Typha* spp), create the environment for the cleanup process, whereas the microorganisms, chiefly bacteria living on roots and rhizomes of these sedges breakdown the contaminants (chlorides, sulphates, bromides etc) entering the system. The new marsh is beginning to establish itself with natural selection of the most ideal strains of microorganisms to attack the pollutants. It is in the developmental stage at present and its effectiveness is likely to increase with time. The marsh is engineered to act as a natural marsh designed with deep holes and shallow areas. The system can handle daily loads ranging from thousands to several million gallons of water. You cannot design a mechanical system that can fluctuate so much. It can handle a serious accidental spill. If a tank truck spilled on site, the marsh would treat. The only problem about these natural systems is that we don't have knobs to shut things off. Albemarle intends to set up similar

facilities in Baton Rouge, Houston and Orangeburg, S.C. in U.S.A., and in Feluy (Belgium) and Thann (France).

Questions

1. What is bioremediation? Discuss the need, scope and environmental applications of bioremediation.
2. Why bioremediation is preferred over physical and chemical methods of environmental cleanup? Discuss the use of microorganisms in upgrading of traditional waste and water treatment systems in European countries.
3. Define bioremediation. Give an account of the efforts being made by Japanese researchers to tackle global warming and other pollution problems.
4. With suitable examples, discuss the American approach towards cleanup of some specific polluted sites by using microorganisms.
5. Write notes on
 - i. Bioremediation
 - ii. Biofilters
 - iii. Oil-eating microorganisms
 - iv. Biodegradable plastics
 - v. Reversal of global warming by microorganisms



Dr. Mandaloju Venkateshwarlu

Dr. Mandaloju Venkateshwarlu obtained his M.Sc. (1995) and Ph.D. Degree in Botany from Kakatiya University (1999). Best NSS Valentor (1991-1992) (For Social Work and Plantation) (Nick name of Chetla Venkanna), nearly above 4-5 lakhs plantation (1989-1999), Haritha Mithra, KU (1999), Honorary fellow FHAS, Life Member in Advanced in Plant Sciences, Asian Journal of Bio Science Natural and Environmental Pollution Technology Indian Botanical Society, etc. He has contributed more than 81 papers in National and International Journal of Reoute Published 10 books. His Areas of interest are Plant Tissue Culture and Plant Biotechnology, Plant Mutation Breeding. Cytology and Cytogenetics. He attended National (40) and International (10) Conferences and many Workshops.

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